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Final Regulatory Impact Analysis

Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks

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

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EXECUTIVE SUMMARY

This assessment examines the costs and benefits of improving the fuel economy of passenger cars and light trucks for model years (MY) 2012 through MY 2016. 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 required by the Energy Independence and Security Act of 2007 (EISA), NHTSA sets attribute-based corporate average fuel economy (CAFE) standards that are based on a mathematical function. For purposes of MYs 2012-2016, as for MY 2011 passenger cars and MYs 2008-2011 light trucks, the CAFE standards have been based on vehicle footprint.[2] The mathematical function or "curve" representing the footprint-based standards is a constrained linear function (as compared to the constrained logistic function used for the MY 2011 standards), 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 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 specific to the vehicles' design capabilities.

The baseline assumptions for this rulemaking differ from previous analyses in support of previous CAFE standards. For previous analyses, NHTSA developed a baseline using confidential product plans for each model year provided by the manufacturers regulated by the rule. For purposes of this analysis, in contrast, in the interest of improving transparency, the 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 2016 and technologies are added to this baseline fleet to determine what mpg levels could be achieved by the manufacturers in the MYs 2012-2016 timeframe. NHTSA has examined a variety of alternatives to the final standards for MYs 2012-2016. The eight alternatives examined include five that are annual percentage improvements over the baseline – 3%/year, 4%/year, 5%/year, 6%/year, and 7%/year. In addition to those five are what NHTSA has called the "Preferred Alternative," the "Maximum Net Benefits" alternative, and the "Total Costs Equal Total Benefits" alternative. The "Preferred Alternative" would require fuel economy levels that are generally between the 4 and 5 percent annual increase alternatives, although the percentage increase varies from year to year. The "Maximum Net Benefits" alternative is based upon availability of technologies and a marginal cost/benefit analysis. In this case the model continues to include technologies until marginal cost of adding the next technology exceeds the marginal benefit. The "Total Costs Equal Total Benefits" alternative represents an increase in the standard to a point where essentially total costs of the

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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.

[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).

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 agency also examined the potential impact of the final standards on consumer welfare. The agency’s analysis of benefits from requiring higher fuel efficiency includes some categories that extend throughout the U.S. economy, such as reductions in the energy security costs associated with U.S. petroleum imports and in the economic damages expected to result from climate change. In contrast, other categories of benefits – principally the economic value of future fuel savings projected to result from higher fuel economy – will be experienced exclusively by the initial purchasers and subsequent owners of vehicle models whose fuel economy manufacturers elect to improve as part of their strategies for complying with higher CAFE standards.

Although the economy-wide or “social” benefits from requiring higher fuel economy represent an important share of the total economic benefits from raising CAFE standards, NHTSA estimates that benefits *to vehicle buyers themselves* will significantly exceed the costs of complying with the stricter fuel economy standards this rule establishes. Since the agency also assumes that the costs of new technologies manufacturers will employ to improve fuel economy will ultimately be shifted to vehicle buyers in the form of higher purchase prices, NHTSA concludes that the benefits to vehicle buyers from requiring higher fuel efficiency will far outweigh the costs they will be required to pay to obtain it. However, this raises the question of why current purchasing patterns do not result in higher average fuel economy, and why stricter fuel efficiency standards should be necessary to achieve that goal. To address this issue, the analysis examines possible explanations for this apparent paradox, including discrepancies between the consumers’ perceptions of the value of fuel savings and those calculated by the agency, or unaccounted-for welfare losses resulting from design restrictions that result from higher fuel economy requirements. The agency provides a sensitivity analysis that recalculates the net benefits from the final standards assuming various levels of overstatement of private net benefits, reflecting either an overestimation of fuel savings or the omission of welfare losses. From this, the agency concludes that it is unlikely that any unaccounted-for loss in consumer welfare would completely offset the benefits of the rule and result in a net loss rather than a net benefit.

Table 1 presents the total costs, benefits, and net benefits for NHTSA’s final CAFE standards. The values in Table 1 display the total costs for all MY2012-2016 vehicles and the benefits and net benefits represent the impacts of the standards over the full lifetime of the vehicles projected to be sold during model years 2012 – 2016. It is important to note 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
NHTSA's Estimated 2012-2016 Model Year Costs, Benefits, and Net Benefits under the CAFE Standards before FFV Credits (Billions of 2007 Dollars)

3% Discount Rate	
Costs	$51.8
Benefits	$182.5
Net Benefits	$130.7
7% Discount Rate	
Costs	$51.8
Benefits	$146.3
Net Benefits	$94.5

Table 2 shows the overall analysis summary of costs, benefits, and net benefits for the five model years combined by alternative. 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 an adjusted 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 (without counting 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[3] benefits from future carbon dioxide reductions are discounted at 3 percent in the main analysis, even when intra-generational benefits are discounted at 7 percent. Sensitivity analyses in Chapter X analyze 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 9 provides the estimates at a 7 percent discount rate.

Net Benefits: Tables 8 and 10 compares societal costs and societal benefits of each alternative at the 3 percent and 7 percent discount rates, respectively.

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[3] 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.

Fuel Savings: Table 11 shows the lifetime fuel savings in millions of gallons.

Table 2
Total Costs, Benefits, and Net Benefits
Passenger Cars and Light Trucks
MY 2012-2016 Combined
(Millions of 2007 Dollars)

	Costs	Benefits Discounted 3%	Net Benefits
Preferred Alternative	51,748	182,457	130,709
3% Annual Increase	22,944	102,770	79,826
4% Annual Increase	39,189	150,735	111,546
5% Annual Increase	63,350	202,275	138,925
6% Annual Increase	89,736	243,147	153,412
7% Annual Increase	111,354	273,960	162,606
Max Net Benefits	102,597	266,830	164,233
Total Cost = Total Benefit	113,577	283,874	170,297
	Costs	Benefits Discounted 7%	Net Benefits
Preferred Alternative	51,748	146,243	94,495
3% Annual Increase	22,944	82,523	59,579
4% Annual Increase	39,189	120,877	81,688
5% Annual Increase	63,350	162,035	98,685
6% Annual Increase	89,736	194,545	104,810
7% Annual Increase	111,354	219,165	107,812
Max Net Benefits	102,597	201,988	106,936
Total Cost = Total Benefit	113,577	227,044	113,858

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

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Passenger Cars					
Preferred Alternative	33.3	34.2	34.9	36.2	37.8
3% Annual Increase	31.7	32.6	33.5	34.4	35.4
4% Annual Increase	32.1	33.3	34.5	35.8	37.2
5% Annual Increase	32.4	33.9	35.5	37.1	39.0
6% Annual Increase	32.7	34.5	36.5	38.6	40.9
7% Annual Increase	33.0	35.2	37.6	40.1	42.9
Max Net Benefits	33.0	36.1	38.1	39.4	40.9
Total Cost = Total Benefit	33.4	36.7	39.2	40.7	42.3
Light Trucks					
Preferred Alternative	25.4	26.0	26.6	27.5	28.8
3% Annual Increase	24.1	24.8	25.5	26.2	27.0
4% Annual Increase	24.4	25.3	26.3	27.2	28.3
5% Annual Increase	24.6	25.8	27.0	28.3	29.7
6% Annual Increase	24.9	26.3	27.8	29.4	31.1
7% Annual Increase	25.1	26.8	28.6	30.5	32.6
Max Net Benefits	26.3	27.7	29.1	30.3	31.1
Total Cost = Total Benefit	26.3	28.0	29.7	30.7	31.8
Passenger Cars & Light Trucks					
Preferred Alternative	29.7	30.5	31.3	32.6	34.1
3% Annual Increase	28.3	29.1	30.0	31.0	32.0
4% Annual Increase	28.6	29.7	30.9	32.2	33.6
5% Annual Increase	28.8	30.3	31.8	33.4	35.2
6% Annual Increase	29.1	30.8	32.7	34.7	36.9
7% Annual Increase	29.4	31.4	33.7	36.0	38.7
Max Net Benefits	30.0	32.3	34.2	35.6	36.9
Total Cost = Total Benefit	30.3	32.8	35.0	36.5	38.0

Estimated Required Preferred Alternative CAFE Levels
Projected Achieved Harmonic Average for the Fleet, in gallons per 100 miles

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
PC	2.9988	2.9277	2.8624	2.7628	2.6483
LT	3.9370	3.8472	3.7622	3.6298	3.4766
Combined	3.3634	3.2783	3.1931	3.0699	2.9329

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

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Passenger Cars					
Preferred Alternative	32.8	34.4	35.3	36.3	37.2
3% Annual Increase	32.2	33.2	33.7	34.3	35.2
4% Annual Increase	32.3	33.6	34.6	35.5	36.7
5% Annual Increase	32.6	34.4	35.8	36.9	38.3
6% Annual Increase	32.8	34.9	36.6	38.0	39.7
7% Annual Increase	33.0	35.4	37.4	38.9	40.7
Max Net Benefits	33.0	35.5	37.3	38.4	39.8
Total Cost = Total Benefit	33.1	35.7	37.7	39.0	40.5
Light Trucks					
Preferred Alternative	25.1	26.0	27.0	27.6	28.5
3% Annual Increase	24.4	25.0	25.8	26.4	26.9
4% Annual Increase	24.7	25.5	26.5	27.2	28.1
5% Annual Increase	24.9	26.0	27.4	28.3	29.3
6% Annual Increase	25.0	26.5	28.1	29.4	30.6
7% Annual Increase	25.2	26.9	28.8	30.1	31.4
Max Net Benefits	25.5	27.3	28.8	29.9	30.6
Total Cost = Total Benefit	25.5	27.4	29.1	30.2	31.1
Passenger Cars & Light Trucks					
Preferred Alternative	29.3	30.6	31.7	32.6	33.7
3% Annual Increase	28.6	29.5	30.3	31.0	31.8
4% Annual Increase	28.8	30.0	31.1	32.1	33.2
5% Annual Increase	29.1	30.6	32.1	33.3	34.6
6% Annual Increase	29.3	31.2	32.9	34.4	36.0
7% Annual Increase	29.4	31.6	33.7	35.2	36.9
Max Net Benefits	29.6	31.8	33.6	34.9	36.1
Total Cost = Total Benefit	29.7	32.0	34.0	35.4	36.7

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

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
PC	3.0517	2.9111	2.8321	2.7581	2.6877
LT	3.9894	3.8417	3.7059	3.6206	3.5048
Combined	3.4161	3.2659	3.1533	3.0635	2.9684

Table 5
Average Incremental Cost or Fines
Per Vehicle
(2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Passenger Cars					
Preferred Alternative	$505	$573	$690	$799	$907
3% Annual Increase	$191	$248	$317	$394	$493
4% Annual Increase	$254	$366	$500	$640	$764
5% Annual Increase	$362	$558	$749	$918	$1,088
6% Annual Increase	$526	$758	$1,064	$1,321	$1,546
7% Annual Increase	$616	$952	$1,361	$1,634	$1,941
Max Net Benefits	$612	$954	$1,282	$1,460	$1,628
Total Cost = Total Benefit	$675	$1,065	$1,440	$1,653	$1,878
Light Trucks					
Preferred Alternative	$322	$416	$621	$752	$961
3% Annual Increase	$1	$78	$234	$348	$484
4% Annual Increase	$166	$293	$506	$646	$830
5% Annual Increase	$417	$633	$1,036	$1,186	$1,361
6% Annual Increase	$516	$943	$1,394	$1,706	$2,007
7% Annual Increase	$575	$1,222	$1,716	$2,181	$2,549
Max Net Benefits	$761	$1,249	$1,665	$1,948	$2,082
Total Cost = Total Benefit	$780	$1,344	$1,806	$2,157	$2,366
Passenger Cars & Light Trucks					
Preferred Alternative	$434	$513	$665	$782	$926
3% Annual Increase	$117	$183	$287	$378	$490
4% Annual Increase	$220	$338	$502	$642	$787
5% Annual Increase	$384	$587	$855	$1,013	$1,182
6% Annual Increase	$522	$829	$1,185	$1,457	$1,705
7% Annual Increase	$600	$1,055	$1,492	$1,828	$2,150
Max Net Benefits	$670	$1,066	$1,423	$1,633	$1,784
Total Cost = Total Benefit	$716	$1,171	$1,575	$1,831	$2,046

Table 6
Incremental Total Costs by Societal Perspective[4], by Alternative
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$4,148	$5,411	$6,855	$8,221	$9,534	$34,170
3% Annual Increase	$1,622	$2,341	$3,142	$4,047	$5,222	$16,375
4% Annual Increase	$2,148	$3,455	$4,944	$6,561	$8,031	$25,138
5% Annual Increase	$3,074	$5,288	$7,426	$9,410	$11,403	$36,601
6% Annual Increase	$4,504	$7,196	$10,567	$13,546	$16,130	$51,943
7% Annual Increase	$5,263	$8,985	$13,451	$16,627	$19,898	$64,224
Max Net Benefits	$5,217	$8,837	$12,535	$14,930	$17,050	$58,568
TC = TB	$5,674	$9,779	$13,898	$16,673	$19,403	$65,427
Light Trucks						
Preferred Alternative	$1,754	$2,479	$3,657	$4,318	$5,369	$17,578
3% Annual Increase	$8	$463	$1,371	$2,009	$2,719	$6,570
4% Annual Increase	$968	$1,747	$2,975	$3,714	$4,647	$14,051
5% Annual Increase	$2,407	$3,791	$6,103	$6,833	$7,614	$26,749
6% Annual Increase	$2,950	$5,646	$8,157	$9,813	$11,226	$37,793
7% Annual Increase	$3,260	$7,298	$10,020	$12,478	$14,074	$47,130
Max Net Benefits	$4,149	$7,370	$9,698	$11,163	$11,648	$44,028
TC = TB	$4,247	$7,891	$10,464	$12,330	$13,218	$48,149
Passenger Cars & Light Trucks						
Preferred Alternative	$5,903	$7,890	$10,512	$12,539	$14,904	$51,748
3% Annual Increase	$1,630	$2,804	$4,513	$6,057	$7,941	$22,944
4% Annual Increase	$3,116	$5,202	$7,919	$10,275	$12,678	$39,189
5% Annual Increase	$5,482	$9,079	$13,529	$16,243	$19,017	$63,350
6% Annual Increase	$7,455	$12,842	$18,724	$23,359	$27,356	$89,736
7% Annual Increase	$8,524	$16,283	$23,471	$29,104	$33,972	$111,354
Max Net Benefits	$9,366	$16,207	$22,233	$26,092	$28,698	$102,597
TC = TB	$9,921	$17,670	$24,362	$29,003	$32,620	$113,577

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[4] Includes technology costs and societal costs, but does not include fines.

Table 7
Present Value of Lifetime Societal Benefits[5],
by Alternative (3% Discount Rate)
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$6,826	$15,155	$21,626	$28,677	$35,200	$107,483
3% Annual Increase	$3,397	$8,374	$12,331	$16,760	$23,122	$63,984
4% Annual Increase	$4,186	$11,006	$17,315	$24,469	$32,309	$89,286
5% Annual Increase	$6,152	$15,404	$24,075	$32,114	$40,905	$118,649
6% Annual Increase	$7,071	$18,062	$28,137	$37,552	$47,754	$138,576
7% Annual Increase	$8,038	$20,627	$32,225	$42,010	$52,606	$155,507
Max Net Benefits	$8,019	$20,896	$31,683	$39,863	$48,228	$148,689
TC = TB	$8,666	$22,374	$33,916	$42,737	$51,659	$159,352
Light Trucks						
Preferred Alternative	$5,110	$10,684	$15,506	$19,364	$24,310	$74,974
3% Annual Increase	$687	$3,920	$7,635	$11,604	$14,940	$38,786
4% Annual Increase	$2,590	$7,361	$12,580	$17,089	$21,830	$61,450
5% Annual Increase	$4,003	$10,407	$17,686	$23,206	$28,324	$83,626
6% Annual Increase	$4,893	$13,933	$22,031	$28,987	$34,727	$104,571
7% Annual Increase	$5,634	$16,326	$25,550	$32,714	$38,229	$118,453
Max Net Benefits	$7,528	$18,302	$25,913	$31,563	$34,835	$118,141
TC = TB	$7,631	$18,954	$27,294	$33,381	$37,262	$124,522
Passenger Cars & Light Trucks						
Preferred Alternative	$11,936	$25,840	$37,132	$48,040	$59,509	$182,457
3% Annual Increase	$4,085	$12,294	$19,966	$28,364	$38,062	$102,770
4% Annual Increase	$6,776	$18,367	$29,895	$41,559	$54,139	$150,735
5% Annual Increase	$10,155	$25,811	$41,760	$55,320	$69,229	$202,275
6% Annual Increase	$11,964	$31,995	$50,168	$66,539	$82,481	$243,147
7% Annual Increase	$13,672	$36,953	$57,776	$74,724	$90,835	$273,960
Max Net Benefits	$15,547	$39,198	$57,596	$71,426	$83,063	$266,830
TC = TB	$16,297	$41,328	$61,209	$76,118	$88,922	$283,874

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[5] 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, etc.

Table 8
Present Value of
Net Total Benefits[6] by Alternative
(Millions of 2007 Dollars)
(3% Discount Rate)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$2,677	$9,745	$14,770	$20,455	$25,665	$73,313
3% Annual Increase	$1,776	$6,033	$9,188	$12,713	$17,900	$47,609
4% Annual Increase	$2,038	$7,551	$12,371	$17,909	$24,278	$64,147
5% Annual Increase	$3,077	$10,116	$16,649	$22,704	$29,502	$82,048
6% Annual Increase	$2,567	$10,866	$17,570	$24,005	$31,624	$86,633
7% Annual Increase	$2,775	$11,642	$18,775	$25,383	$32,709	$91,283
Max Net Benefits	$2,802	$12,059	$19,148	$24,933	$31,179	$90,121
TC = TB	$2,992	$12,595	$20,017	$26,064	$32,257	$93,925
Light Trucks						
Preferred Alternative	$3,356	$8,205	$11,849	$15,045	$18,940	$57,396
3% Annual Increase	$679	$3,458	$6,264	$9,595	$12,222	$32,217
4% Annual Increase	$1,622	$5,614	$9,605	$13,375	$17,183	$47,399
5% Annual Increase	$1,596	$6,616	$11,582	$16,373	$20,710	$56,877
6% Annual Increase	$1,943	$8,287	$13,874	$19,174	$23,501	$66,779
7% Annual Increase	$2,373	$9,028	$15,531	$20,236	$24,155	$71,324
Max Net Benefits	$3,379	$10,932	$16,215	$20,400	$23,186	$74,112
TC = TB	$3,384	$11,063	$16,830	$21,050	$24,045	$76,373
Passenger Cars & Light Trucks						
Preferred Alternative	$6,033	$17,950	$26,619	$35,501	$44,606	$130,709
3% Annual Increase	$2,455	$9,490	$15,453	$22,307	$30,121	$79,826
4% Annual Increase	$3,660	$13,165	$21,976	$31,284	$41,461	$111,546
5% Annual Increase	$4,673	$16,732	$28,231	$39,076	$50,213	$138,925
6% Annual Increase	$4,509	$19,154	$31,444	$43,180	$55,125	$153,412
7% Annual Increase	$5,148	$20,670	$34,305	$45,619	$56,864	$162,606
Max Net Benefits	$6,181	$22,991	$35,363	$45,333	$54,365	$164,233
TC = TB	$6,377	$23,658	$36,847	$47,114	$56,301	$170,297

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

Table 9
Present Value of Lifetime Societal Benefits[7],
by Alternative (7% Discount Rate)
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$5,474	$12,255	$17,499	$23,235	$28,567	$87,031
3% Annual Increase	$2,727	$6,778	$9,980	$13,585	$18,774	$51,844
4% Annual Increase	$3,356	$8,904	$14,015	$19,838	$26,241	$72,353
5% Annual Increase	$4,941	$12,472	$19,493	$26,030	$33,185	$96,122
6% Annual Increase	$5,667	$14,612	$22,763	$30,402	$38,735	$112,180
7% Annual Increase	$6,448	$16,692	$26,080	$34,028	$42,669	$125,917
Max Net Benefits	$6,134	$16,378	$25,041	$31,517	$38,120	$117,191
TC = TB	$6,957	$18,112	$27,453	$34,625	$41,897	$129,044
Light Trucks						
Preferred Alternative	$4,015	$8,427	$12,243	$15,302	$19,225	$59,212
3% Annual Increase	$545	$3,099	$6,035	$9,178	$11,823	$30,679
4% Annual Increase	$2,035	$5,802	$9,927	$13,500	$17,260	$48,524
5% Annual Increase	$3,129	$8,189	$13,929	$18,300	$22,365	$65,913
6% Annual Increase	$3,823	$10,966	$17,349	$22,842	$27,385	$82,366
7% Annual Increase	$4,404	$12,838	$20,108	$25,767	$30,132	$93,248
Max Net Benefits	$5,736	$12,761	$18,525	$22,485	$25,290	$84,797
TC = TB	$6,039	$14,926	$21,502	$26,237	$29,295	$97,999
Passenger Cars & Light Trucks						
Preferred Alternative	$9,490	$20,682	$29,742	$38,538	$47,791	$146,243
3% Annual Increase	$3,272	$9,877	$16,014	$22,763	$30,597	$82,523
4% Annual Increase	$5,390	$14,706	$23,942	$33,338	$43,500	$120,877
5% Annual Increase	$8,070	$20,661	$33,422	$44,330	$55,551	$162,035
6% Annual Increase	$9,490	$25,579	$40,111	$53,245	$66,120	$194,545
7% Annual Increase	$10,852	$29,530	$46,187	$59,795	$72,801	$219,165
Max Net Benefits	$11,870	$29,140	$43,566	$54,002	$63,410	$201,988
TC = TB	$12,997	$33,037	$48,955	$60,862	$71,193	$227,044

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[7] 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, etc.

Table 10
Present Value of
Net Total Benefits[8] by Alternative
(Millions of 2007 Dollars)
(7% Discount Rate)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$1,326	$6,844	$10,644	$15,014	$19,032	$52,861
3% Annual Increase	$1,106	$4,436	$6,838	$9,537	$13,552	$35,469
4% Annual Increase	$1,208	$5,449	$9,071	$13,277	$18,210	$47,215
5% Annual Increase	$1,867	$7,184	$12,067	$16,620	$21,782	$59,521
6% Annual Increase	$1,163	$7,416	$12,196	$16,856	$22,605	$60,237
7% Annual Increase	$1,185	$7,707	$12,629	$17,401	$22,771	$61,693
Max Net Benefits	$1,170	$7,894	$12,838	$16,969	$21,583	$60,454
TC = TB	$1,283	$8,333	$13,555	$17,952	$22,495	$63,617
Light Trucks						
Preferred Alternative	$2,261	$5,948	$8,586	$10,984	$13,855	$41,635
3% Annual Increase	$537	$2,636	$4,664	$7,169	$9,104	$24,110
4% Annual Increase	$1,067	$4,055	$6,952	$9,786	$12,613	$34,473
5% Annual Increase	$722	$4,398	$7,826	$11,467	$14,751	$39,164
6% Annual Increase	$872	$5,321	$9,192	$13,029	$16,159	$44,573
7% Annual Increase	$1,143	$5,540	$10,088	$13,289	$16,058	$46,119
Max Net Benefits	$1,647	$6,581	$10,195	$12,936	$15,123	$46,482
TC = TB	$1,579	$7,463	$10,988	$13,982	$16,229	$50,241
Passenger Cars & Light Trucks						
Preferred Alternative	$3,587	$12,792	$19,230	$25,998	$32,888	$94,495
3% Annual Increase	$1,642	$7,073	$11,501	$16,706	$22,656	$59,579
4% Annual Increase	$2,274	$9,504	$16,023	$23,064	$30,822	$81,688
5% Annual Increase	$2,589	$11,583	$19,893	$28,087	$36,534	$98,685
6% Annual Increase	$2,035	$12,737	$21,387	$29,885	$38,764	$104,810
7% Annual Increase	$2,328	$13,247	$22,717	$30,690	$38,829	$107,812
Max Net Benefits	$2,818	$14,475	$23,033	$29,904	$36,706	$106,936
TC = TB	$2,863	$15,795	$24,543	$31,933	$38,724	$113,858

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

Table 11
Savings in Millions of Gallons of Fuel
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	2,396	5,153	7,233	9,446	11,433	35,660
3% Annual Increase	1,197	2,845	4,120	5,509	7,490	21,161
4% Annual Increase	1,476	3,740	5,787	8,046	10,475	29,524
5% Annual Increase	2,157	5,230	8,066	10,630	13,381	39,463
6% Annual Increase	2,520	6,200	9,530	12,589	15,770	46,609
7% Annual Increase	2,855	7,086	10,933	14,080	17,419	52,374
Max Net Benefits	2,848	7,159	10,731	13,324	15,893	49,956
TC = TB	3,071	7,673	11,492	14,295	17,086	53,619
Light Trucks						
Preferred Alternative	1,805	3,698	5,281	6,504	8,061	25,350
3% Annual Increase	234	1,349	2,589	3,882	4,935	12,988
4% Annual Increase	916	2,557	4,298	5,751	7,251	20,773
5% Annual Increase	1,434	3,631	6,076	7,856	9,463	28,460
6% Annual Increase	1,758	4,869	7,584	9,859	11,677	35,747
7% Annual Increase	2,019	5,718	8,813	11,139	12,866	40,555
Max Net Benefits	2,688	6,395	8,919	10,735	11,700	40,437
TC = TB	2,724	6,621	9,392	11,348	12,507	42,591
Passenger Cars & Light Trucks						
Preferred Alternative	4,201	8,851	12,514	15,950	19,494	61,010
3% Annual Increase	1,431	4,193	6,709	9,391	12,425	34,149
4% Annual Increase	2,391	6,296	10,085	13,798	17,726	50,297
5% Annual Increase	3,590	8,860	14,142	18,486	22,845	67,923
6% Annual Increase	4,279	11,069	17,114	22,448	27,447	82,356
7% Annual Increase	4,875	12,804	19,746	25,219	30,285	92,929
Max Net Benefits	5,536	13,555	19,650	24,059	27,593	90,392
TC = TB	5,795	14,294	20,884	25,643	29,593	96,210

Breakdown of costs and benefits for the preferred alternative

Tables 12 and 13 provides a breakdown of the costs and benefits for the preferred alternative using a 3 percent and 7 percent discount rate, respectively, safety estimates are not included.

Table 12
Preferred Alternative
Cost and Benefit Estimates
Passenger Cars and Light Trucks Combined
3% Discount Rate

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Technology Costs	$5,902	$7,890	$10,512	$12,539	$14,903	$51,748
Benefits						
Lifetime Fuel Expenditures	$9,264	$20,178	$29,082	$37,700	$46,824	$143,048
Consumer Surplus from Additional Driving	$696	$1,504	$2,151	$2,754	$3,387	$10,492
Refueling Time Value	$707	$1,383	$1,939	$2,464	$2,950	$9,443
Petroleum Market Externalities	$546	$1,153	$1,630	$2,079	$2,543	$7,951
Congestion Costs	($447)	($902)	($1,282)	($1,634)	($2,000)	($6,265)
Noise Costs	($9)	($17)	($25)	($32)	($39)	($122)
Crash Costs	($217)	($430)	($614)	($778)	($950)	($2,989)
CO2	$921	$2,025	$2,940	$3,840	$4,804	$14,530
CO	$0	$0	$0	$0	$0	$0
VOC	$42	$76	$102	$125	$149	$494
NOX	$70	$105	$127	$146	$165	$613
PM	$206	$434	$612	$777	$946	$2,975
SOX	$157	$332	$469	$598	$731	$2,287
Total	$11,936	$25,840	$37,132	$48,040	$59,509	$182,457
Net Benefits	$6,033	$17,950	$26,619	$35,501	$44,606	$130,709

Table 13
Preferred
Alternative
Cost and Benefit Estimates
Passenger Cars and Light Trucks Combined
7% Discount Rate

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Technology Costs	$5,902	$7,890	$10,512	$12,539	$14,903	$51,748
Benefits						
Lifetime Fuel Expenditures	$7,197	$15,781	$22,757	$29,542	$36,727	$112,004
Consumer Surplus from Additional Driving	$542	$1,179	$1,686	$2,163	$2,663	$8,233
Refueling Time Value	$567	$1,114	$1,562	$1,986	$2,379	$7,608
Petroleum Market Externalities	$432	$917	$1,296	$1,654	$2,023	$6,322
Congestion Costs	($355)	($719)	($1,021)	($1,302)	($1,595)	($4,992)
Noise Costs	($7)	($14)	($20)	($26)	($31)	($98)
Crash Costs	($173)	($342)	($488)	($619)	($756)	($2,378)
CO2	$921	$2,025	$2,940	$3,840	$4,804	$14,530
CO	$0	$0	$0	$0	$0	$0
VOC	$32	$60	$80	$99	$119	$390
NOX	$53	$80	$98	$114	$131	$476
PM	$154	$336	$480	$611	$748	$2,329
SOX	$125	$265	$373	$475	$581	$1,819
Total	$9,490	$20,682	$29,742	$38,538	$47,791	$146,243
Net Benefits	$3,587	$12,792	$19,230	$25,998	$32,888	$94,495

I. INTRODUCTION

The purpose of this study is to analyze the effects of changes in the fuel economy standards for passenger cars and for light trucks for MY 2012 - 2016. It 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.

The agency issued a final rule on April 7, 2003 (68 FR 16868), setting the CAFE standard applicable to light trucks for MY 2005 at 21.0 mpg, for MY 2006 at 21.6 mpg, and for MY 2007 at 22.2 mpg. On April 6, 2006 (71 FR 17566), the agency issued a final rule for light trucks for MYs 2008 to 2011 under a new "CAFE Reform" structure.

In December 2007, Congress passed the Energy Independence and Security Act (EISA). 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. EISA additionally gave NHTSA authority to reform passenger car CAFE, allowing the agency to set standards for those vehicles according to an attribute-based mathematical function.

In mid-October 2008, the agency completed and released a final environmental impact statement in anticipation of issuing standards for those years. Based on its consideration of the public comments and other available information, including information on the financial condition of the automotive industry, the agency adjusted its analysis and the standards and prepared a final rule and Final Regulatory Impact Analysis (FRIA) for MYs 2011-2015. On November 14, the Office of Information and Regulatory Affairs (OIRA) of the Office of Management and Budget concluded review of the rule and FRIA.[9] However, issuance of the final rule was held in abeyance. On January 7, 2009, the Department of Transportation announced that the final rule would not be issued, writing:

> The Bush Administration will not finalize its rulemaking on Corporate Fuel Economy Standards. The recent financial difficulties of the automobile industry will require the next administration to conduct a thorough review of matters affecting the industry, including how to effectively implement the Energy Independence and Security Act of 2007 (EISA). The National Highway Traffic Safety Administration has done significant work that will position the next Transportation Secretary to finalize a rule before the April 1, 2009 deadline.[10]

In light of the requirement to prescribe standards for MY 2011 by March 30, 2009 and in order to provide additional time to consider issues concerning the analysis used to determine the appropriate level of standards for MYs 2012 and beyond, the President issued a memorandum on January 26, 2009, requesting the Secretary of Transportation and Administrator of the National

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[9] Record of OIRA's action can be found at http://www.reginfo.gov/public/do/eoHistReviewSearch (last visited March 4, 2010). To find the report on the clearance of the draft final rule, select "Department of Transportation" under "Economically Significant Reviews Completed" and select "2008" under "Select Calendar Year."

[10] The statement can be found at http://www.dot.gov/affairs/dot0109.htm (last accessed March 4, 2010).

Highway Traffic Safety Administration NHTSA to divide the rulemaking into two parts: (1) MY 2011 standards, and (2) standards for MY 2012 and beyond.

The request that the final rule establishing CAFE standards for MY 2011 passenger cars and light trucks be prescribed by March 30, 2009 was based on several factors. One was the requirement that the final rule regarding fuel economy standards for a given model year must be adopted at least 18 months before the beginning of that model year (49 U.S.C. 32902(g)(2)). The other was that the beginning of MY 2011 is considered for the purposes of CAFE standard setting to be October 1, 2010. As part of that final rule, the President requested that NHTSA consider whether any provisions regarding preemption are consistent with the EISA, the Supreme Court's decision in Massachusetts v. EPA and other relevant provisions of law and the policies underlying them.

The President requested that, before promulgating a final rule concerning the model years after model year 2011, NHTSA

> [C]onsider the appropriate legal factors under the EISA, the comments filed in response to the Notice of Proposed Rulemaking, the relevant technological and scientific considerations, and to the extent feasible, the forthcoming report by the National Academy of Sciences mandated under section 107 of EISA.

In addition, the President requested that NHTSA further consider whether any provisions regarding preemption are appropriate under applicable law and policy.

On March 20, 2009 (74 FR 14196) NHTSA issued a final rule for MY 2011 passenger cars and light trucks, superseding the previously issued final rule for MY 2011 light trucks. Similar to this report, a Final Regulatory Impact Analysis accompanied that final rule.[11]

In keeping with the President’s remarks on January 26 for new national policies to address the closely intertwined issues of energy independence, energy security and climate change, and for the initiation of serious and sustained domestic and international action to address them, NHTSA and EPA proposed standards for MY 2012 - 2016 after collecting new information, conducting a careful review of technical and economic inputs and assumptions, and standard setting methodology, and completing new analyses. The NPRM was issued on September 22, 2009 (74 FR 48192) and it was accompanied by a Preliminary Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks, (Docket No. 2009-0059-0016.1).

The goal of the review and re-evaluation was to ensure that the approach used for MY 2012 and thereafter produces standards that contribute, to the maximum extent possible under EPCA/EISA, to meeting the energy and environmental challenges and goals outlined by the President. We seek to craft our program with the goal of creating the maximum incentives for innovation, providing flexibility to the regulated parties, and meeting the goal of making substantial and continuing reductions in the consumption of fuel.

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[11] “Final Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks”, March 2009, Docket No. NHTSA-2009-0062-0004.1.

The dual fuel incentive program, through which manufacturers may improve their calculated fuel economies by producing vehicles capable of operating on alternative fuels, is not considered in this analysis. By law, the agency has always analyzed fuel economy without considering the dual fuel credits.[12]

Throughout this analysis, unless otherwise noted, the agency has not considered the ability of manufacturers to use credits or credit trading in achieving the alternative fuel economy levels. This is also a statutory requirement.[13]

Throughout this document, confidential information is presented in brackets [ ].

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[12] See 49 U.S.C. § 32902(h)

[13] *Id*.

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."[14]

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 and is now declining slowly, averaging approximately 19.4 million barrels per day in 2008.[15] World demand, however, is expected to continue to rise until 2030.[16]

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 $99 per barrel in 2008, having peaked at $129 per barrel in July 2008. Prices declined to $49 per barrel in April 2009, but then rose to $75 per barrel in February 2010.[17] As recently as 1998, crude prices averaged about $13 per barrel.[18] Gasoline prices more than doubled during this ten-year period, from $1.22 in 1998 to $3.32 in 2008, declining to $2.75 in early March 2010.[19]
- U.S. domestic petroleum production stood at 10 million barrels per day in 1975, rose slightly, and then declined to 6.7 million barrels per day in 2008. Between 1975 and 2008, U.S. petroleum consumption increased from 16.3 million barrels per day to 20.8 million barrels per day. In 2008, net petroleum imports accounted for 57 percent of U.S. domestic petroleum consumption.[20]
- 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 $2.59 in 2006 to

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[14] 49 U.S.C. § 32902(f)

[15] U.S. Department of Energy, Energy Information Administration, *Petroleum Basic Statistics, October 2009. See* http://www.eia.doe.gov/emeu/international/oilconsumption.html (last accessed March 4, 2010).

[16] U.S. Department of Energy, Energy Information Administration, *International Energy Outlook 2009. See* http://www.eia.doe.gov/oiaf/ieo/highlights.html (last accessed March 4, 2010).

[17] U.S. Department of Energy, Energy Information Administration, *World Crude Oil Prices. See* http://tonto.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm (last accessed March 4, 2010).

[18] U.S. Department of Energy, Energy Information Administration, *Petroleum Marketing Monthly*, *July 2009*, Table 1. See http://www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum_marketing_monthly/pmm.html (last accessed March 4, 2010).

[19] U.S. Department of Energy, Energy Information Administration, *Weekly Retail and Gasoline Diesel Prices. See* http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm (last accessed March 4, 2010).

[20] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review, February 2010*. *See* http://www.eia.doe.gov/emeu/mer/pdf/pages/sec3_7.pdf (last accessed March 4, 2010).

$2.80 in 2007 (an 8.1 percent increase) and vehicle miles traveled decreased by 0.6 percent. Within the United States, demand for gasoline, diesel, and jet fuel within the transportation sector is particularly inelastic.

- Demand for oil may increase significantly in Asia and worldwide in the future resulting in upward oil cost pressure.
- 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.[21] 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.

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, U.S. energy consumption has increasingly been outstripping U.S. energy production.

Table II-1 presents trend data on the production and consumption of petroleum for transportation. Domestic petroleum production has been decreasing over time, while imports of petroleum have been increasing to meet the rising U.S. demand for petroleum.

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 final rule 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.

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[21] 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/, (last accessed March 4, 2010).

Table II-1

Petroleum Production and Supply

(Million Barrels per Day)[22]

	Domestic Petroleum Production	Net Petroleum Imports	U.S. Petroleum Consumption	World Petroleum Consumption	Net Imports as a Share of U.S. Consumption
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	84.0	60.3%
2008	6.7	11.0	19.4	N/A	56.9%
DOE Predictions					
2015	7.6	9.7	20.2	90.6	49%
2025	9.1	8.0	20.8	101.1	40%
2030	9.3	8.4	21.7	106.6	41%

Note: DOE predictions are based on petroleum demand.

Table II-2

Petroleum
Transportation Consumption by Mode
(Thousand Barrels per Day)[23]

	Passenger Cars	Light Trucks	Total Light Vehicles	Total Transportation	Light Vehicles as % of Trans.
1975	4,836	1,245	6,081	8,474	72%
1985	4,665	1,785	6,450	9,538	68%
1995	4,440	2,975	7,415	11,347	65%
2005	5,050	3,840	8,890	13,537	66%
2007	4,850	4,032	8,883	13,710	65%

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[22] U.S. Department of Energy, EIA, *Monthly Energy Review, February 2010*, Table 3.1. *Available at* http://www.eia.doe.gov/emeu/mer/petro.html (last accessed March 4, 2010). U.S. Department of Energy, EIA, *Annual Energy Outlook 2009*, Table 20. *Available at* http://www.eia.doe.gov/oiaf/archive/aeo09/pdf/0383(2009).pdf (last accessed March 4, 2010).

[23] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *Transportation Energy Data Book*, Table 1.14. *Available at* http://cta.ornl.gov/data/chapter1.shtml (last accessed March 4, 2010).

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 baseline 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 baseline fleet helps to keep, to some extent, the agencies' models from adding technologies to vehicles that already have these technologies, which would result in "double counting" of technologies' costs and benefits. The second step was to project the baseline fleet sales into MYs 2011-2016. This is called the reference fleet, and it represents the fleet that would exist in MYs 2011-2016 absent any change from current regulations. 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 2011 CAFE standards. This final "reference fleet" is the light duty fleet estimated to exist in MYs 2012-2016 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 baseline vehicle fleet developed?

At proposal, EPA and NHTSA developed a baseline fleet comprised of model year 2008 data gathered from EPA's emission certification and fuel economy database. MY 2008 was used as the basis for the baseline vehicle fleet because it was the most recent model year for which a complete set of data is publicly available. This remains the case. Manufacturers are not required to submit final sales and mpg figures for MY 2009 until April 2010,[24] after the CAFE standard's mandated promulgation date. Consequently, in this final rule, EPA and NHTSA made no changes to the method or the results of the MY 2008 baseline fleet used at proposal, except for some specific corrections to engineering inputs for some vehicle models reflected in the market forecast input to NHTSA's CAFE model. More details about how the agencies constructed this baseline fleet can be found in Chapter 1.2 of the Joint TSD. Corrections to engineering inputs for some vehicle models in the market forecast input to NHTSA's CAFE model are discussed in Chapter 2 of the Joint TSD.

3. How was the projected MY 2011-2016 vehicle fleet developed?

EPA and NHTSA have based the projection of total car and total light truck sales for MYs 2011-2016 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

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[24] 40 CFR 600.512-08, Model Year Report

light trucks. In the proposal, the agencies used the three reports published by EIA as part of the AEO 2009. We also stated that updated versions of these reports could be used in the final rules should AEO timely issue a new version. EIA published an early version of its AEO 2010 in December 2009, and the agencies are making use of it in this final rulemaking. The differences in projected sales in the 2009 report (used in the NPRM) and the early 2010 report are very small, so NHTSA and EPA have decided to simply scale the NPRM volumes for cars and trucks (in the aggregate) to match those in the 2010 report.[25] We thus employ the sales projections from the scaled updated 2009 Annual Energy Outlook, which is equivalent to AEO 2010 Early Release, for the final rule. The scaling factors for each model year are presented in Chapter 1 of the Joint TSD for this final rule.

In the AEO 2010 Early Release, EIA projects that total light-duty vehicle sales will gradually recover from their currently depressed levels by around 2013. In 2016, car sales are projected to be 9.4 million (57 percent) and truck sales are projected to be 7.1 million (43 percent). Although the total level of sales of 16.5 million units is similar to pre-2008 levels, the fraction of car sales is projected to be higher than that existing in the 2000-2007 timeframe. This projection reflects the impact of higher fuel prices, as well as EISA's requirement that the new vehicle fleet average at least 35 mpg by MY 2020. The agencies note that AEO does not represent the fleet at a level of detail sufficient to explicitly account for the reclassification—promulgated as part of NHTSA's final rule for MY 2011 CAFE standards—of a number of 2-wheel drive sport utility vehicles from the truck fleet to the car fleet for MYs 2011 and after. Sales projections of cars and trucks for future model years can be found in the Joint TSD for these final rules.

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have been changing and are expected to continue to change. Manufacturers are introducing more crossover models which offer much of the utility of SUVs but use more car-like designs. The AEO 2010 report does not, however, distinguish such changes within the car and truck classes. In order to reflect these changes in fleet makeup, EPA and NHTSA considered several other available forecasts. EPA purchased and shared with NHTSA forecasts from two well-known industry analysts, CSM Worldwide (CSM), and J.D. Powers. NHTSA and EPA decided to use the forecast from CSM, modified as described below, for several reasons presented in the NPRM preamble[26] and draft Joint TSD. The changes between company market share and industry market segments were most significant from 2011-2014, while for 2014-2015 the changes were relatively small. Noting this, and lacking a credible forecast of company and segment shares after 2015, the agencies assumed 2016 market share and market segments to be the same as for 2015.

CSM Worldwide provides quarterly sales forecasts for the automotive industry. In the NPRM, the agencies identified a concern with the 2nd quarter CSM forecast that was used as a basis for the projection. CSM projections at that time were based on an industry that was going through a significant financial transition, and as a result the market share forecasts for some companies

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[25] EPA and NHTSA have evaluated the differences between the AEO 2010 (early draft) and AEO 2009 and found little difference in the fleet projections (or fuel prices). This analysis can be found in the memo to the docket, available at Docket No. NHTSA-2009-0059-0222. The agencies therefore conclude that EIA has made no significant changes to its projections.

[26] *See*, e.g., 74 FR 49484.

were impacted in surprising ways. As the industry's situation has settled somewhat over the past year, the 4th quarter projection appears to address this issue – for example, it shows nearly a two-fold increase in sales for Chrysler compared to significant loss of market share shown for Chrysler in the 2nd quarter projection. Additionally, some commenters, such as GM, recognized that the fleet appeared to include an unusually high number of large pickup trucks.[27] In fact, the agencies discovered (independently of the comments) that CSM's standard forecast included all vehicles below 14,000 GVWR, including class 2b and 3 heavy duty vehicles, which are not regulated by this final rule.[28] The commenters were thus correct that light duty reference fleet projections at proposal had more full size trucks and vans due to the mistaken inclusion of the heavy duty versions of those vehicles. The agencies requested a separate data forecast from CSM that filtered their 4th quarter projection to exclude these heavy duty vehicles. The agencies then used this filtered 4th quarter forecast for the final rule. A detailed comparison of the market by manufacturer can be found in the final TSD. For the public's reference, copies of the 2nd, 3rd, and 4th quarter CSM forecasts have been placed in the docket for this rulemaking.[29]

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 2010. Tables III.A.3-1 and III.A.3-2 show the resulting projections for the reference 2016 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.

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[27] GM argued that the unusually large volume of large pickups led to higher overall requirements for those vehicles. As discussed below, the agencies' analysis for the final rule corrects the number of large pickups. With this correction and other updates to the agencies' market forecast and other analytical inputs, the target functions defining the final standards (and achieving the average required performance levels defining the national program) are very similar to those from the NPRM, especially for light trucks.

[28] These include the Ford F-250 & F-350, Econoline E-250, & E-350; Chevy Express, Silverado 2500, & 3500; GMC Savana, Dodge 2500, & 3500; among others.

[29] The CSM Sales Forecast Excel file ("CSM North America Sales Forecasts 2Q09 3Q09 4Q09 for the Docket") is available in the docket (Docket EPA-HQ-OAR-2009-0472).

Table III-1. Annual Sales of Light-Duty Vehicles by Manufacturer in 2008 and Estimated for 2016

	Cars		Light Trucks		Total	
	2008 MY	2016 MY	2008 MY	2016 MY	2008 MY	2016 MY
BMW	291,796	424,923	61,324	171,560	353,120	596,482
Chrysler	537,808	340,908	1,119,397	525,128	1,657,205	866,037
Daimler	208,052	272,252	79,135	126,880	287,187	399,133
Ford	709,583	1,118,727	1,158,805	1,363,256	1,868,388	2,481,983
General Motors	1,370,280	230,705	1,749,227	95,054	3,119,507	325,760
Honda	899,498	1,283,937	612,281	1,585,828	1,511,779	2,869,766
Hyundai	270,293	811,214	120,734	671,437	391,027	1,482,651
Kia	145,863	401,372	135,589	211,996	281,452	613,368
Mazda	191,326	455,643	111,220	210,717	302,546	666,360
Mitsubishi	76,701	350,055	24,028	144,992	100,729	495,047
Porsche	18,909	49,914	18,797	88,754	37,706	138,668
Nissan	653,121	33,471	370,294	16,749	1,023,415	50,220
Subaru	149,370	876,677	49,211	457,114	198,581	1,333,790
Suzuki	68,720	97,466	45,938	26,108	114,658	123,574
Tata	9,596	65,806	55,584	42,695	65,180	108,501
Toyota	1,143,696	2,069,283	1,067,804	1,249,719	2,211,500	3,319,002
Volkswagen	290,385	586,011	26,999	124,703	317,384	710,011
Total	7,034,997	9,468,365	6,806,367	7,112,689	13,841,364	16,580,353

Table III-2. Annual Sales of Light-Duty Vehicles by Market Segment in 2008 and Estimated for 2016

Cars			Light Trucks		
	2008 MY	2016 MY		2008 MY	2016 MY
Full-Size Car	829,896	530,945	Full-Size Pickup	1,331,989	1,379,036
Luxury Car	1,048,341	1,548,242	Mid-Size Pickup	452,013	332,082
Mid-Size Car	2,166,849	2,550,561	Full-Size Van	33,384	65,650
Mini Car	617,902	1,565,373	Mid-Size Van	719,529	839,194
Small Car	1,912,736	2,503,566	Mid-Size MAV*	110,353	116,077
Specialty Car	459,273	769,679	Small MAV	231,265	62,514
			Full-Size SUV*	559,160	232,619
			Mid-Size SUV	436,080	162,502
			Small SUV	196,424	108,858
			Full-Size CUV*	264,717	260,662
			Mid-Size CUV	923,165	1,372,200
			Small CUV	1,548,288	2,181,296
Total Sales**	7,034,997	9,468,365		6,806,367	7,079,323

* 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 final 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[30] cars sales in 2008 were broken down as shown in Table III-3:

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[30] Note: In the NPRM, Ford's 2008 sales per segment, and the total number of cars was different than shown here. The change in values is due to a correction of vehicle segments for some of Ford's vehicles.

Table III-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-1, Ford's total car sales in 2008 were 709,583 units, while the agencies project that they will increase to 1,113,333 units by 2016. This represents an increase of 56.9 percent. Thus, the agencies increased the 2008 sales of each Ford car segment by 56.9 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 2016 in Table III-2).

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 2016, the figures in Table III.A.3-2 indicate that luxury car sales in 2016 are 1,548,242 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 2016 projected by EIA and a change in manufacturer market share per CSM, luxury car sales decreased to 1,523,171 units. Thus, overall for 2016, luxury car sales had to increase by 25,071 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 2012-2016--the reference fleet--which matched the total sales projections of the AEO forecast and the manufacturer and segment splits of the CSM forecast. These sales splits can be found in Chapter 1 of the Joint TSD for the final rule.

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 1,286,184 units in 2016 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 1,379,036 units. Thus, we increased each manufacturer's sales of large pickups by 7 percent.[31] 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

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[31] Note: In the NPRM this example showed 29 percent instead of 7 percent. The significant decrease was due to using the filtered 4th quarter CSM forecast. Commenters such as GM had commented that we had too many full-size trucks and vans, and this change addresses their comment.

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.[32] 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.[33]

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, if the Prius represented 30 percent of Toyota's sales of compact cars in 2008 and Toyota's sales of compact cars in 2016 was projected to double by 2016, then the sales of the Prius were doubled, and the Prius sales in 2016 remained 30 percent of Toyota's compact car sales.

The projection of average footprint for both cars and trucks remained virtually constant over the years covered by the final rulemaking. This occurrence is strictly a result of the CSM projections. There are a number of trends that occur in the CSM projections that caused the average footprint to remain constant. First, as the number of subcompacts increases, so do the

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

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

number of 2-wheel drive crossover vehicles (that are regulated as cars). Second, truck volumes have many segment changes during the rulemaking time frame. There is no specific footprint related trend in any segment that can be linked to the unchanging footprint, but there is a trend that non-pickups' volumes will move from truck segments that are ladder frame to those that are unibody-type vehicles. A table of the footprint projections is available in the TSD as well as further discussion on this topic.

4. How is the development of the baseline fleet for this rule different from NHTSA's historical approach and why is this approach preferable?

NHTSA has historically based its analysis of potential new CAFE standards on detailed product plans the agency has requested from manufacturers planning to produce light vehicles for sale in the United States. Although the agency has not attempted to compel manufacturers to submit such information, most major manufacturers and some smaller manufacturers have voluntarily provided it when requested.

The proposal discusses many of the advantages and disadvantages of the market forecast approach used by the agencies, including the agencies' interest in examining product plans as a check on the reference fleet developed by the agencies for this rulemaking. One of the primary reasons for the request for data in 2009 was to obtain permission from the manufacturers to make public their product plan information for model years 2010 and 2011. There are a number of reasons that this could be advantageous in the development of a reference fleet. First, some known changes to the fleet may not be captured by the approach of solely using publicly available information. For example, the agencies' current market forecast includes some vehicles for which manufacturers have announced plans for elimination or drastic production cuts such as the Chevrolet Trailblazer, the Chrysler PT Cruiser, the Chrysler Pacifica, the Dodge Magnum, the Ford Crown Victoria, the Mercury Sable, the Pontiac Grand Prix, the Pontiac G5 and the Saturn Vue. These vehicle models appear explicitly in market inputs to NHTSA's analysis, and are among those vehicle models included in the aggregated vehicle types appearing in market inputs to EPA's analysis. However, although the 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.[34]

Second, the agencies' market forecast does not include some forthcoming vehicle models, such as the Chevrolet Volt, the Ford Fiesta and several publicly announced electric vehicles, including the announcements from Nissan regarding the Leaf. Nor does it include several MY 2009 or 2010 vehicles, such as the Honda Insight, the Hyundai Genesis and the Toyota Venza, as our starting point for defining specific vehicle models in the reference fleet was Model Year 2008. Additionally, the market forecast does not account for publicly announced technology introductions, such as Ford's EcoBoost system, whose product plans specify which vehicles and how many are planned to have this technology. Chrysler Group LLC has announced plans to offer small- and medium-sized cars using Fiat powertrains. Were the agencies to rely on

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[34] An example of this is in the GM Pontiac line, which is in the process of being phased out during the course of this rulemaking. GM has similar vehicles within their other brands (like Chevy) that will presumable pick up the loss in Pontiac share. We model this simply by leaving the Pontiac brand in.

manufacturers' product plans (that were submitted), the market forecast would account for not only these specific examples, but also for similar examples that have not yet been announced publicly.

Additionally, NHTSA acknowledges that Pontiac and Saturn lines are being discontinued. We also are aware that as of October, General Motors Corp. and Sichuan Tengzhong Heavy Industrial Machinery Co., Ltd had tentatively reached an agreement for Tengzhong to acquire GM's Hummer truck brand. As we understand it, GM was planning to continue to build the trucks and provide business services to the buyer during a transitional period. Two GM assembly plants that produce the H2, H3 and H3T models were supposed to continue production of those trucks until June 2011, with the option of a one year extension until June 2012. As of late February, the agencies were made aware that the deal to sell Hummer to Sichuan Tengzhong Heavy Industrial Machinery Co., Ltd. had fallen through because Sichuan Tengzhong Heavy Industrial Machinery Co., Ltd. failed to win Chinese government approval of the sale. It is believed that GM is planning to wind down the Hummer brand, while at the same time being open to other potential bidders for Hummer.

We are also aware that as of late February, GM completed the sale of Saab to Dutch sports car maker Spyker Cars NV. The purchase created a new company, called Saab Spyker Automobiles NV. According to the CEO of Saab Automobile, Jan Ake Jonsson, Saab has a production- and intelligence-sharing agreement with GM that lasts through the introduction of redesigned Saab 9-3 in 2012.

Some commenters, such as CBD and NESCAUM, suggested that the agencies' omission of known future vehicles and technologies in the reference fleet causes inaccuracies, which CBD further suggested could lead the agencies to set lower standards. On the other hand, CARB commented that "the likely impact of this omission is minor." 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. This is discussed further below. The agencies believe the above-mentioned comments by CBD, NESCAUM, and others are based on a misunderstanding of the agencies' approach to analyzing potential increases in regulatory stringency. The agencies also note that manufacturers do not always use technology solely to increase fuel economy, and that use of technology to increase vehicles' acceleration performance or utility would probably make that technology unavailable toward more stringent standards. 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.

Moreover, EPA and NHTSA believe that not including such vehicles after MY 2008 does not significantly impact our estimates of the technology required to comply with the standards. If included, these vehicles could increase the extent to which manufacturers are—in the reference case—expected to over-comply with the MY 2011 CAFE standards, and could thereby make the new standards appear to cost less and yield less benefit relative to the reference case. However, in the agencies' judgment, production of the most advanced technology vehicles, such as the Chevy Volt or the Nissan Leaf (for example), will most likely be too limited during MY 2011 through MY 2016 to significantly impact manufacturers' compliance positions. While we are projecting the characteristics of the future fleet by extrapolating from the MY 2008 fleet, the primary difference between the future fleet and the 2008 fleet in the same vehicle segment is the use of additional CO_2-reducing and fuel-saving technologies. Both the NHTSA and EPA models add such technologies to evaluate means of complying with the standards, and the costs of doing so. Thus, our future projections of the vehicle fleet generally shift vehicle designs towards those more likely to be typical of newer vehicles. Compared to using product plans that show continued fuel economy increases planned based on expectations that CAFE standards will continue to increase, this approach helps to clarify the costs and benefits of the new standards, as the costs and benefits of all fuel economy improvements beyond those required by the MY 2011 CAFE standards are being assigned to the final rules. In some cases, the "actual" (vs. projected or "modeled") new vehicles being introduced into the market by manufacturers are done so in anticipation of this rulemaking. On the other hand, manufacturers may plan to continue using technologies to improve vehicle performance and/or utility, not just fuel economy. Our approach prevents some of these actual technological improvements and their associated cost and fuel economy improvements from being assumed in the reference fleet. Thus, the added technology will not be considered to be free (or having no benefits) for the purposes of this rule.

In this regard, the agencies further note that manufacturer announcements regarding forward models (or future vehicle models) need not be accepted automatically. Manufacturers tend to limit accurate production intent information in these releases for reasons such as: (a) competitors will closely examine their information for data in their product planning decisions; (b) the press coverage of forward model announcements is not uniform, meaning highly anticipated models have more coverage and materials than models that may be less exciting to the public and consistency and uniformity cannot be ensured with the usage of press information; and (c) these market projections are subject to change (sometimes significant), and manufacturers may not want to give the appearance of being indecisive, or under/over-confident to their shareholders and the public with premature release of information.

NHTSA has evaluated the use of public manufacturer forward model press information to update the vehicle fleet inputs to the baseline and reference fleet. The challenges in this approach are evidenced by the continuous stream of manufacturer press releases throughout a defined rulemaking period. Manufacturers' press releases suffer from the same types of inaccuracies that many commenters believe can affect product plans. Manufacturers can often be overly optimistic in their press releases, both on projected date of release of new models and on sales volumes.

More generally and more critically, as discussed in the proposal and as endorsed by many of the public comments, there are several advantages to the approach used by the agencies in this final rule. Most importantly, today's market forecast is much more transparent. The information sources used to develop today's market forecast are all either in the public domain or available commercially. Another significant advantage of today's market forecast is the agencies' ability to assess more fully the incremental costs and benefits of the proposed standards. 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. 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 final rule, 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.

5. How is this baseline different quantitatively from the baseline that NHTSA used for the MY 2011 (March 2009) final rule?

As discussed above, the current baseline was developed from adjusted MY 2008 compliance data and covers MYs 2011-2016, while the baseline that NHTSA used for the MY 2011 CAFE rule was developed from confidential manufacturer product plans for MY 2011. This section describes, for the reader's comparison, some of the differences between the current baseline and the MY 2011 CAFE rule baseline. This comparison provides a basis for understanding general characteristics and measures of the difference, in this case, between using publicly (and commercially) available sources and using manufacturers' confidential product plans. The current baseline, while developed using the same methods as the baseline used for MYs 2012-2016 NPRM, reflects updates to the underlying commercially-available forecast of manufacturer and market segment shares of the future light vehicle market. These changes are discussed above.

Estimated vehicle sales:

The sales forecasts, based on the Energy Information Administration's (EIA's) Annual Energy Outlook 2010 (AEO 2010), used in the current baseline indicate that the total number of light vehicles expected to be sold during MYs 2011-2015 is 77 million, or about 15.4 million vehicles annually. NHTSA's MY 2011 final rule forecast, based on AEO 2008, of the total number of light vehicles likely to be sold during MY 2011 through MY 2015 was 83 million, or about 16.6 million vehicles annually. Light trucks are expected to make up 41 percent of the MY 2011 baseline market forecast in the current baseline, compared to 42 percent of the baseline market forecast in the MY 2011 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, and changes in AEO's forecast of future fuel prices.

The figures below attempt to demonstrate graphically the difference between the variation of fuel economy with footprint for passenger cars under the current baseline and MY 2011 final rule, and for light trucks under the current baseline and MY 2011 final rule, respectively. Figures III-1 and III-2 show the variation of fuel economy with footprint for passenger car models in the current baseline and in the MY 2011 final rule, while Figures III-3 and III-4 show the variation of fuel economy with footprint for light truck models in the current baseline and in the MY 2011 final rule. However, it is difficult to draw meaningful conclusions by comparing figures from the current baseline with those of the MY 2011 final rule. In the current baseline the number of make/models, and their associated fuel economy and footprint, are fixed and do not vary over time—this is why the number of data points in the current baseline figures appears smaller as compared to the number of data points in the MY 2011 final rule baseline. In contrast, the baseline fleet used in the MY 2011 final rule varies over time as vehicles (with different fuel economy and footprint characteristics) are added to and dropped from the product mix.

Figure III-1. Planned Fuel Economy vs. Footprint, Passenger Cars in Current Baseline

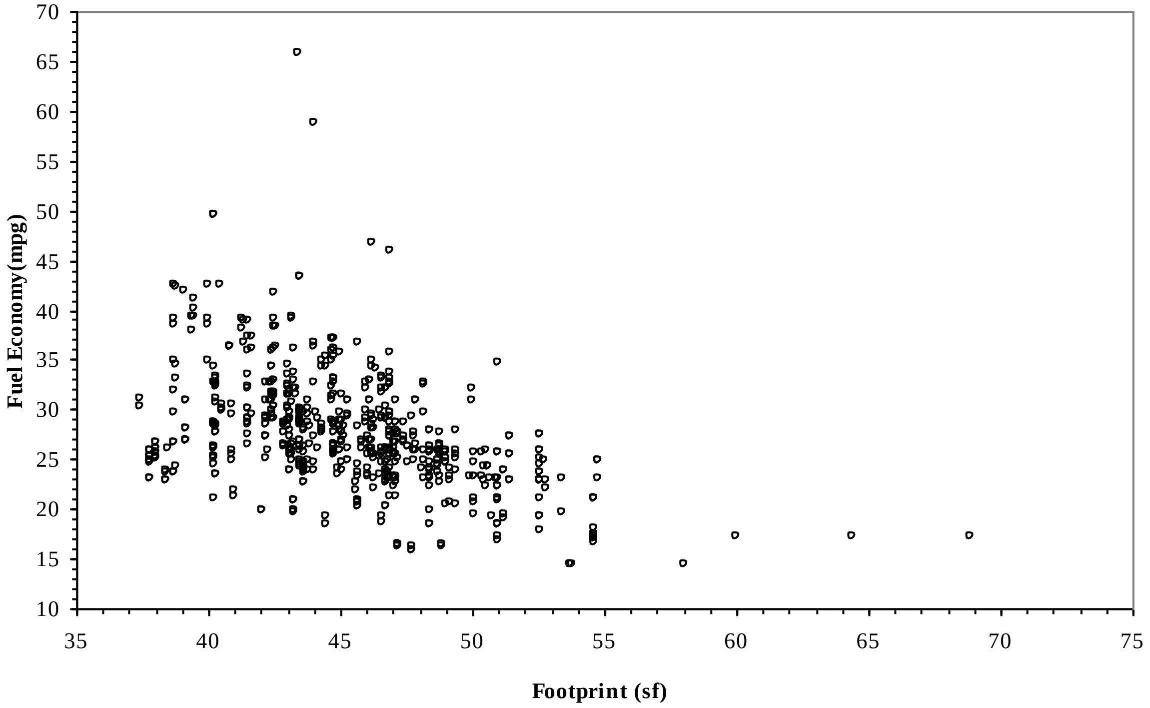


Figure III-2. Planned Fuel Economy vs. Footprint, Passenger Cars in MY 2011 Final Rule

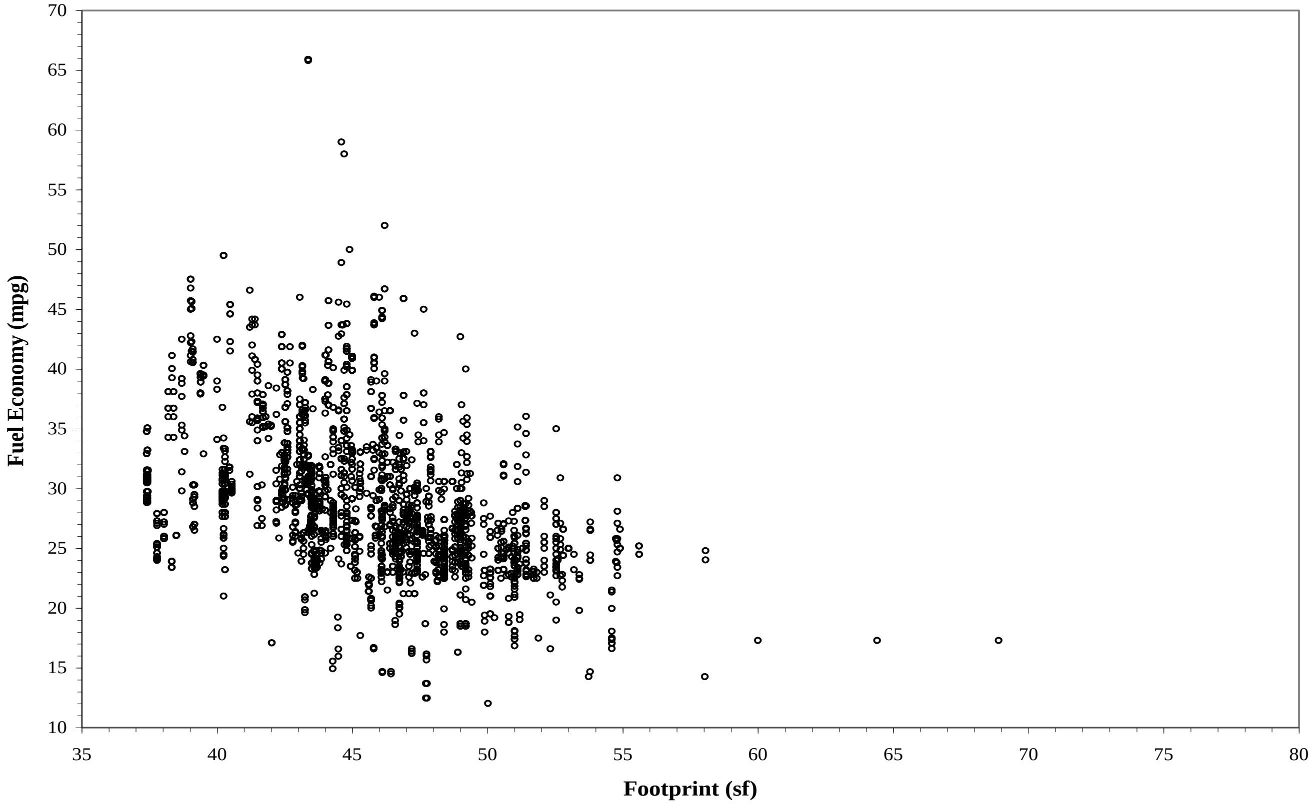


Figure III-3. Planned Fuel Economy vs. Footprint, Light Trucks in Current Baseline

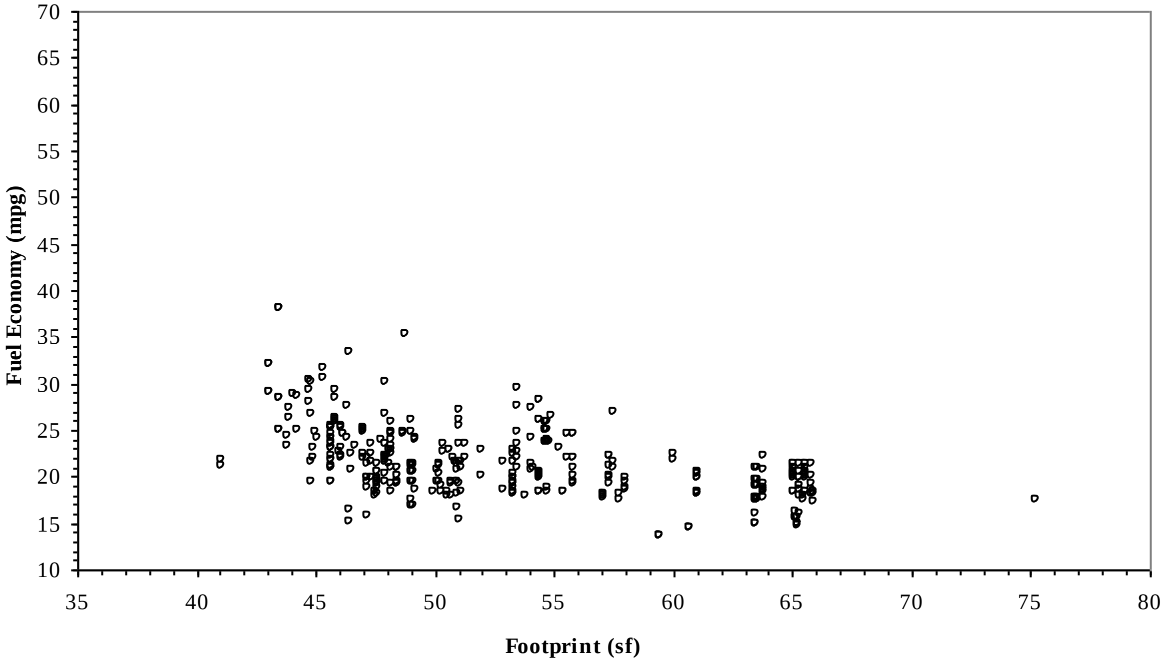
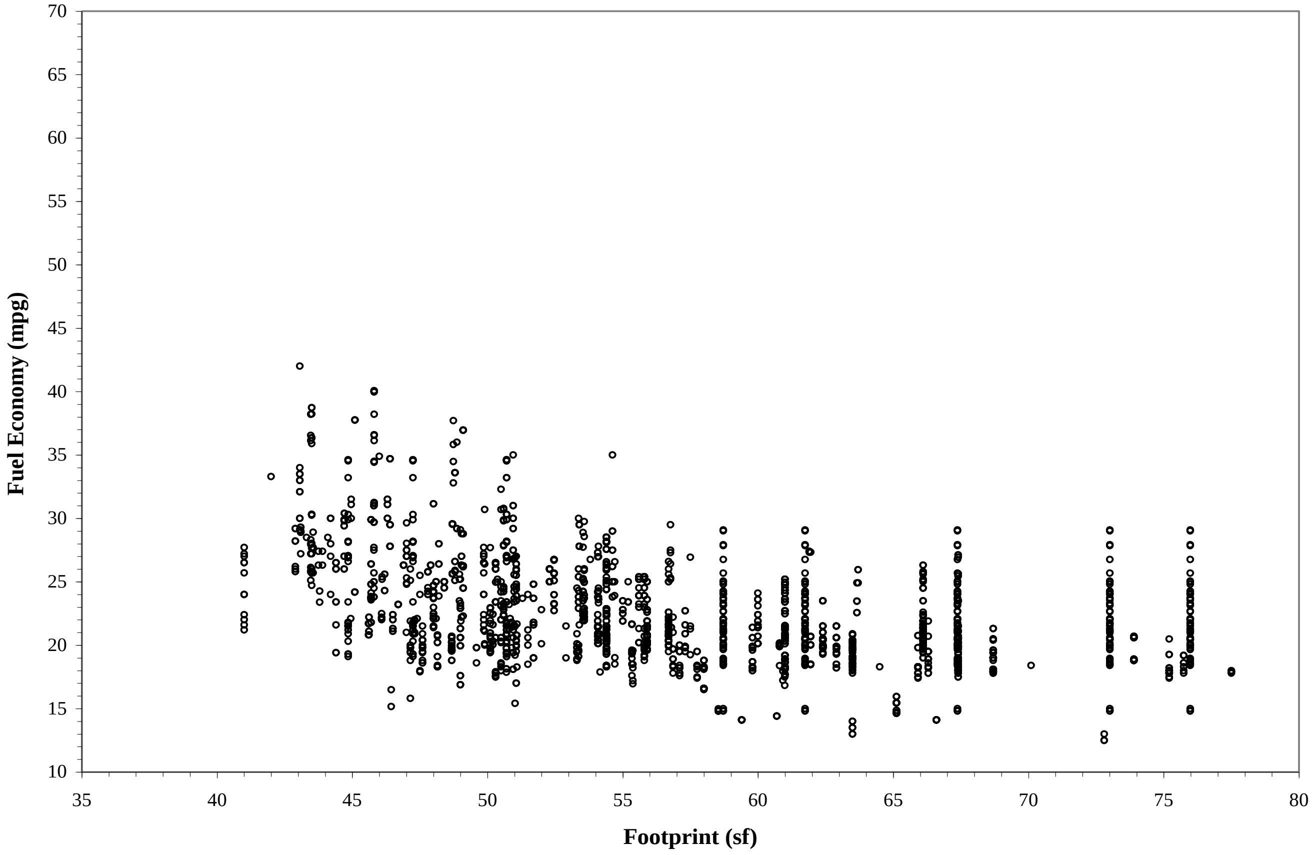


Figure III-4. Planned Fuel Economy vs. Footprint, Light Trucks in MY 2011 Final Rule



Estimated manufacturer market shares:

NHTSA's expectations regarding manufacturers' market shares (the basis for which is discussed below) have also changed since the MY 2011 final rule, given that the agency is relying on different sources of material for these assumptions as discussed above and in Chapter 1 of the joint TSD. These changes are reflected below in Table III-4, which shows the agency's sales forecasts for passenger cars and light trucks under the current baseline and the MY 2011 final rule.[35]

Table III-4. Sales Forecasts (Production for U.S. Sale in MY 2011, Thousand Units)

	Current Baseline		**MY 2011 Final Rule**	
Manufacturer	**Passenger**	**Nonpassenger**	**Passenger**	**Nonpassenger**
Chrysler	326	737	707	1,216
Ford	1,344	792	1,615	1,144
General Motors	1,249	1,347	1,700	1,844
Honda	851	585	1,250	470
Hyundai	382	46	655	221
Kia	306	88		
Nissan	612	331	789	479
Toyota	1,356	888	1,405	1,094
Other Asian	664	246	441	191
European	833	396	724	190
Total	7,923	5,458	9,286	6,849

Dual-fueled vehicles:

Manufacturers have also, during and since MY 2008, indicated to the agency that they intend to sell more dual-fueled or flexible-fuel vehicles (FFVs) in MY 2011 than indicated in the current baseline of adjusted MY 2008 compliance data. FFVs create a potential market for alternatives to petroleum-based gasoline and diesel fuel. For purposes of determining compliance with CAFE standards, the fuel economy of a FFV is, subject to limitations, adjusted upward to account for this potential.[36] However, NHTSA is precluded from "taking credit" for the compliance flexibility by accounting for manufacturers' ability to earn and use credits in setting the level of the standards."[37] Some manufacturers plan to produce a considerably greater share of FFVs than can earn full credit under EPCA. The projected average FFV share of the market in MY 2011 is 7 percent for the current baseline, versus 17 percent for the MY 2011 final rule. NHTSA notes that in MY 2008 (the model year providing the vehicle models upon which today's market forecast is based), the three U.S.-based OEMs produced most of the FFVs offered

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[35] As explained below, although NHTSA normalized each manufacturer's overall market share to produce a realistically-sized fleet, the product mix for each manufacturer that submitted product plans was preserved. The agency has reviewed manufacturers' product plans in detail, and understands that manufacturers do not sell the same mix of vehicles in every model year.

[36] *See* 49 U.S.C. 32905 and 32906.

[37] 49 U.S.C..32902(h).

for sale in the U.S., yet these OEMs are projected to account for a smaller share of the future market in the forecast the agency has used to develop and analyze today's rule than in the forecast the agency used to develop and analyze the MY 2011 standards.

Estimated achieved fuel economy levels:

Because manufacturers' product plans also reflect simultaneous changes in fleet mix and other vehicle characteristics, the relationship between increased technology utilization and increased fuel economy cannot be isolated with any certainty. To do so would require an apples-to-apples "counterfactual" fleet of vehicles that are, except for technology and fuel economy, identical—for example, in terms of fleet mix and vehicle performance and utility. The current baseline market forecast shows industry-wide average fuel economy levels somewhat lower in MY 2011 than shown in the MY 2011 final rule and the MYs 2012-2016 NPRM. Under the current baseline, average fuel economy for MY 2011 is 26.4 mpg, versus 26.5 mpg under the baseline in the MY 2011 final rule, and 26.7 mpg under the baseline in the MYs 2012-2016 NPRM. The 0.3 mpg change relative to the MYs 2012-2016 baseline is the result of changes in manufacturer and market segment shares of the MY 2011 market.

These differences are shown in greater detail below in Table III-5, which shows manufacturer-specific CAFE levels (not counting FFV credits that some manufacturers expect to earn) from the current baseline versus the MY 2011 final rule baseline (from manufacturers' 2008 product plans) for passenger cars and light trucks. Table III-6 shows the combined averages of these planned CAFE levels in the respective baseline fleets. These tables demonstrate that, while the difference at the industry level is not so large, there are significant differences in CAFE at the manufacturer level between the current baseline and the MY 2011 final rule baseline. For example, while Volkswagen is essentially the same under both, Toyota and Nissan show increased combined CAFE levels under the current baseline (by 1.9 and 0.7 mpg respectively), while Chrysler, Ford, and GM show decreased combined CAFE levels under the current baseline (by 1.4, 1.1, and 0.8 mpg, respectively) relative to the MY 2011 final rule baseline.

Table III-5. Current Baseline Planned CAFE Levels in MY 2011 versus MY 2011 Final Rule Planned CAFE Levels (Passenger and Nonpassenger)

	Current baseline CAFE levels		**MY 2011 planned CAFE levels**	
Manufacturer	Passenger	Nonpassenger	Passenger	Nonpassenger
BMW	27.2	23.0	27.0	23.0
Chrysler	27.8	21.8	28.2	23.1
Ford	28.0	21.0	29.3	22.5
Subaru	29.2	26.1	28.6	28.6
General Motors	28.2	21.2	30.3	21.4
Honda	33.5	25.0	32.3	25.2
Hyundai	32.5	24.3	31.7	26.0
Tata	24.6	19.6	24.7	23.9
Kia[38]	31.7	23.7		
Mazda[39]	30.6	26.0		
Daimler	26.4	21.0	25.2	20.6
Mitsubishi	29.4	23.6	29.3	26.7
Nissan	31.7	21.7	31.3	21.4
Porsche	26.2	20.0	27.2	20.0
Ferrari[40]			16.2	
Maserati[41]			18.2	
Suzuki	30.9	23.3	28.7	24.0
Toyota	35.1	23.7	33.2	22.7
Volkswagen	29.1	20.2	28.5	20.1
Total/Average	30.3	22.2	30.4	22.6

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[38] Again, Kia is not listed in the table for the MY 2011 final rule because it was considered as part of Hyundai for purposes of that analysis (*i.e.*, Hyundai-Kia).

[39] Mazda is not listed in the table for the MY 2011 final rule because it was considered as part of Ford for purposes of that analysis.

[40] EPA did not include Ferrari in the current baseline based on the conclusion that including them would not impact the results, and therefore Ferrari is not listed in the table for the current baseline.

[41] EPA did not include Maserati in the current baseline based on the conclusion that including them would not impact the results, and therefore Maserati is not listed in the table for the current baseline.

Table III-6. Current Baseline Planned CAFE Levels in MY 2011 versus MY 2011 Final Rule Planned CAFE Levels (Combined)

Manufacturer	Current baseline	MY 2011 Final Rule baseline
BMW	25.0	26.0
Chrysler	23.3	24.7
Ford	24.9	26.0
Subaru	27.9	28.6
General Motors	24.1	24.9
Honda	29.5	30.0
Hyundai	31.3	30.0
Tata	21.4	24.4
Kia	29.5	
Mazda	29.8	
Daimler	24.4	23.6
Mitsubishi	27.4	29.1
Nissan	27.3	26.6
Porsche	23.7	22.0
Ferrari		16.2
Maserati		18.2
Suzuki	29.7	27.8
Toyota	29.5	27.6
Volkswagen	27.0	27.1
Total/Average	26.4	26.5

Tables III-7 through III-9 summarize other differences between the current baseline and manufacturers' product plans submitted to NHTSA in 2008 for the MY 2011 final rule. These tables present average vehicle footprint, curb weight, and power-to-weight ratios for each manufacturer represented in the current baseline and of the seven largest manufacturers represented in the product plan data used in that rulemaking, and for the overall industry. The tables containing product plan data do not identify manufacturers by name, and do not present them in the same sequence.

Tables III-7a and III-7b show that the current baseline reflects a slight decrease in overall average passenger vehicle size relative to the manufacturers' plans. This is a reflection of the market segment shifts underlying the sales forecasts of the current baseline.

Table III-7a. Current Baseline Average MY 2011 Vehicle Footprint
(Square Feet)

Manufacturer	PC	LT	Avg.
BMW	45.4	49.9	47.5
Chrysler	46.8	52.8	50.9
Daimler	47.1	53.3	49.0
Ford	46.3	56.1	49.9
General Motors	46.4	58.2	52.5
Honda	44.3	49.1	46.3
Hyundai	44.4	48.7	44.8
Kia	45.2	51.0	46.5
Mazda	44.4	47.3	44.9
Mitsubishi	43.8	46.5	44.6
Nissan	45.3	53.9	48.3
Porsche	38.6	51.0	42.8
Subaru	43.1	26.6	36.8
Suzuki	40.8	47.2	41.6
Tata	50.3	47.8	48.8
Toyota	44.0	53.0	47.6
Volkswagen	43.5	52.6	45.1
Industry Average	45.2	53.5	48.6

Table III-7b. MY 2011 Final Rule Average Planned MY 2011 Vehicle Footprint
(Square Feet)

	PC	LT	Avg.
Manufacturer 1	46.7	58.5	52.8
Manufacturer 2	46.0	5.4	47.1
Manufacturer 3	44.9	52.8	48.4
Manufacturer 4	45.4	55.8	49.3
Manufacturer 5	45.2	57.5	50.3
Manufacturer 6	48.5	54.7	52.4
Manufacturer 7	45.1	49.9	46.4
Industry Average	45.6	55.1	49.7

Tables III-8a and III-8b show that the current baseline reflects a decrease in overall average vehicle weight relative to the manufacturers' plans. As above, this is most likely a reflection of the market segment shifts underlying the sales forecasts of the current baseline.

Table III-8a. Current Baseline Average MY 2011 Vehicle Curb Weight
(Pounds)

Manufacturer	PC	LT	Avg.
BMW	3,535	4,648	4,055
Chrysler	3,572	4,469	4,194
Daimler	3,583	5,127	4,063
Ford	3,526	4,472	3,877
General Motors	3,528	4,978	4,281
Honda	3,040	4,054	3,453
Hyundai	3,014	4,078	3,129
Kia	3,035	4,007	3,252
Mazda	3,258	3,803	3,348
Mitsubishi	3,298	3,860	3,468
Nissan	3,251	4,499	3,689
Porsche	3,159	4,906	3,760
Subaru	3,176	2,001	2,727
Suzuki	2,842	3,843	2,965
Tata	3,906	5,171	4,627
Toyota	3,109	4,321	3,589
Volkswagen	3,445	5,672	3,839
Industry Average	3,313	4,499	3,797

Table III-8b. MY 2011 Final Rule Average Planned MY 2011 Vehicle Curb Weight
(Pounds)

	PC	LT	Avg.
Manufacturer 1	3,197	4,329	3,692
Manufacturer 2	3,691	4,754	4,363
Manufacturer 3	3,293	4,038	3,481
Manufacturer 4	3,254	4,191	3,510
Manufacturer 5	3,547	5,188	4,401
Manufacturer 6	3,314	4,641	3,815
Manufacturer 7	3,345	4,599	3,865
Industry Average	3,380	4,687	3,935

Tables III-9a and III-9b show that the current baseline reflects a decrease in average performance relative to that of the manufacturers' product plans. This decreased performance is most likely a reflection of the market segment shifts underlying the sales forecasts of the current baseline, that is, an assumed shift away from higher performance vehicles.

Table III-9a. Current Baseline Average MY 2011 Vehicle Power-to-Weight Ratio (hp/lb)

Manufacturer	PC	LT	Avg.
BMW	0.072	0.061	0.067
Chrysler	0.055	0.052	0.053
Daimler	0.068	0.056	0.064
Ford	0.058	0.054	0.056
General Motors	0.057	0.056	0.056
Honda	0.056	0.054	0.056
Hyundai	0.052	0.055	0.052
Kia	0.050	0.056	0.051
Mazda	0.052	0.055	0.052
Mitsubishi	0.053	0.056	0.054
Nissan	0.059	0.057	0.058
Porsche	0.105	0.073	0.094
Subaru	0.060	0.030	0.048
Suzuki	0.049	0.062	0.051
Tata	0.077	0.057	0.065
Toyota	0.053	0.062	0.056
Volkswagen	0.057	0.052	0.056
Industry Average	0.057	0.056	0.056

Table III-9b. MY 2011 Final Rule Average Planned MY 2011 Vehicle Power-to-Weight Ratio (hp/lb)

	PC	LT	Avg.
Manufacturer 1	0.065	0.058	0.060
Manufacturer 2	0.061	0.065	0.062
Manufacturer 3	0.053	0.059	0.056
Manufacturer 4	0.060	0.058	0.059
Manufacturer 5	0.060	0.057	0.059
Manufacturer 6	0.063	0.065	0.065
Manufacturer 7	0.053	0.055	0.053
Industry Average	0.060	0.059	0.060

As discussed above, the agencies' market forecast for MY 2012-2016 holds the performance and other characteristics of individual vehicle models constant, adjusting the size and composition of the fleet from one model year to the next.

Refrefresh and redesign schedules (for application in NHTSA's modeling):

Expected model years in which each vehicle model will be redesigned or freshened constitute another important aspect of NHTSA's market forecast. As discussed in Chapter V below, NHTSA's analysis supporting the current rulemaking times the addition of nearly all technologies to coincide with either a vehicle redesign or a vehicle freshening. Product plans submitted to NHTSA preceding the MY 2011 final rule contained manufacturers' estimates of vehicle redesign and freshening schedules and NHTSA's estimates of the timing of the five-year redesign cycle and the two- to three-year refresh cycle were made with reference to those plans. In the current baseline, in contrast, estimates of the timing of the refresh and redesign cycles were based on historical dates—*i.e.*, counting forward from known redesigns occurring in or prior to MY 2008 for each vehicle in the fleet and assigning refresh and redesign years accordingly. After applying these estimates, the shares of manufacturers' passenger car and light truck estimated to be redesigned in MY 2011 were as summarized below for the current baseline and the MY 2011 final rule. Table III-10 below shows the percentages of each manufacturer's fleets expected to be redesigned in MY 2011 for the current baseline. Table III-11 presents corresponding estimates from the market forecast used by NHTSA in the analysis supporting the MY 2011 final rule (again, to protect confidential information, manufacturers are not identified by name).

Table III-10. Current Baseline, Share of Fleet Redesigned in MY 2011

Manufacturer	**PC**	**LT**	**Avg.**
BMW	32%	37%	34%
Chrysler	0%	13%	9%
Daimler	0%	0%	0%
Ford	12%	8%	11%
General Motors	17%	3%	9%
Honda	29%	26%	28%
Hyundai	26%	0%	23%
Kia	38%	83%	48%
Mazda	0%	0%	0%
Mitsubishi	0%	59%	18%
Nissan	5%	25%	12%
Porsche	0%	100%	34%
Subaru	0%	42%	16%
Suzuki	4%	21%	6%
Tata	28%	100%	69%
Toyota	5%	15%	9%
Volkswagen	16%	0%	13%
Industry Average	13%	15%	14%

Table III-11. MY 2011 Final Rule, Share of Fleet Redesigned in MY 2011

	PC	**LT**	**Avg.**
Manufacturer 1	19%	0%	11%
Manufacturer 2	34%	27%	29%
Manufacturer 3	5%	0%	3%
Manufacturer 4	7%	0%	5%
Manufacturer 5	19%	0%	11%
Manufacturer 6	34%	28%	33%
Manufacturer 7	27%	28%	28%
Overall	20%	9%	15%

We continue, therefore, to estimate that manufacturers' redesigns will not be uniformly distributed across model years. This is in keeping with standard industry practices, and reflects what manufacturers actually do–NHTSA has observed that manufacturers in fact do redesign more vehicles in some years than in others. NHTSA staff has closely examined manufacturers' planned redesign schedules, contacting some manufacturers for clarification of some plans, and confirmed that these plans remain unevenly distributed over time. For example, although the table above shows that NHTSA expects Company 2 to redesign 34 percent of its passenger car models in MY 2011, current information indicates that this company will then redesign only (a different) 10 percent of its passenger cars in MY 2012. Similarly, although the table above shows that NHTSA expects four of the largest seven light truck manufacturers to redesign virtually no light truck models in MY 2011, current information also indicates that these four manufacturers will redesign 21-49 percent of their light trucks in MY 2012.

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

While the agencies received updated product plans in Spring and Fall 2009 in response to NHTSA's requests, the baseline data used in this final rule is not informed by these product plans, except with respect to specific engineering characteristics (*e.g.*, GVWR) of some MY 2008 vehicle models, because these product plans contain confidential business information that the agencies are legally required to protect from disclosure, and because the agencies have concluded that, for purposes of this final rule, a transparent baseline is preferable.

For the NPRM, NHTSA conducted a separate analysis that did make use of these product plans. NHTSA performed this separate analysis for purposes of comparison only. For the final rule which this FRIA accompanies, NHTSA used the publicly-available baseline for all analysis related to the development and evaluation of the new CAFE standards. As discussed above, while a baseline developed using publicly and commercially available sources has both advantages and disadvantages relative to a baseline developed using manufacturers' product plans, NHTSA has concluded for today's analysis that the advantages outweigh the disadvantages. NHTSA plans to consider these advantages and disadvantages further in connection with future rulemakings, taking into account changes in the market, changes in the scope and quality of publicly and commercially available data, and any changes in manufacturers' willingness to make some product planning information publicly available.

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

In developing the proposed MY 2012-16 standards, the agency developed and considered a wide variety of alternatives. In response to comments received in the last round of rulemaking, in our March 2009 notice of intent to prepare an environmental impact statement, the agency selected a range of candidate stringencies that increased annually, on average, 3% to 7%.[42] That same approach has been carried over to this final rule and to the accompanying FEIS and FRIA. Thus, the majority of the alternatives considered in this rulemaking are defined as average percentage increases in stringency—3 percent per year, 4 percent per year, 5 percent per year, and so on. 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 requirements under EPCA/EISA.

In the NPRM, we noted that 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. We were mindful that 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 3% Alternative, the least stringent alternative, places more weight on technological feasibility and economic practicability. We recognized that 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. We also recognized that some technologies (*e.g.*, PHEVs and EVs) will not be available for more than limited commercial use through MY 2016, and that even those technologies that could be more widely commercialized through MY 2016 cannot all be deployed on every vehicle model in MY 2012 but require a realistic schedule for more widespread commercialization to be within the realm of economically practicability.

In addition to the alternatives that increase evenly at annual rates ranging from 3% to 7%, NHTSA also included alternatives developed using benefit-cost criteria. The agency emphasized benefit-cost-related alternatives in its rulemakings for MY 2008-2011 and, subsequently, MY 2011 standards. By including such alternatives in its current 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 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).[43] With respect

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[42] Notice of intent to prepare an EIS, 74 FR 14857, 14859-60, April 1, 2009.

[43] 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

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 thus far set attribute-based CAFE standards at the point at which net benefits are maximized, we believed it would be useful and informative to consider the potential impacts of that approach as compared to the new approach for MYs 2012-2016.

After working with EPA in thoroughly reviewing and in some cases reassessing the effectiveness and costs of technologies (most of which are already being incorporated in at least some vehicles), market forecasts and economic assumptions, NHTSA used the Volpe model extensively to assess the technologies that the manufacturers could apply in order to comply with each of the alternatives. This allowed us to assess the variety, amount and cost of the technologies that could be used to enable the manufacturers to comply with each of the alternatives. NHTSA estimated how the application of these and other technologies could increase vehicle costs, reduce fuel consumption, and reduce CO_2 emissions.

The agency then assessed which alternative would represent a reasonable balancing of the statutory criteria, given the difficulties confronting the industry and the economy, and other relevant goals and priorities. Those priorities and goals include maximizing energy conservation and achieving a nationally harmonized and coordinated program for regulating fuel economy and GHG emissions.

Part of that assessment of alternatives entailed an evaluation of the stringencies necessary to achieve both Federal and State GHG emission reduction goals, especially those of California and the States that have adopted its GHG emission standard for motor vehicles. Given that EPCA requires attribute-based standards, NHTSA and EPA determined the level at which a national attribute-based GHG emissions standard would need to be set to achieve the same emission reductions in California as the California GHG program. This was done by evaluating a nationwide Clean Air Act standard for MY 2016 that would apply across the country and require the levels of emissions reduction which California standards would require for the subset of vehicles sold in California under the California standards for MY 2009-2016 (known as "Pavley 1"). In essence, the stringency of the California Pavley 1 program was evaluated, but for a national standard. For a number of reasons discussed in the final rule, an assessment was developed of national new vehicle fleet-wide CO_2 performance standards for model year 2016 which would result in the new light-duty vehicle fleet in the State of California having CO_2 performance equal to the performance from the California Pavley 1 standards. That level, 250 g/mi, is equivalent to 35.5 mpg if the GHG standard were met exclusively by fuel economy improvements – and the overall result is the model year 2016 goals of the National Program.

However, the level of stringency for the National Program goal of 250 g/mi CO_2 can be met with both fuel economy "tailpipe" improvements as well as other GHG-reduction related improvements, such as A/C refrigerant leakage reductions. CAFE standards, as discussed elsewhere in this final rule, cannot be met by improvements that cannot be accounted for on the

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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.

FTP/HFET tests. Thus, setting CAFE standards at 35.5 mpg would require more tailpipe technology (at more expense to manufacturers) than would be required under such a CAA standard. To obtain an equivalent CAFE standard, we determined how much tailpipe technology would be necessary in order to meet a mpg level of 35.5 if manufacturers also employed what EPA deemed to be an average amount of A/C “credits” (leakage and efficiency) to reach the 250 g/mi equivalent. This results in a figure of 34.1 mpg as the appropriate counterpart CAFE standard. This differential gives manufacturers the opportunity to reach 35.5 mpg equivalent under the CAA in ways that would significantly reduce their costs. Were NHTSA instead to establish its standard at the same level, manufacturers would need to make substantially greater expenditures on fuel-saving technologies to reach 35.5 mpg under EPCA.

Thus, as part of the process of considering all of the factors relevant under EPCA for setting standards, in a context where achieving a harmonized National Program is important, for the proposal we created a new alternative whose annual percentage increases would achieve 34.1 mpg by MY 2016. That alternative is one which increases on average at 4.3% annually. This new alternative, like the seven alternatives presented above, represents a unique balancing of the statutory factors and other relevant considerations. For the reader’s reference, the estimated required levels of stringency for each alternative in each model year are presented in Table III-12.

Table III-12. Estimated Required Fuel Economy Level for Regulatory Alternatives.[44]

	Alt. 1	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**	**Alt. 9**
	No Action	**3%/year Increase**	**4%/year Increase**	**~4.3%/year Increase**	**5%/year Increase**	**~6.0%/year Increase MNB**	**6%/year Increase**	**7%/year Increase**	**~6.6%/year Increase TCTB**
2012									
Passenger Cars	30.5	31.7	32.1	33.4	32.4	33.0	32.7	33.0	33.4
Light Trucks	24.4	24.1	24.4	25.3	24.6	26.3	24.9	25.1	26.3
Combined	27.8	28.3	28.6	29.7	28.8	30.0	29.1	29.4	30.3
2013									
Passenger Cars	30.5	32.6	33.3	34.2	33.9	36.1	34.5	35.2	36.7
Light Trucks	24.4	24.8	25.3	25.9	25.8	27.7	26.3	26.8	28.0
Combined	27.8	29.1	29.7	30.5	30.3	32.3	30.8	31.4	32.8
2014									
Passenger Cars	30.5	33.5	34.5	35.0	35.5	38.1	36.5	37.6	39.2
Light Trucks	24.5	25.5	26.3	26.6	27.0	29.1	27.8	28.6	29.7
Combined	28.0	30.0	30.9	31.3	31.8	34.2	32.7	33.7	35.0
2015									
Passenger Cars	30.5	34.4	35.8	36.2	37.1	39.4	38.6	40.1	40.7
Light Trucks	24.4	26.2	27.2	27.5	28.3	30.3	29.4	30.5	30.7
Combined	28.0	31.0	32.2	32.6	33.4	35.6	34.7	36.0	36.5
2016									
Passenger Cars	30.5	35.4	37.2	37.8	39.0	40.9	40.9	42.9	42.3
Light Trucks	24.4	27.0	28.3	28.7	29.7	31.1	31.1	32.6	31.8
Combined	28.1	32.0	33.6	34.1	35.2	36.9	36.9	38.7	38.0

Figure III-1 presents this same information but in a different way, comparing estimated average fuel economy levels required of manufacturers under the eight regulatory alternatives in MYs 2012, 2014, and 2016. Required levels for MY 2013 and MY 2015 fall between those for MYs 2012 and 2014 and MYs 2014 and 2016, respectively. Required levels for these interim years are not presented in the Figure III-1 simply to limit the complexity of the figure.

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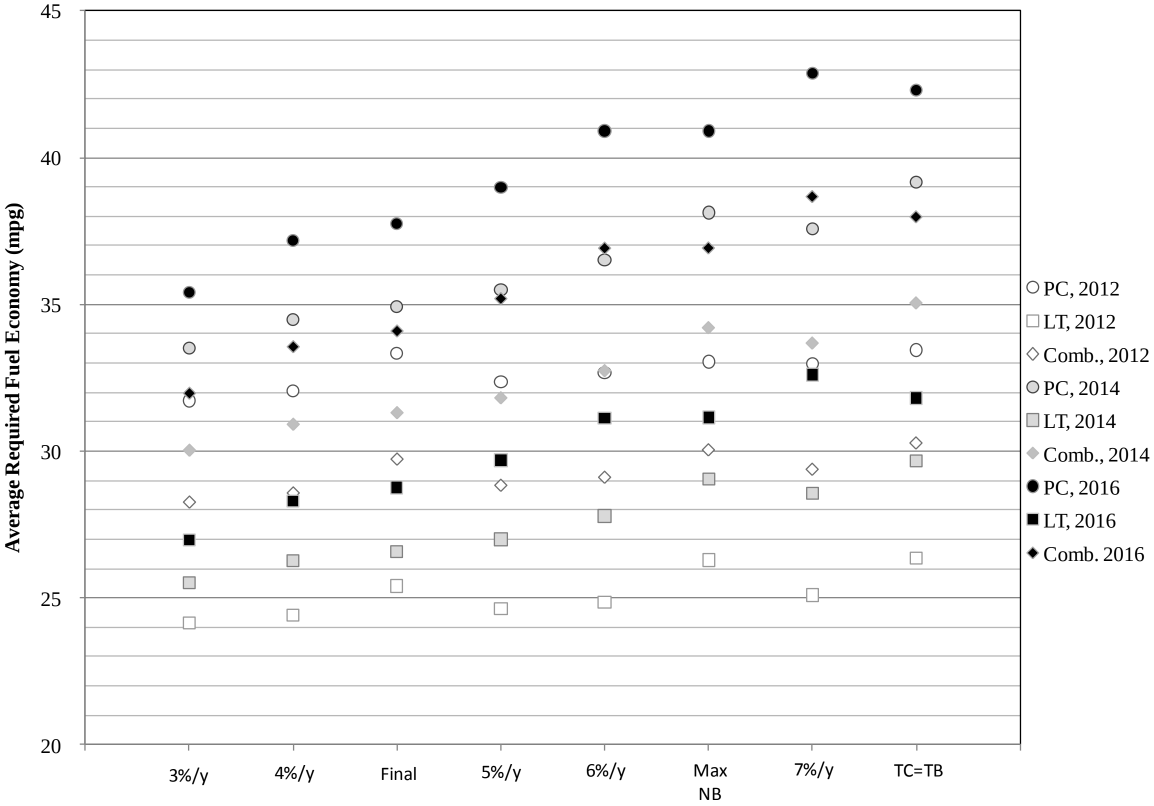
[44] Also, the "MNB" and the "TCTB" alternatives depend on the inputs to the agencies' analysis. The sensitivity analysis presented in the Chapter X documents the response of these alternatives to changes in key economic inputs. For example, the combined average required fuel economy under the "MNB" alternative is 36.9 mpg under the reference case economic inputs presented here, and ranges from 32.0 mpg to 37.2 mpg under the alternative economic inputs.

Figure III-1. Average Estimated Required Fuel Economy (MYs 2012, 2014, and 2016)



As this figure illustrates, the final standards involve a "faster start" toward increased stringency than do any of the alternatives that increase steadily (*i.e.*, the 3%/y, 4%/y, 5%/y, 6%/y, and 7%/y alternatives). However, by MY 2016, the stringency of the final standards reflects an average annual increase of 4.3%/y. The final standards, therefore, represent an alternative that could be referred to as "4.3% per year with a fast start" or a "front-loaded 4.3% average annual increase."

For each alternative, including today's final standards, NHTSA has estimated all corresponding effects for each model year, including fuel savings, CO_2 reductions, and other effects, as well as the estimated societal benefits of these effects. The accompanying FRIA presents a detailed analysis of these results. Table III-13 presents fuel savings, CO_2 reductions, and total industry cost outlays for model year 2012 – 2016 for the eight alternatives.

Table III-13. Fuel Savings, CO_2 Reductions, and Technology Costs for Regulatory Alternatives

Regulatory Alternative	Fuel Savings (b. gal)	CO_2 Reductions (mmt)	Cost ($b)
3% per Year	34	373	23
4% per Year	50	539	39
Final (4.3% per Year)	61	655	52
5% per Year	68	709	63
6% per Year	82	840	90
Maximum Net Benefit	90	925	103
7% per Year	93	945	111
Total Cost = Total Benefit	96	986	114

As noted earlier, NHTSA has used the Volpe model to analyze each of these alternatives based on analytical inputs determined jointly with EPA. For a given regulatory alternative, the Volpe model estimates how each manufacturer could apply technology in response to the MY 2012 standard (separately for cars and trucks), carries technologies applied in MY 2012 forward to MY 2013, and then estimates how each manufacturer could apply technology in response to the MY 2013 standard. When analyzing MY 2013, the model considers the potential to add "extra" technology in MY 2012 in order to carry that technology into MY 2013, thereby avoiding the use of more expensive technologies in MY 2013. The model continues in this fashion through MY 2016, and then performs calculations to estimate the costs, effects, and benefits of the applied technologies, and to estimate any civil penalties owed based on projected noncompliance. For each regulatory alternative, the model calculates incremental costs, effects, and benefits relative to the regulatory baseline (*i.e.*, the no-action alternative), under which the MY 2011 CAFE standards continue through MY 2016. The model calculates results for each model year, because EPCA requires that NHTSA set its standards for each model year at the "maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that model year" considering four statutory factors. Pursuant to EPCA's requirement that NHTSA not consider statutory credits in establishing CAFE standards, NHTSA did not consider FFV credits, credits carried forward and backward, and transferred credits in this calculation[45, 46] In addition, the analysis incorporates fines for some manufacturers that have traditionally paid fines rather than comply with the standards. Because it entails year-by-year examination of eight regulatory alternatives for, separately, passenger cars and light trucks, NHTSA's analysis involves a large amount of information. Detailed results of this analysis are presented separately in Chapter XI below.

In reviewing the results of the various alternatives, NHTSA confirmed that progressive increases in stringency require progressively greater deployment of fuel-saving technology and corresponding increases in technology outlays and related costs, fuel savings, and CO_2 emission

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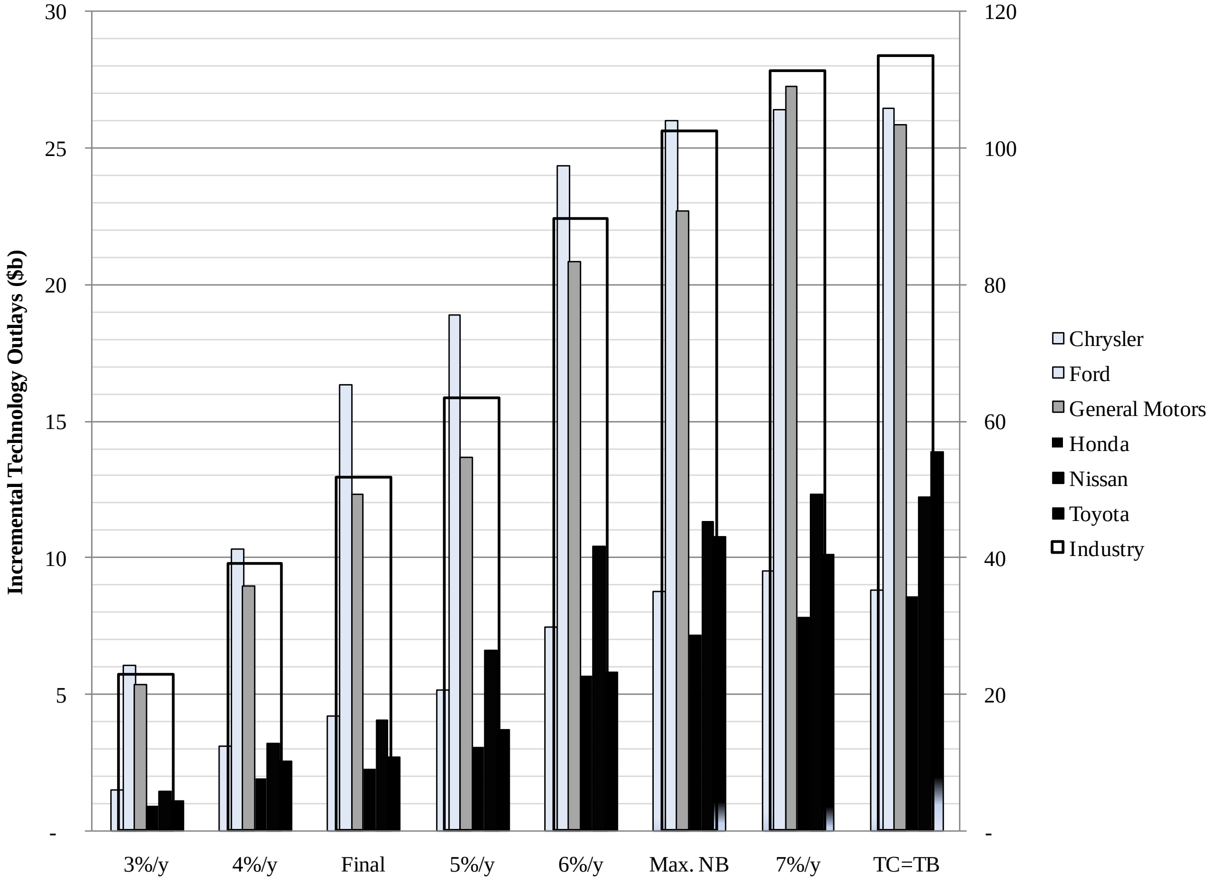
[45] NHTSA has conducted a separate analysis, discussed in Chapter XI, which accounts for EPCA's provisions regarding FFVs.

[46] For a number of reasons, the results of this modeling differ from EPA's for specific manufacturers, fleets, and model years. These reasons include representing every model year explicitly, accounting for estimates of when vehicle model redesigns will occur, and not considering those compliance flexibilities where EPCA forbids such consideration in setting CAFE standards. It should be noted, however, that these flexibilities in fact provide manufacturers significant latitude to manage their compliance obligations.

reductions. To begin, NHTSA estimated total incremental outlays for additional technology in each model year. The following figure shows cumulative results for MYs 2012-2016 for industry as a whole and Chrysler, Ford, General Motors, Honda, Nissan, and Toyota. This figure focuses on these manufacturers as they currently (in MY 2010) represent three large U.S.-headquartered and three large foreign-headquartered full-line manufacturers.

Figure III-2. Incremental Technology Outlays (MYs 2012-2016)



As part of the incremental technology outlays, NHTSA also analyzes which technologies manufacturers could apply to meet the standards. In NHTSA's analysis, manufacturers achieve compliance with the fuel economy levels through application of technology rather than through changes in the mix of vehicles produced for sale in the U.S. The accompanying FRIA presents detailed estimates of additional technology penetration into the NHTSA reference fleet associated with each regulatory alternative. The following four charts illustrate the results of this analysis, considering the application of four technologies by six manufacturers and by the industry as a whole. Technologies include gasoline direct injection (GDI), engine turbocharging and downsizing, diesel engines, and strong HEV systems (including CISG systems). GDI and turbocharging are presented because they are among the technologies that play an important role in achieving the fuel economy improvements shown in NHTSA's analysis, and diesels and strong HEVs are presented because they represent technologies involving significant cost and related lead time challenges for widespread use through MY 2016. These figures focus on

Chrysler, Ford, General Motors, Honda, Nissan, and Toyota, as above. For each alternative, the figures show additional application of technology by MY 2016.

Figure III-3. Additional Application of GDI (MY 2016)

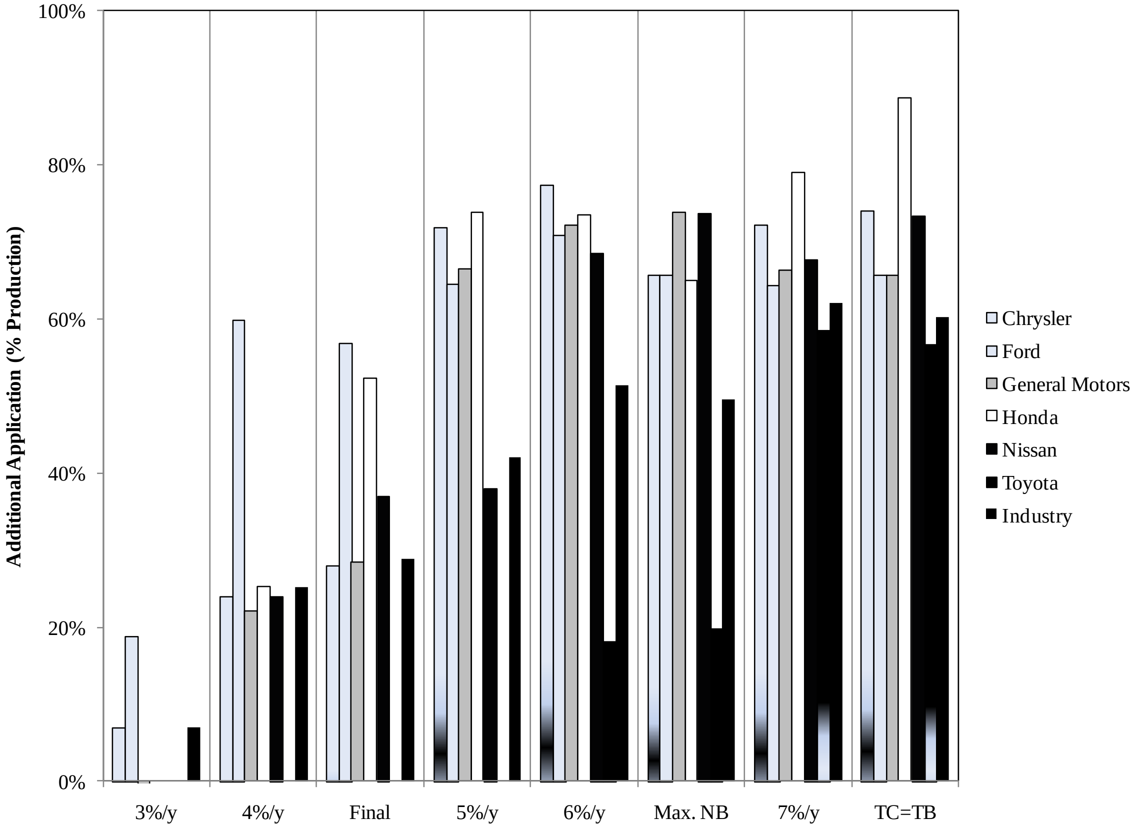


Figure III-4. Additional Application of Engine Turbocharging & Downsizing (MY 2016)

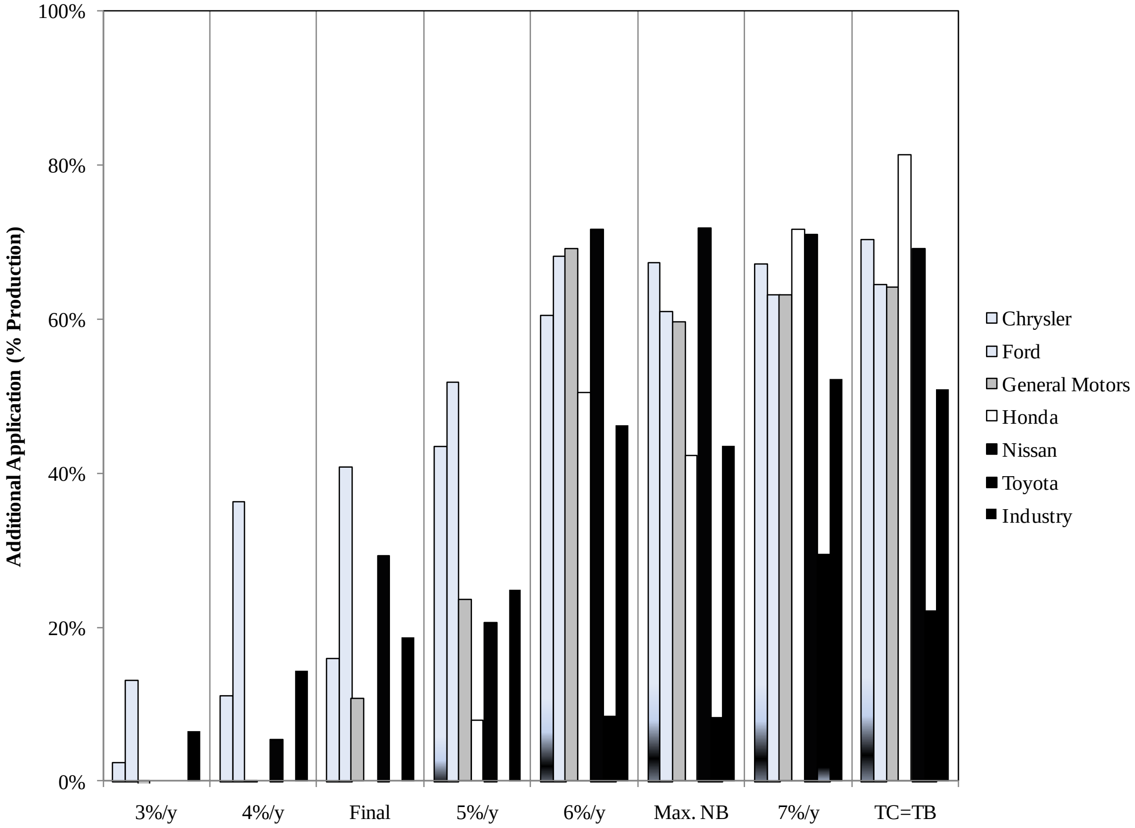


Figure III-5. Additional Application of Diesel Engines (MY 2016)

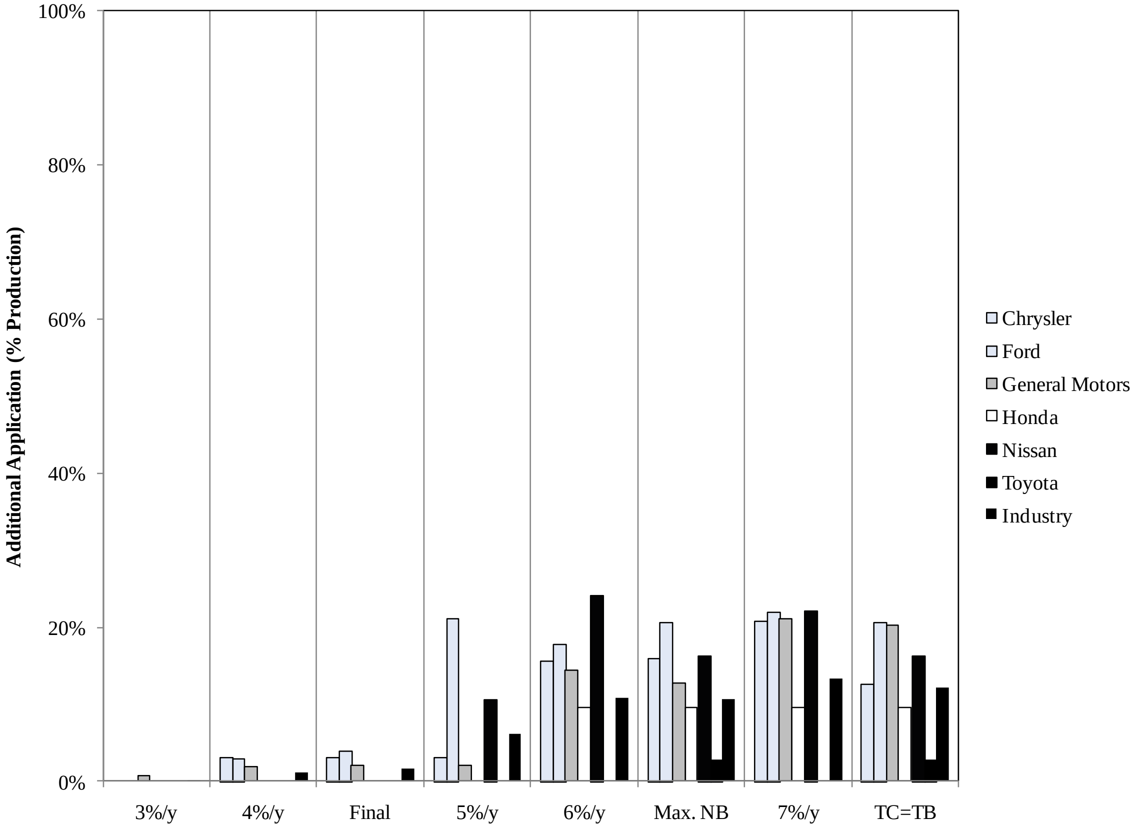
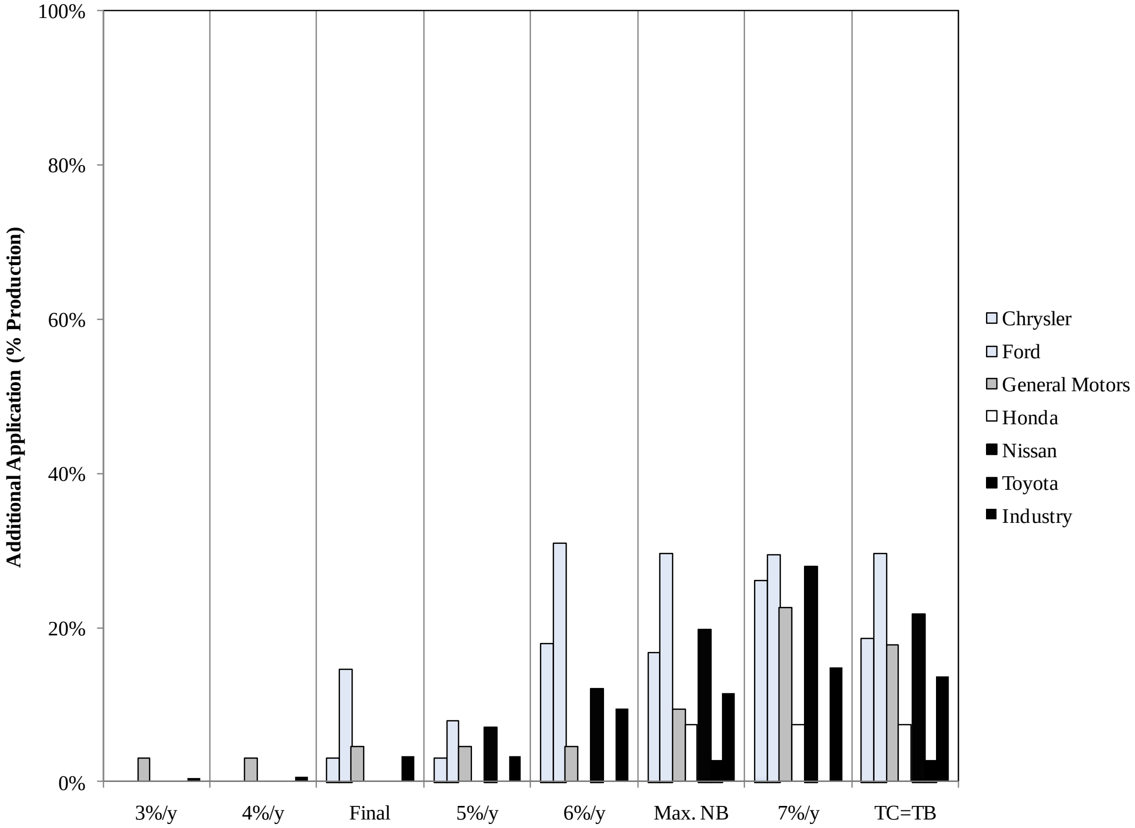
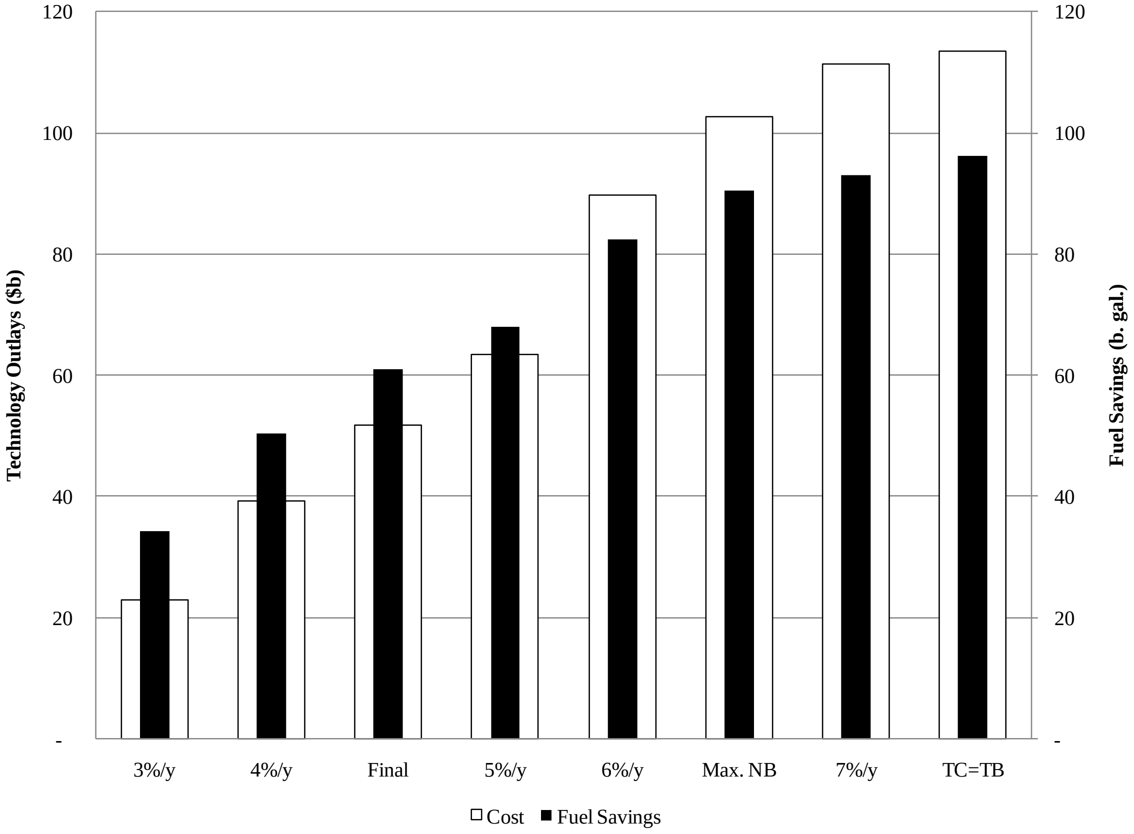


Figure III-6. Additional Application of CISG and Strong HEV Systems (MY 2016)



The modeling analysis demonstrates that applying these technologies, of course, results in fuel savings. Relevant to EPCA's requirement that NHTSA consider, among other factors, economic practicability and the need of the nation to conserve energy, the following figure compares the incremental technology outlays and related cost presented above for the industry to the corresponding cumulative fuel savings.

Figure III-7. Incremental Technology Outlays and Fuel Savings (MYs 2012-2016)



These incremental technology outlays (and corresponding fuel savings) also result in corresponding increases in incremental cost per vehicle, as shown below. The following five figures show industry-wide average incremental (*i.e.*, relative to the reference fleet) per-vehicle costs, for each model year, each fleet, and the combined fleet. Estimates specific to each manufacturer are shown in Chapter VII.

Figure III-8. Average Incremental Per-Vehicle Costs (MY 2012)

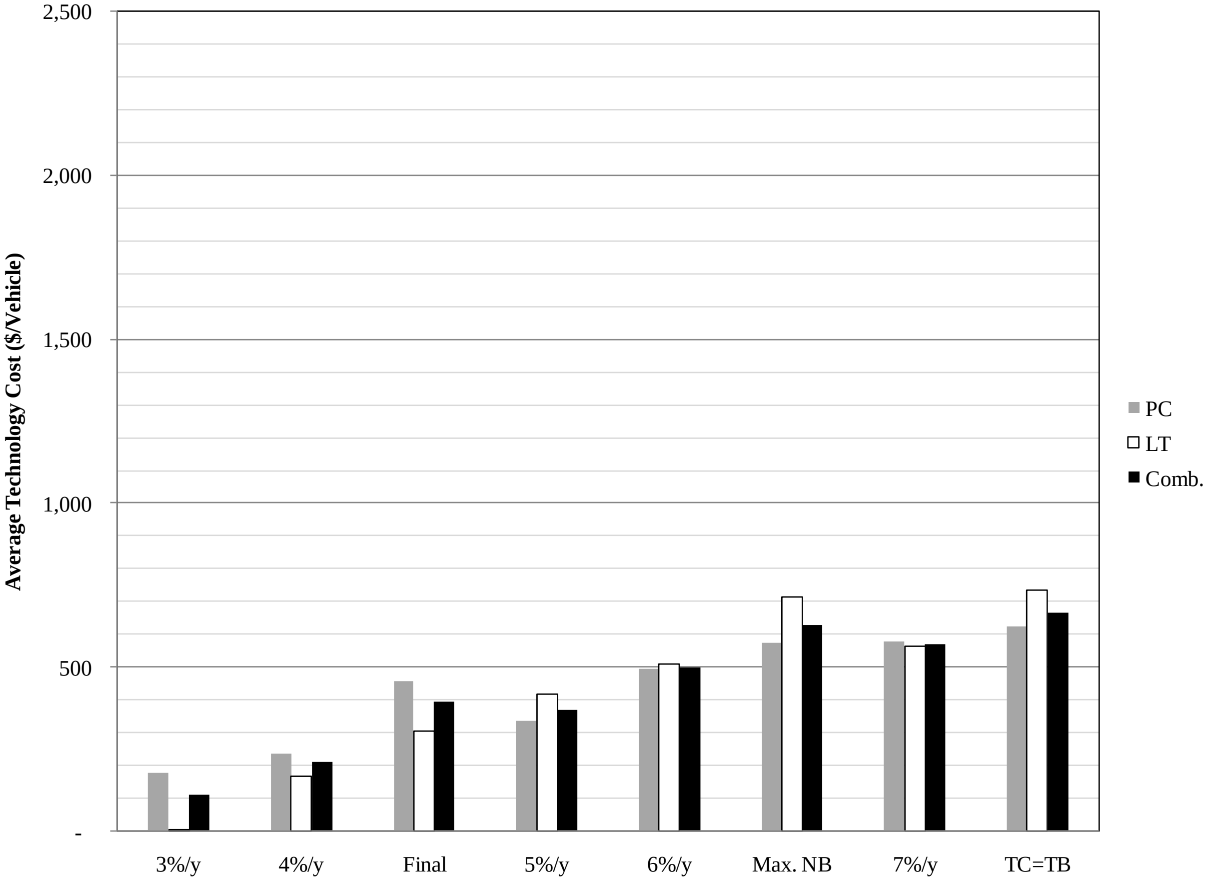


Figure III-9. Average Incremental Per-Vehicle Costs (MY 2013)

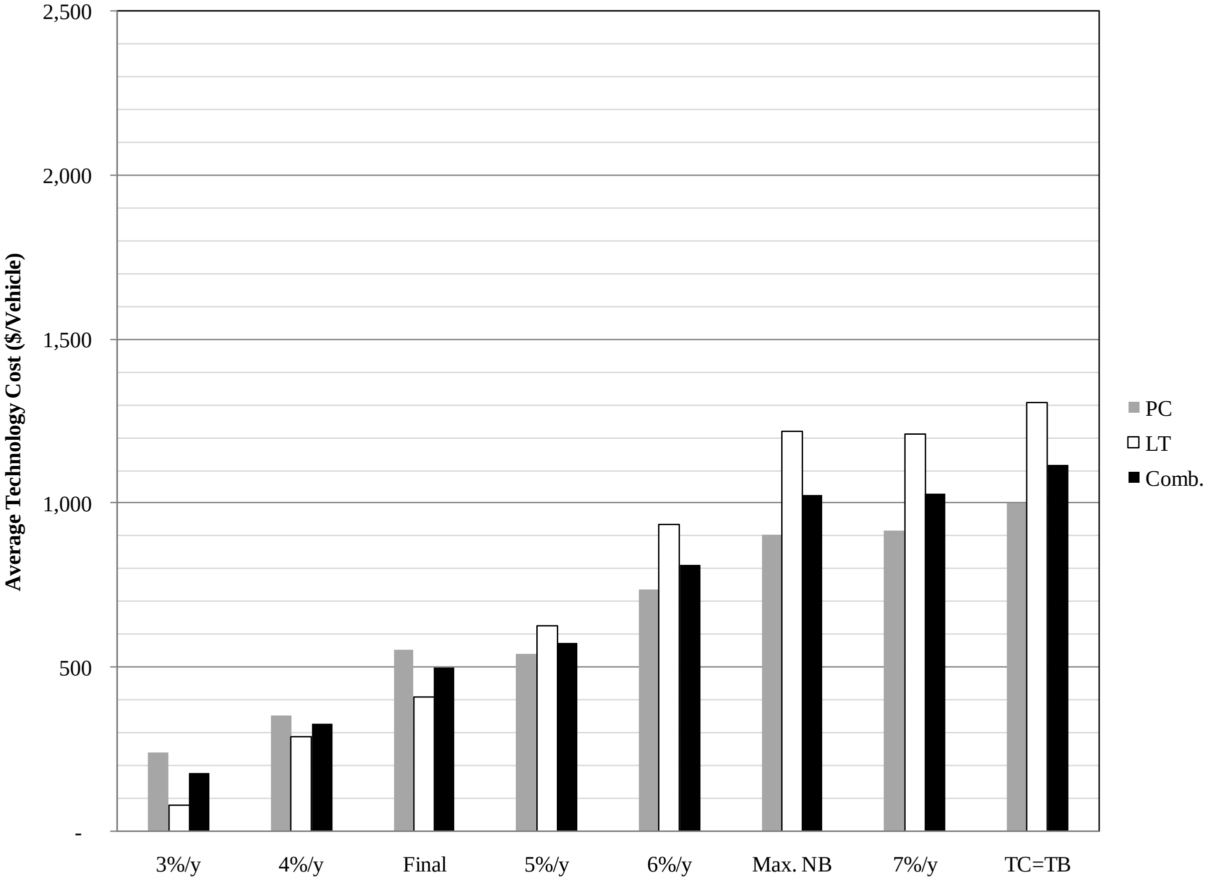


Figure III-10. Average Incremental Per-Vehicle Costs (MY 2014)

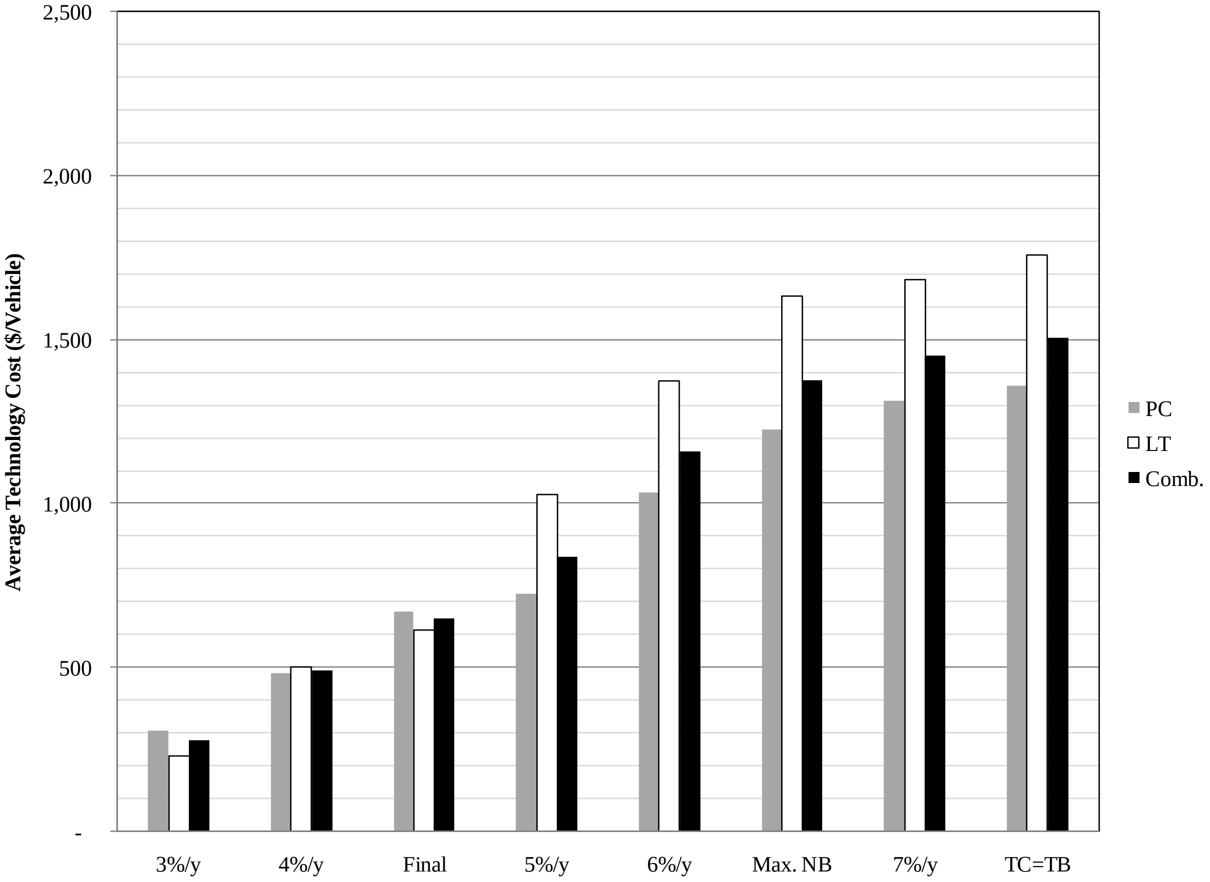


Figure III-11. Average Incremental Per-Vehicle Costs (MY 2015)

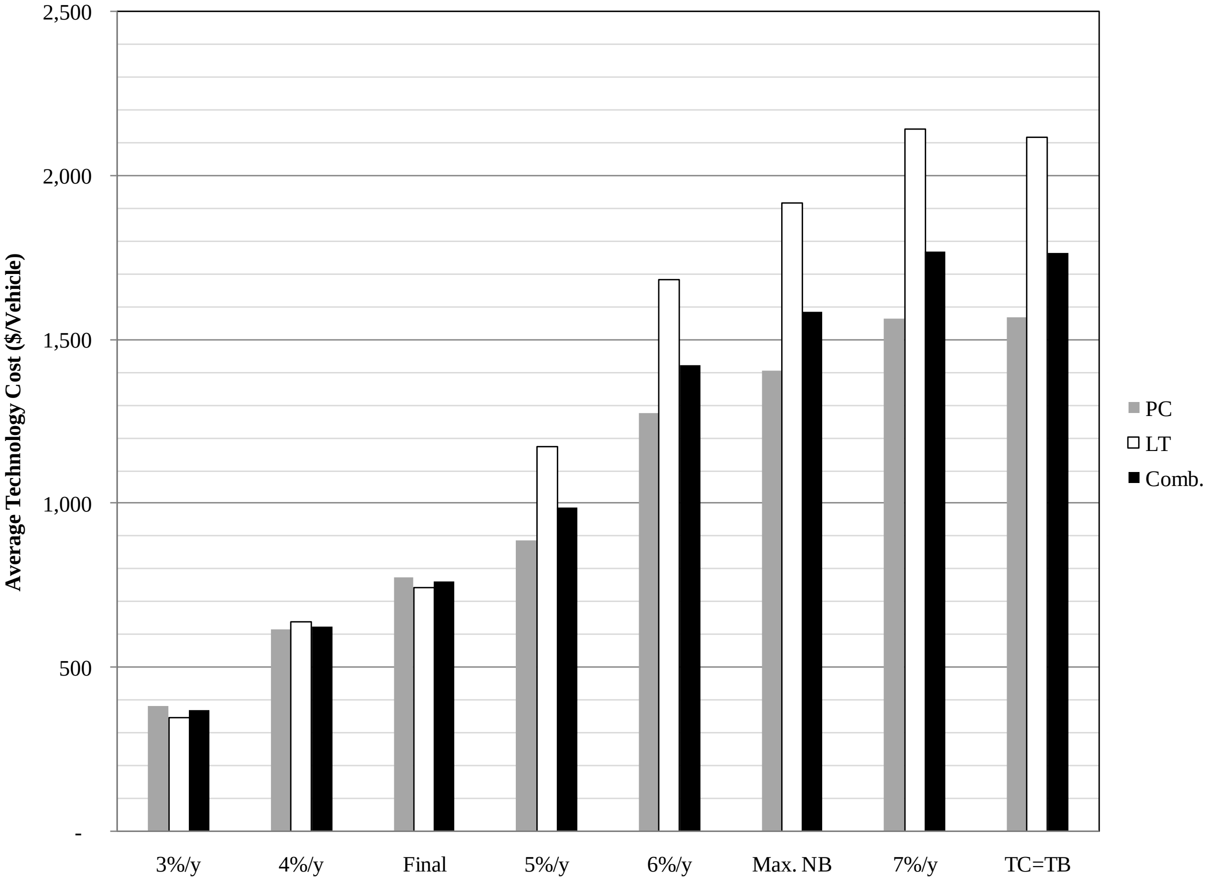
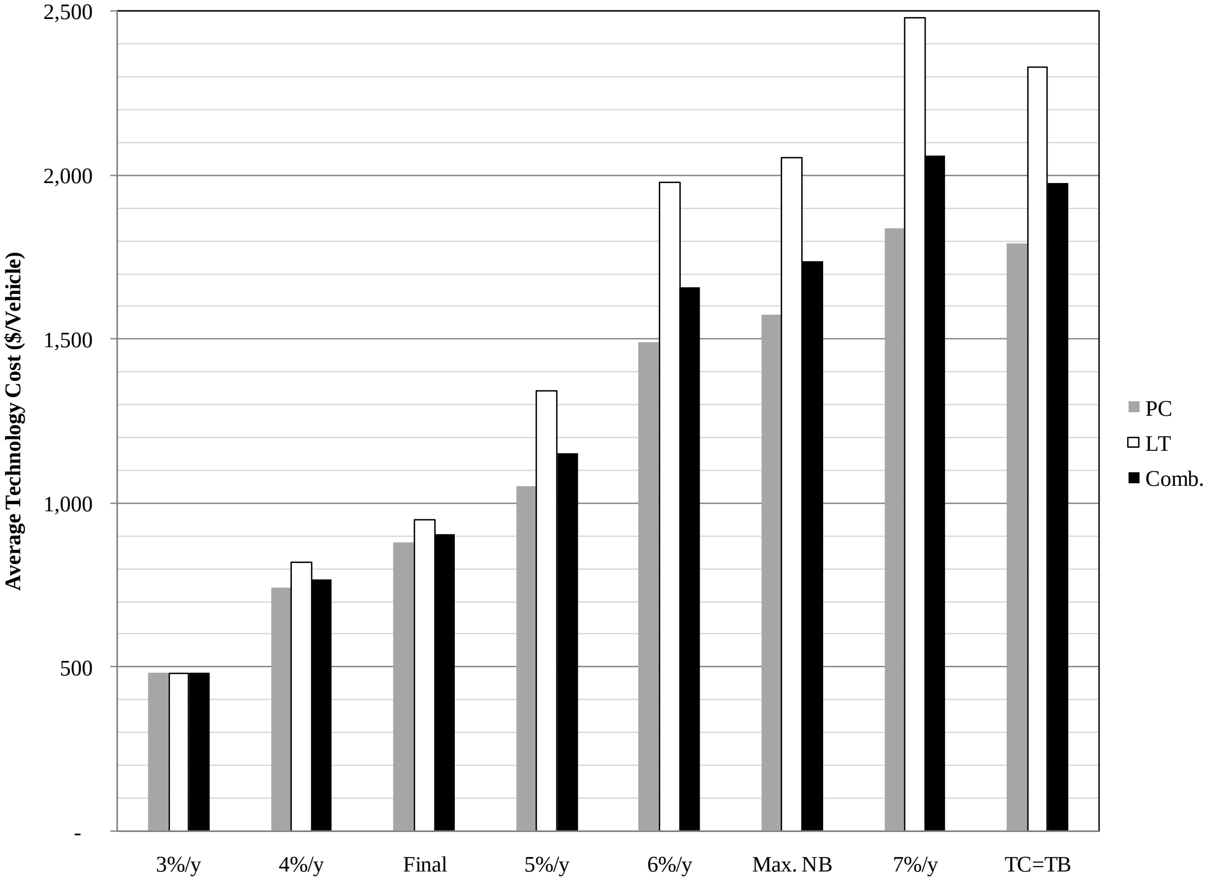


Figure III-12. Average Incremental Per-Vehicle Costs (MY 2016)



As discussed in the NPRM, the agency began the process of winnowing the alternatives by determining whether any of the lower stringency alternatives should be eliminated from consideration. To begin with, the agency needs to ensure that its standards are high enough to enable the combined fleet of passenger cars and light trucks to achieve at least 35 mpg not later than MY 2020, as required by EISA. Achieving that level makes it necessary for the chosen alternative to increase at over 3 percent annually. Additionally, given that CO_2 and fuel savings are very closely correlated, the 3%/y and 4%/y alternative would not produce the reductions in fuel savings and CO_2 emissions that the Nation needs at this time. Picking either of those alternatives would unnecessarily result in foregoing substantial benefits, in terms of fuel savings and reduced CO_2 emissions, which would be achievable at reasonable cost. And finally, neither the 3%/y nor the 4%/y alternatives would lead to the regulatory harmonization that forms a vital core principle of the National Program that EPA and NHTSA are jointly striving to implement. These alternatives would give inadequate weight to other standards of the Government, specifically EPA's and CARB's. Thus, the agency concluded that alternatives less stringent than the proposed standards would not yield the emissions reductions required to produce a harmonized national program and would not produce corresponding fuel savings, and therefore would not place adequate emphasis on the nation's need to conserve energy. NHTSA has therefore concluded that it must reject the 3%/y and 4%/y alternatives.

NHTSA then considered the "environmentally-preferable" alternative. Based on the information provided in the FEIS, the environmentally-preferable alternative would be that involving stringencies that increase at 7% annually.[47] NHTSA notes that NEPA does not require that agencies choose the environmentally-preferable alternative if doing so would be contrary to the choice that the agency would otherwise make under its governing statute. Given the levels of technology and cost required by the environmentally-preferable alternative and the lack of lead time to achieve such levels between now and MY 2016, as discussed further below, NHTSA concludes that the environmentally-preferable alternative would not be economically practicable or technologically feasible, and thus concludes that it would result in standards that would be beyond the level achievable for MYs 2012-2016.

For the other alternatives, NHTSA determined that it would be inappropriate to choose any of the other more stringent alternatives due to concerns over lead time and economic practicability. There are real-world technological and economic time constraints which must be considered due to the short lead time available for the early years of this program, in particular for MYs 2012 and 2013. The alternatives more stringent than the final standards begin to accrue costs considerably more rapidly than they accrue fuel savings and emissions reductions, and at levels that are increasingly economically burdensome, especially considering the need to make underlying investments (*e.g.*, for engineering and tooling) well in advance of actual production. As shown in Figures III-2 to III-6 above, while the final standards already require aggressive application of technologies, more stringent standards would require more widespread use (including more substantial implementation of advanced technologies such as stoichiometric gasoline direct injection engines, diesel engines, and strong hybrids), and would raise serious issues of adequacy of lead time, not only to meet the standards but to coordinate such significant changes with manufacturers' redesign cycles. The agency maintains, as it has historically, that there is an important distinction between considerations of technological feasibility and economic practicability, both of which enter into the agency's determination of the maximum feasible levels of stringency. 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 immediately (*i.e.*, within 18 months of the rule's promulgation) perform at its highest technologically feasible level, because manufacturers do not have unlimited access to the financial resources or the time required to hire enough engineers, build enough facilities, and install enough tooling. The lead time reasonably needed to make capital investments and to devote the resources and time to design and prepare for commercial production of a more fuel efficient vehicle is an important element that NHTSA takes into consideration in establishing the standards.

In addition, the figures presented above reveal that increasing stringency beyond the final standards would entail significant additional application of technology. Among the more stringent alternatives, the one closest in stringency to the standards being finalized today is the alternative under which combined CAFE stringency increases at 5% annually. As indicated above, this alternative would yield fuel savings and CO_2 reductions about 11% and 8% higher, respectively, than the final standards. However, compared to the final standards, this alternative

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[47] See, *e.g.*, FEIS, figure S-12, p. 18, which shows that 7%/y alternative yields greatest cumulative effect on global mean temperature.

would increase outlays for new technologies during MY 2012-2016 by about 22%, or $12b. Average MY 2016 cost increases would, in turn, rise from $903 under the final standards to $1,152 when stringency increases at 5% annually. This represents a 28% increase in per-vehicle cost for only a 3% increase in average performance (on a gallon-per-mile basis to which fuel savings are proportional). Additionally, the 5%/y alternative disproportionally burdens the light truck fleet requiring a nearly $400 (42 percent) cost increase in MY 2016 compared to the final standards. The following three tables summarize estimated manufacturer-level average incremental costs for the 5%/y alternative and the average of the passenger and light truck fleets:

Table III-14. Average Incremental Costs ($/vehicle) under the 5%/y Alternative CAFE Standards for Passenger Cars

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	3	4	24	184	585
Chrysler	734	1,303	1,462	1,653	1,727
Daimler	-	-	410	801	1,109
Ford	743	1,245	1,261	1,583	1,923
General Motors	448	823	1,187	1,425	1,594
Honda	50	109	271	375	606
Hyundai	747	877	1,057	1,052	1,124
Kia	49	128	197	261	369
Mazda	555	718	1,166	1,407	1,427
Mitsubishi	534	507	2,534	3,213	3,141
Nissan	294	491	965	1,064	1,125
Porsche	68	(52)	(51)	(50)	(49)
Subaru	292	324	1,372	1,723	1,679
Suzuki	-	959	1,267	1,316	1,540
Tata	111	93	183	306	710
Toyota	31	29	52	129	212
Volkswagen	145	428	477	492	783
Average	337	540	726	886	1,053

Table III-15. Average Incremental Costs ($/vehicle) under the 5%/y Alternative CAFE Standards for Light Trucks

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	169	160	201	453	868
Chrysler	360	559	1,120	1,216	1,432
Daimler	60	55	51	52	51
Ford	1,207	1,663	1,882	2,258	2,225
General Motors	292	628	866	968	1,136
Honda	258	234	611	750	1,047
Hyundai	711	685	1,923	1,909	1,862
Kia	47	293	556	782	1,157
Mazda	248	408	419	519	768
Mitsubishi	-	-	1,037	1,189	1,556
Nissan	613	723	2,142	2,148	2,315
Porsche	-	(0)	(1)	469	469
Subaru	1,225	1,220	1,365	1,374	1,330
Suzuki	-	1,998	1,895	1,837	2,096
Tata	-	-	-	-	503
Toyota	63	187	594	734	991
Volkswagen	-	-	514	458	441
Average	415	628	1,026	1,173	1,343

Table III-16. Average Incremental Costs ($/vehicle) under the 5%/y Alternative CAFE Standards

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	72	64	84	265	666
Chrysler	499	870	1,272	1,414	1,569
Daimler	20	20	281	554	773
Ford	914	1,407	1,498	1,838	2,034
General Motors	371	726	1,033	1,205	1,379
Honda	135	157	396	518	769
Hyundai	742	838	1,237	1,186	1,235
Kia	49	168	273	355	506
Mazda	500	667	1,053	1,272	1,330
Mitsubishi	371	352	1,973	2,386	2,506
Nissan	399	565	1,344	1,387	1,467
Porsche	52	(39)	(35)	130	124
Subaru	617	628	1,369	1,597	1,553
Suzuki	-	1,134	1,381	1,404	1,630
Tata	61	56	101	182	629
Toyota	43	82	239	333	466
Volkswagen	117	333	486	486	723
Average	367	573	836	987	1,152

These cost increases derive from increased application of advanced technologies as stringency increases past the levels in the final standards. For example, under the final standards, additional diesel application rates average 1.6% for the industry and range from 0% to 3% among Chrysler, Ford, GM, Honda, Nissan, and Toyota. Under standards increasing in combined stringency at 5% annually, these rates more than triple, averaging 6.2% for the industry and ranging from 0% to 21% for the same six manufacturers.

These technology and cost increases are significant, given the amount of lead-time between now and model years 2012-2016. In order to achieve the levels of technology penetration for the final standards, the industry needs to invest significant capital and product development resources right away, in particular for the 2012 and 2013 model year, which is only 2-3 years from now. For the 2014-2016 time frame, significant product development and capital investments will need to occur over the next 2-3 year in order to be ready for launching these new products for those model years. Thus a major part of the required capital and resource investment will need to occur now and over the next few years, under the final standards. NHTSA believes that the final rule requires significant investment and product development costs for the industry, focused on the next few years.

It is important to note, and as discussed in the final rule, as well as in the Joint Technical Support Document and later in this FRIA, the average model year 2016 per-vehicle cost increase of more than $900 includes an estimate of both the increase in capital investments by the auto companies and the suppliers as well as the increase in product development costs. These costs can be significant, especially as they must occur over the next 2-3 years. Both the domestic and transplant auto firms, as well as the domestic and world-wide automotive supplier base, are experiencing one of the most difficult markets in the U.S. and internationally that has been seen in the past 30 years. One major impact of the global downturn in the automotive industry and certainly in the U.S. is the significant reduction in product development engineers and staffs, as well as a tightening of the credit markets which allow auto firms and suppliers to make the near-term capital investments necessary to bring new technology into production.

The agency concludes that the levels of technology penetration required by the final standards are reasonable. Increasing the standards beyond those levels would lead to rapidly increasing dependence on advanced technologies with higher costs—technology that, though perhaps technologically feasible for individual vehicle models, would, at the scales involved, pose too great an economic burden given the state of the industry, particularly in the early years of the rulemaking time frame.[48]

Therefore, the agency concluded that these more stringent alternatives would give insufficient weight to economic practicability and related lead time concerns, given the current state of the industry and the rate of increase in stringency that would be required. Overall, the agency concluded that among the alternatives considered by the agency, the proposed alternative contained the maximum feasible CAFE standards for MYs 2012-2016 as they were the most appropriate balance of the various statutory factors.

Some commenters argued that the agency should select a more stringent alternative than that proposed in the NPRM. The Union of Concerned Scientists (UCS) commented that NHTSA should set standards to produce the “maximum environmental benefit” available at “reasonable” cost, and at least at the stringency maximizing net benefits. Students from the University of California at Santa Barbara commented that the agency should have based standards not just on technologies known to be available, but also on technologies that may be available in the future—and should do so in order to force manufacturers to “reach” to greater levels of performance. Also, the Center for Biological Diversity (CBD) commented that, having conducted an unbiased cost-benefit analysis showing benefits three times the magnitude of costs for the proposed alternative, the agency should select a more stringent alternative. CBD also argued that the agency should have evaluated the extent to which manufacturers could deploy technology more rapidly than suggested by a five-year redesign cycle.

Conversely, other commenters argued that NHTSA should select a less stringent alternative, either in all model years or at least in the earlier model years. Chrysler, VW, and the Alliance of Automobile Manufacturers commented that the stringency of NHTSA’s CAFE standards should be further reduced relative to that of EPA’s GHG emissions standards, so that manufacturers would not be required by CAFE to add any tailpipe technology beyond what they thought would be necessary to meet an mpg level of 35.5 minus the maximum possible A/C credits that could be obtained under the EPA program. Also, Chrysler, Daimler, Toyota, Volkswagen, and the

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[48] Although the final standards are projected to be slightly more costly than the 5% alternative in MY 2012, that alternative standard becomes progressively more costly than the final standards in the remaining model years. See Figures III.B.8 through III.B.10 above. Moreover, as discussed above, after MY 2012, the 5% alternative standard yields less incremental fuel economy benefits at increased cost (both industry-wide and per vehicle), directionally the less desirable result. These increased costs incurred to increase fuel economy through MY 2016 would impose significantly increased economic burden on the manufacturers in the next few calendar years to prepare for these future model years. In weighing the statutory factors, NHTSA accordingly rejected this alternative in favor of the final standard.

Alliance argued that the agency should reduce the rate of increase in stringency to produce steadier and more "linear" increases between MY 2011 and MY 2016. In addition, the Heritage Foundation commented that the proposed standards would, in effect, force accelerated progress toward EISA's "35 mpg by 2020" requirement, causing financially-stressed manufacturers to incur undue costs that would passed along to consumers.

However, most commenters supported the agency's selection of the proposed standards. The American Chemical Society, the New York Department of Environmental Conservation, the Washington State Department of Ecology, and several individuals all expressed general support for the levels of stringency proposed by NHTSA as part of the joint proposal. General Motors and Nissan both indicated that the proposed standards are consistent with the National Program announced by the President and supported in letters of commitment signed by these companies' executives. Finally, the California Air Resources Board (CARB) strongly supported the stringency of the proposed standards, as well as the agencies' underlying technical analysis and weighing of statutory factors. CARB further commented that the stringency increases in the earlier model years are essential to providing environmental benefits at least as great as would be achieved through state-level enforcement of CARB's GHG emissions standards.[49]

The agency has considered these comments and all others, and having considered those comments, believes the final standards best balance of all relevant factors that the agency considers when determining maximum feasible CAFE standards. As discussed below, having updated inputs to its analysis and correspondingly updated its definition and analysis of these regulatory alternatives, the agency continues to conclude that manufacturers can respond to the proposed standards with technologies that will be available at reasonable cost. The agency finds that alternatives less stringent that the one adopted today would leave too much technology "on the shelf" unnecessarily, thereby failing to deliver the fuel savings that the nation needs or to yield environmental benefits necessary to support a harmonized national program. In response to some manufacturers' suggestion that NHTSA's CAFE standards should be made even less stringent compared to EPA's GHG emissions standards, NHTSA notes that the difference, consistent with the underlying Notice of Intent, is based on the agencies' estimate of the *average* amount of air conditioning credit earned, not the maximum theoretically available, and that NHTSA's analysis indicates that most manufacturers can achieve the CAFE standards by MY 2016 using tailpipe technologies. This is fully consistent with the agency's historical position. As NHTSA explained in the NPRM, the Conference Report for EPCA, as enacted in 1975, makes clear, and applicable law affirms, "a determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy." CEI-I, 793 F.2d 1322, 1352 (D.C. Cir. 1986). Instead, NHTSA is compelled "to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers." *Id*. Thus, the law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole.

While some manufacturers may find greater A/C improvements to be a more cost-effective way of meeting the GHG standards, that does not mean those manufacturers will be *unable* to meet

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[49] Generally speaking, the cumulative benefits (in terms of fuel savings and GHG reductions) of front-loaded standards will be greater than standards that increase linearly.

the CAFE standards with tailpipe technologies. NHTSA's analysis has demonstrated a feasible path to compliance with the CAFE standards for most manufacturers using those technologies. "Economic practicability" means just that, practicability, and need not always mean what is "cheapest" or "most cost-effective" for a specific manufacturer. Moreover, many of the A/C improvements on which manufacturers intend to rely for meeting the GHG standards will reduce GHG emissions, specifically HFC emissions, but they will not lead to greater fuel savings.[50] The core purpose of the CAFE standards under EPCA is to reduce fuel consumption. NHTSA believes that less stringent standards would allow tailpipe fuel economy technologies to be left on the table that can be feasibly and economically applied, and failing to apply them would lead to a loss in fuel savings. This would not place appropriate emphasis on the core CAFE purpose of conserving fuel. For this reason, we decline to reduce the stringency of our standards as requested by some manufacturers. Similarly, we decline to pursue with EPA in this rulemaking the suggestion by one commenter that that agency's calculation authority under EPCA be used to provide A/C credits.

With respect to some manufacturers' concerns regarding the increase in stringency through MY 2013, the agency notes that stringency increases in these model years are especially important in terms of the accumulation of fuel savings and emission reductions over time. In addition, a weakening would risk failing to produce emission reductions at least as great as might be achieved through CARB's GHG standards. Therefore, the agency believes that alternatives less stringent than the one adopted today would not give sufficient emphasis to the nation's need to conserve energy. The requirement to set standards that increase ratably between MYs 2011 and 2020 must also be considered in the context of what levels of standards would be maximum feasible. The agency believes that the rate of increase of the final standards is reasonable.

On the other hand, the agency disagrees with comments by UCS, CBD, and others indicating that more stringent standards would be appropriate. As discussed above, alternatives more stringent than the one adopted today would entail a rapidly increasing dependence on the most expensive technologies and those which are technically more demanding to implement, with commensurately rapid increases in costs. In the agency's considered judgment, these alternatives are not economically practicable, nor do they provide correspondingly sufficient lead time. The agency also disagrees with CBD's assertion that NHTSA and EPA have been overly conservative in assuming an average redesign cycle of 5 years. There are some manufacturers who apply longer cycles (such as smaller manufacturers described above), there are others who have shorter cycles for some of their products, and there are some products (*e.g.*, cargo vans) that tend to be redesigned on longer cycles. NHTSA believes that there are no full line manufacturers who can maintain significant redesigns of vehicles (with relative large sales) in 1 or 2 years, and CBD has provided no evidence indicating this would be practicable. A complete redesign of the entire U.S. light-duty fleet by model year 2012 is clearly infeasible, and NHTSA and EPA believe that several model years additional lead time is necessary in order for the manufacturers to meet the most stringent standards. The graduated increase in the stringency of

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[50] This is not to say that NHTSA means, in any way, to deter manufacturers from employing A/C technologies to meet EPA's standards, but simply to say that NHTSA's independent obligation to set maximum feasible CAFE standards to be met through application of tailpipe technologies alone must be fulfilled, while recognizing the flexibilities offered in another regulatory program.

the standards from MYs 2012 through 2016 accounts for the economic necessity of timing the application of many major technologies to coincide with scheduled model redesigns.

In contrast, through analysis of the illustrative results shown above, as well as the more complete and detailed results presented in this analysis, NHTSA has concluded that the final standards are technologically feasible and economically practicable. The final standards will require manufacturers to apply considerable additional technology, starting with very significant investment in technology design, development and capital investment called for in the next few years. Although NHTSA cannot predict how manufacturers *will* respond to the final standards, the agency's analysis indicates that the standards could lead to significantly greater use of advanced engine and transmission technologies. As shown above, the agency's analysis shows considerable increases in the application of SGDI systems and engine turbocharging and downsizing. Though not presented above, the agency's analysis also shows similarly large increases in the use of dual-clutch automated manual transmissions (AMTs). However, the agency's analysis does not suggest that the additional application of these technologies in response to the final standards would extend beyond levels achievable by the industry. These technologies are likely to be applied to at least some extent even in the absence of new CAFE standards. In addition, the agency's analysis indicates that most manufacturers would rely only to a limited extent on the most costly technologies, such as diesel engines and advanced technologies, such as strong HEVs.

As shown below, NHTSA estimates that the final standards could lead to average incremental costs ranging from $303 per vehicle (for light trucks in MY 2012) to $947 per vehicle (for light trucks in MY 2016), increasing steadily from $396 per vehicle for all light vehicles in MY 2012 to $903 for all light vehicle in MY 2016. NHTSA estimates that these costs would vary considerably among manufacturers, but would rarely exceed $1,800 per vehicle. The following three tables summarize estimated manufacturer-level average incremental costs for the final standards and the average of the passenger and light truck fleets:

Table III-17. Average Incremental Costs ($/vehicle) under Final Passenger Car CAFE Standards

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	3	4	24	184	585
Chrysler	734	1,043	1,129	1,270	1,358
Daimler	-	-	410	801	1,109
Ford	1,619	1,537	1,533	1,713	1,884
General Motors	448	896	1,127	1,302	1,323
Honda	33	98	205	273	456
Hyundai	559	591	768	744	838
Kia	110	144	177	235	277
Mazda	555	656	799	854	923
Mitsubishi	534	460	1,588	1,875	1,831
Nissan	119	323	707	723	832
Porsche	68	(52)	(51)	(50)	(49)
Subaru	292	324	988	1,385	1,361
Suzuki	-	625	779	794	1,005
Tata	111	93	183	306	710
Toyota	31	29	41	121	126
Volkswagen	145	428	477	492	783
Average	455	552	670	774	880

Table III-18. Average Incremental Costs ($/vehicle) under Final Light Truck CAFE Standards

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	252	239	277	281	701
Chrysler	360	527	876	931	1,170
Daimler	60	51	51	52	51
Ford	465	633	673	1,074	1,174
General Motors	292	513	749	807	986
Honda	233	217	370	457	806
Hyundai	693	630	1,148	1,136	1,113
Kia	400	467	582	780	1,137
Mazda	144	241	250	354	480
Mitsubishi	-	-	553	686	1,371
Nissan	398	489	970	1,026	1,362
Porsche	-	(1)	(1)	469	469
Subaru	1,036	995	1,016	1,060	1,049
Suzuki	-	1,797	1,744	1,689	1,732
Tata	-	-	-	-	503
Toyota	130	150	384	499	713
Volkswagen	-	-	514	458	441
Average	303	411	615	741	947

Table III-19. Average Incremental Costs ($/vehicle) under Final CAFE Standards

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	106	94	110	213	618
Chrysler	499	743	989	1,084	1,257
Daimler	20	18	281	554	773
Ford	1,195	1,187	1,205	1,472	1,622
General Motors	371	705	946	1,064	1,165
Honda	116	144	266	343	585
Hyundai	577	599	847	805	879
Kia	176	221	263	334	426
Mazda	482	587	716	778	858
Mitsubishi	371	319	1,200	1,389	1,647
Nissan	211	376	792	813	984
Porsche	52	(39)	(35)	130	124
Subaru	551	552	998	1,267	1,248
Suzuki	-	823	954	946	1,123
Tata	61	56	101	182	629
Toyota	67	70	159	248	317
Volkswagen	117	333	486	486	723
Average	396	498	650	762	903

In summary, NHTSA has considered eight regulatory alternatives, including the final standards, examining technologies that could be applied in response to each alternative, as well as corresponding costs, effects, and benefits. The agency has concluded that alternatives less stringent than the final standards would not produce the fuel savings and CO_2 reductions necessary at this time to achieve either the overarching purpose of EPCA, *i.e.*, energy conservation, or an important part of the regulatory harmonization underpinning the National Program, and would forego these benefits even though there is adequate lead time to implement reasonable and feasible technology for the vehicles. Conversely, the agency has concluded that more stringent standards would involve levels of additional technology and cost that would be economically impracticable and, correspondingly, would provide inadequate lead time, considering the economic state of the automotive industry, would not be economically practicable. Therefore, having considered these eight regulatory alternatives, and the statutorily-relevant factors of 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, along with other relevant factors such as the safety impacts of the final standards, NHTSA concludes that the final standards represent a reasonable balancing of all of these concerns, and are the maximum feasible average fuel economy levels that the manufacturers can achieve in MYs 2012-2016.

IV. IMPACT OF OTHER MOTOR VEHICLE STANDARDS OF THE GOVERNMENT ON FUEL ECONOMY

Introduction

The Energy Policy and Conservation Act (EPCA or the Act) requires that fuel economy standards 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) 2012-2016 passenger car and light truck fuel economy. These effects have not been included in the Volpe model at this time, which is based on MY 2008 vehicles.

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. NHTSA requested, and various manufacturers provided, confidential estimates in 2009 of increases in weight resulting from safety improvements. Those increases are shown in subsequent tables.

We have broken down our analysis of the impact of safety standards that might affect the MY 2012-16 fleets into three parts: 1) those NHTSA final rules with known effective dates, 2) proposed rules or soon to be proposed rules by NHTSA, without final effective dates, and 3) currently voluntary safety improvements planned by the manufacturers.

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 2009 and MY 2016. We will examine the potential impact on passenger car and light truck weights for MY 2012-2016, using MY 2008 as a baseline.

1. FMVSS 126, Electronic Stability Control
2. FMVSS 206, Door Latches for Sliding Doors
3. FMVSS 208, 35 mph Belted Testing of 5th Female
4. FMVSS 214, Side Impact Oblique Pole Test
5. FMVSS 216, Roof Crush

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. All light vehicles must meet the requirements by MY 2012.

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[51] 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).

The incremental weight for the period of MY 2012-2016 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 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 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.). The incremental weight for

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

each year of MY 2012-2016 compared to the MY 2008 baseline is 0 lbs. for passenger cars and 0.11 lbs. for light trucks for the sliding door latch requirements.

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. Only one of the manufacturers' confidential submissions showed a small weight increase for FMVSS 208.

FMVSS 214, Oblique Pole Side Impact Test

The phase-in requirements for the side impact test are as shown below in Table IV-3:

Table IV-3
FMVSS 214 Final Rule Phase-In Schedule

Phase-in Date	Percent of each manufacturer's light vehicles that must comply during the production period
September 1, 2010 to August 31, 2011	20 percent (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2011 to August 31, 2012	40 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2012 to August 31, 2013	60 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2013 to August 31, 2014	80 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
On or after September 1, 2014	All vehicles including limited line vehicles, except vehicles with GVWR > 8,500 lbs., alterers, and multi-stage manufacturers
On or after September 1, 2015	All vehicles, including vehicles with GVWR > 8,500 lbs., excluding alterers and multi-stage manufacturers
On or after September 1, 2016	All vehicles, including vehicles with GVWR > 8,500 lbs., alterers and multi-stage manufacturers

A teardown study of five thorax air bags resulted in an average weight increase per vehicle of 4.77 pounds (2.17 kg).[52] A second study[53] 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 is assumed to be average for all vehicles in the future.

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[52] 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. (Docket NHTSA-2009-0059-0158)

[53] Ludtke & Associates, "Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201", page 4-3 to 4-5, DOT HS 809 842. (Docket NHTSA-2009-0059-0157)

Based on MY 2008 Buying a Safer Car data supplied by the manufacturers, the projected number of side air bags with head protection was 98.5 percent of passenger cars and 85.4 percent of light trucks and torso protection was projected at 92.1 percent of passenger cars and 50.1 percent of light trucks. Combined this information indicates that on average the MY 2012 phase-in requirement would be already be met voluntarily in MY 2008 and that the weight increases for MY 2013 would be 0 for passenger cars and 0.47 lbs. for light trucks, MY 2014 would be 0 for passenger cars and 1.43 lbs. for light trucks, MY 2015 and MY 2016 would be 0.48 lbs. for passenger cars and 3.37 lbs. 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.[54] 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. 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 later tables and will be multiplied by the percentages in Table IV-4 to get incremental weights by model year (2.91 lbs. in MY 2013, 5.83 lbs. in MY 2014, 8.74 lbs. in MY 2015, and 11.65 lbs. in MY 2016). The final rule effective dates are shown in Table IV-4.

Table IV-4
FMVSS 216 Final Rule Phase-In Schedule

Phase-in Date	Percent of each manufacturer's light vehicles that must comply during the production period
September 1, 2012 to August 31, 2013	25 percent
September 1, 2013 to August 31, 2014	50 percent
September 1, 2014 to August 31, 2015	75 percent
On or after September 1, 2015	All vehicles

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[55] 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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[54] Final Regulatory Impact Analysis, FMVSS 216 Upgrade Roof Crush Resistance, (Docket No. 2009-0093-4) (May 12, 2009) (74 FR 22347)

[55] 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.

NPRM on Ejection Mitigation

The agency has published an NPRM on ejection mitigation[56]. The likely result of the planned proposal is for window curtain side air bags (likely to be used to meet the FMVSS 214 oblique pole test in all vehicles) to be larger and for a rollover sensor to be installed. Preliminary agency estimates are that there will be a weight increase of 1.7 pounds for passenger cars and 4.32 pounds for light trucks (which takes into account that about 50 percent of light trucks have a third row of seats that need to be covered). The proposed effective dates and the phase-in schedule are 20% in MY 2014, 40% in MY 2015, and 75% in MY 2016, resulting in weight increases of 0.34 lbs. in MY 2014, 0.68 lb. in MY 2015, and 1.28 lbs. in MY 2016 for passenger cars and weight increases of 0.86 lbs. in MY 2014, 1.73 lb. in MY 2015, and 3.24 lbs. in MY 2016 for light trucks.

In addition, advanced glazing is one alternative that manufacturers might pursue for specific window applications for ejection mitigation (possibly for fixed windows for third row applications) or more broadly. Advanced glazing is likely to have weight implications. The agency has not made an estimate of the likelihood that advanced glazing might be used or its weight implications.

NHTSA initiative on Pedestrian Protection

The agency has started to analyze the costs and benefits of a Global Technical Regulation on pedestrian protection. The effective dates have not been decided, however, it is possible that a rule on pedestrian protection could start to be phased in by the end of the period of this proposed rulemaking. Potential weight increases for pedestrian head and leg protection have not yet been identified.

Summary – Overview of Anticipated Weight Increases

Table IV-5 summarizes estimates made by NHTSA regarding the weight added by the above discussed standards or likely rulemakings. NHTSA estimates that weight additions required by final rules and likely NHTSA regulations effective by MY 2016, compared to the MY 2008 fleet, will increase passenger car weight by at least 17.59 lbs. and light truck weight by at least 20.23 lbs.

Table IV-6 shows the distribution by model year.

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[56] 74 FR 63180, December 2, 2009, (Docket No. NHTSA-2009-0183.0002.1)

Table IV-5

Weight Additions Due to Final Rules or Likely NHTSA Regulations
Comparing MY 2016 to the MY 2008 Baseline fleet

Standard No.	Added Weight in pounds **Passenger Car**	Added Weight in kilograms **Passenger Car**	Added Weight in pounds **Light Trucks**	Added Weight in kilograms **Light trucks**
126	**3.08**	**1.40**	**0.75**	**0.34**
206	**0**	**0**	**0.11**	**0.05**
214	**0.48**	**0.22**	**3.37**	**1.53**
216	**11.65**	**5.28**	**11.65**	**5.28**
301	**1.11**	**0.50**	**1.11**	**0.50**
Ejection Mitigation	**1.28**	0.58	3.24	1.47
Pedestrian Protection	**?**	?	?	?
Total	**17.59**	**7.98**	**20.23**	**9.18**

Table IV-6

Weight Additions by Model Year Due to Final Rules or Likely NHTSA Regulations Compared to a MY 2008 Baseline

	Added Weight in pounds **Passenger Car**	Added Weight in kilograms **Passenger Car**	Added Weight in pounds **Light Trucks**	Added Weight in kilograms **Light trucks**
MY 2012	**4.19**	**1.90**	**1.97**	**0.89**
MY 2013	**7.10**	**3.22**	**5.35**	**2.43**
MY 2014	**10.36**	**4.70**	**10.09**	**4.58**
MY 2015	**14.09**	**6.39**	**15.81**	**7.17**
MY 2016	**17.59**	**7.98**	**20.23**	**9.18**

Based on NHTSA's weight-versus-fuel-economy algorithms, a 3-4 pound increase in weight equates to a loss of 0.01 mpg in fuel economy. Assuming an average of 3.5 pounds increase in weight equates to a loss of 0.01 mpg in fuel economy, Table IV-7 shows the results for final rules or likely future safety standards.

Table IV-7

Estimated mpg Impact of Weight Additions by Model Year Due to Final Rules or Likely NHTSA Regulations Compared to a MY 2008 Baseline

	MPG Impact of Added Weight **Passenger Car**	MPG Impact of Added Weight **Light Trucks**
MY 2012	**0.012**	**0.006**
MY 2013	**0.020**	**0.015**
MY 2014	**0.030**	**0.029**
MY 2015	**0.040**	**0.045**
MY 2016	**0.050**	**0.058**

CONFIDENTIAL SUBMISSIONS

At the time the agency requested information about fuel economy plans and capabilities for the future, the agency also requested information on weight increases that could occur due to safety improvements. Several manufacturers provided confidential information in 2009 about plans they had to meet final rules, proposed safety standards, or to voluntarily increase safety for the years 2012-2016. The plans are compared to a MY 2008 baseline fleet. The areas covered above and the regulatory areas described as final and proposed, and voluntary safety initiatives from manufacturers that have confidential increases for the period after MY 2008 are shown in the following tables.

Table IV-8

GM Estimates of Impact on mpg

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Domestic PC					
Import PC					
Trucks					

Table IV-9a
Confidential Submissions of Weight Impacts compared to a Baseline of MY 2008

		Ford											
		Car MY						**Light Truck MY**					
Final and Proposed		**2012**	**2013**	**2014**	**2015**	**2016**		**2012**	**2013**	**2014**	**2015**	**2016**	
126	**ESC**												
208	**5th Female Belted**												
214	**Side Impact**												
216	**Roof Crush**												
226	**Ejection Mitigation**												
301	**Fuel System**												
Total Final and Proposed Rule Increments													
Voluntary and Other Rules													
202a	**Head Restraints**												
TBD	**Ped. Protection**												
TBD	**Compatibility**												
	EDR part 563												
N/A	**Other Voluntary**												
Total Voluntary and Other Rule Increments													
Total by Year													

Table IV-9b
Confidential Submissions of Weight Impacts compared to a Baseline of MY 2008

		General Motors											
		Car MY						**Light Truck MY**					
Final and Proposed		**2012**	**2013**	**2014**	**2015**	**2016**		**2012**	**2013**	**2014**	**2015**	**2016**	
126	**ESC**												
208	**5th Female Belted**												
214	**Side Impact**												
216	**Roof Crush**												
226	**Ejection Mitigation**												
301	**Fuel System**												
Total Final and Proposed Rule Increments													
Voluntary and Other Rules													
202a	**Head Restraints**												
TBD	**Ped. Protection**												
TBD	**Compatibility**												
	EDR part 563												
N/A	**Other Voluntary**												
Total Voluntary and Other Rule Increments													
Total by Year													

Table IV-9c
Confidential Submissions of Weight Impacts compared to a
Baseline of MY 2008

		Chrysler											
		Car MY						**Light Truck MY**					
Final and Proposed		**2012**	**2013**	**2014**	**2015**	**2016**		**2012**	**2013**	**2014**	**2015**	**2016**	
126	**ESC**												
208	**5th Female Belted**												
214	**Side Impact**												
216	**Roof Crush**												
226	**Ejection Mitigation**												
301	**Fuel System**												
Total Final and Proposed Rule Increments													
Voluntary and Other Rules													
202a	**Head Restraints**												
TBD	**Ped. Protection**												
TBD	**Compatibility**												
	EDR part 563												
N/A	**Other Voluntary**												
Total Voluntary and Other Rule Increments													
Total by Year													

Fuel Economy Impacts of Government Emission Standards

The only program EPA has that has been finalized but is not yet in-force for light-duty vehicles and MDPVs is the new cold hydrocarbon standard finalized under the Mobile Source Air Toxics (MSAT) rule. For <6,000 lb. vehicles the standard begins in MY 2010. But for 6,000-8,500 lb GVWR vehicles and for MDPVs, the standard has a phase-in that starts with MY 2012 and ends in MY 2015. EPA estimated the new standard could have a small, but unquantified, impact on improving fuel consumption during cold start conditions. However, in the temperature range during which the CAFE test procedures are performed (68 - 86 deg. F); EPA does not believe the new cold hydrocarbon standard will have any impact on fuel economy. Therefore, the impact on fuel economy is expected to be zero for both passenger cars for light trucks.

V. FUEL ECONOMY ENHANCING TECHNOLOGIES AND THE VOLPE MODEL

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

In the NPRM, NHTSA and EPA proposed to set attribute-based CAFE and CO_2 standards that are defined by a mathematical function for MYs 2012-2016 passenger cars and light trucks. 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.[57] The CAA has no such requirement, though in past rules, EPA has relied on both universal and attribute-based standards (*e.g.*, for nonroad engines, EPA uses the attribute of horsepower). However, given the advantages of using attribute-based standards and given the goal of coordinating and harmonizing CO_2 standards promulgated under the CAA and CAFE standards promulgated under EPCA. EPA also proposed to issue standards that are attribute-based and defined by mathematical functions. There was consensus in the public comments that EPA should develop attribute-based CO_2 standards.

Comments received in response to the agencies' decision to base standards on vehicle footprint were largely supportive. Several commenters (BMW, NADA, and NESCAUM) expressed support for attribute-based (as opposed to flat or universal) standards generally, and agreed with EPA's decision to harmonize with NHTSA in this respect. Many commenters (Aluminum Association, BMW, ICCT, NESCAUM, NY DEC, Schade, Toyota) also supported the agencies' decision to continue setting CAFE standards, and begin setting GHG standards, on the basis of vehicle footprint, although one commenter (NJ DEP) opposed the use of footprint due to concern that it encourages manufacturers to upsize vehicles and undercut the gains of the standard. Of the commenters supporting the use of footprint, several focused on the benefits of harmonization—both between EPA and NHTSA, and between the U.S. and the rest of the world. BMW commented, for example, that many other countries use weight-based standards rather than footprint-based. While BMW did not object to NHTSA's and EPA's use of footprint-based standards, it emphasized the impact of this non-harmonization on manufacturers who sell vehicles globally, and asked the agencies to consider these effects. NADA supported the use of footprint, but cautioned that the agencies must be careful in setting the footprint curve for light trucks to ensure that manufacturers can continue to provide functionality like 4WD and towing/hauling capacity.

Some commenters requested that the agencies consider other or more attributes in addition to footprint, largely reiterating comments submitted to the MYs 2011-2015 CAFE NPRM. Cummins supported the agencies using a secondary attribute to account for towing and hauling capacity in large trucks, for example, while Ferrari asked the agencies to consider a multi-attribute approach incorporating curb weight, maximum engine power or torque, and/or engine displacement, as it had requested in the previous round of CAFE rulemaking. An individual, Mr. Kenneth Johnson, commented that

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[57] 49 U.S.C. 32902(a)(3)(A).

weight-based standards would be preferable to footprint-based ones, because weight correlates better with fuel economy than footprint, because the use of footprint does not necessarily guarantee safety the way the agencies say it does, and because weight-based standards would be fairer to manufacturers.

In response, EPA and NHTSA continue to believe that the benefits of footprint-attribute-based standards outweigh any potential drawbacks raised by commenters, and that harmonization between the two agencies should be the overriding goal on this issue. As discussed by NHTSA in the MY 2011 CAFE final rule,[58] the agencies believe that the possibility of gaming attribute-based standards is lowest with footprint-based standards, as opposed to weight-based or multi-attribute-based standards.[59] Specifically, standards that incorporate weight, torque, power, towing capability, and/or off-road capability in addition to footprint would not only be significantly more complex, but by providing degrees of freedom with respect to more easily-adjusted attributes, they would make it less certain that the future fleet would actually achieve the average fuel economy and CO_2 levels projected by the agencies. The agencies are therefore finalizing MYs 2012-2016 CAFE and GHG standards based on footprint.

The agencies also recognize that there could be benefits for a number of manufacturers if there was greater international harmonization of fuel economy and GHG standards, but this is largely a question of how stringent standards are and how they are enforced. It is entirely possible that footprint-based and weight-based systems can coexist internationally and not present an undue burden for manufacturers. 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. Given differences in fleet composition, identical attribute-based standards would produce different levels of compliance burden in different countries. The agencies anticipate working more closely with other countries and regions in the future to consider how to mitigate these issues in a way that least burdens manufacturers while respecting each country’s need to meet its own particular challenges.

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[58] *See* 74 Fed. Reg. at 14359 (Mar. 30, 2009).

[59] NHTSA has considered the possibility that manufacturers will redesign vehicles in ways that tend to reduce compliance burdens rather than to increase fleet average vehicle fuel economy. Under a footprint-based system, manufacturers have an incentive to increase the footprint of their vehicles, to the extent that the market will support them doing so, because larger-footprint vehicles generally have less stringent CAFE targets.[59] However, larger-footprint vehicles have historically also been heavier vehicles, and heavier vehicles generally have more difficultly achieving their CAFE targets, even if those larger-footprint targets are less stringent. One way around this, theoretically, would be for manufacturers to attempt to increase vehicle footprint by pushing wheels further to the corners of the vehicles, perhaps beyond the bounds of optimal design, without increasing vehicle weight.

However, NHTSA does not believe that this possibility is likely. Any change in footprint requires manufacturers to reevaluate almost every aspect of how a vehicle performs in handling, crash testing, etc., and changes that result in non-optimally-designed vehicles seem very unlikely to make it to the market. Manufacturers attempting to reduce their compliance burden instead of increasing their average fuel economy will have to contend with market forces, which are driven by consumer preferences, income levels, and fuel prices, among many other things.

Under an attribute-based standard, every vehicle model has a performance target (fuel economy and CO_2 emissions for CAFE and CO_2 emissions standards, respectively), the level of which depends on the vehicle's attribute (for this rule, footprint). The manufacturers' fleet average performance is determined by the production-weighted[60] average (for CAFE, harmonic average) of those targets. NHTSA and EPA are promulgating CAFE and CO_2 emissions standards defined by constrained linear functions and, equivalently, piecewise linear functions.[61] As a possible option for future rulemakings, the constrained linear form was introduced by NHTSA in the 2007 NPRM proposing CAFE standards for MY 2011-2015. Described mathematically, the proposed constrained linear function was defined according to the following formula:[62]

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

where

> *TARGET* = the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet),
> *a* = the function's upper limit (in mpg),
> *b* = the function's lower limit (in mpg),
> *c* = the slope (in gpm per square foot) of the sloped portion of the function,
> *d* = the intercept (in gpm) 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, and
> the *MIN* and *MAX* functions take the minimum and maximum, respectively, of the included values; for example, *MIN*(1,2) = 1, *MAX*(1,2) = 2, and *MIN*[*MAX*(1,2),3)]=2.

Because the format is linear on a gallons-per-mile basis, not on a miles-per-gallon basis, it is plotted as fuel consumption below. Graphically, the constrained linear form appears as shown in Figure V-1.

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[60] Production for sale in the United States.

[61] The equations are equivalent but are specified differently due to differences in the agencies' respective models.

[62] This function is linear in fuel consumption but not in fuel economy.

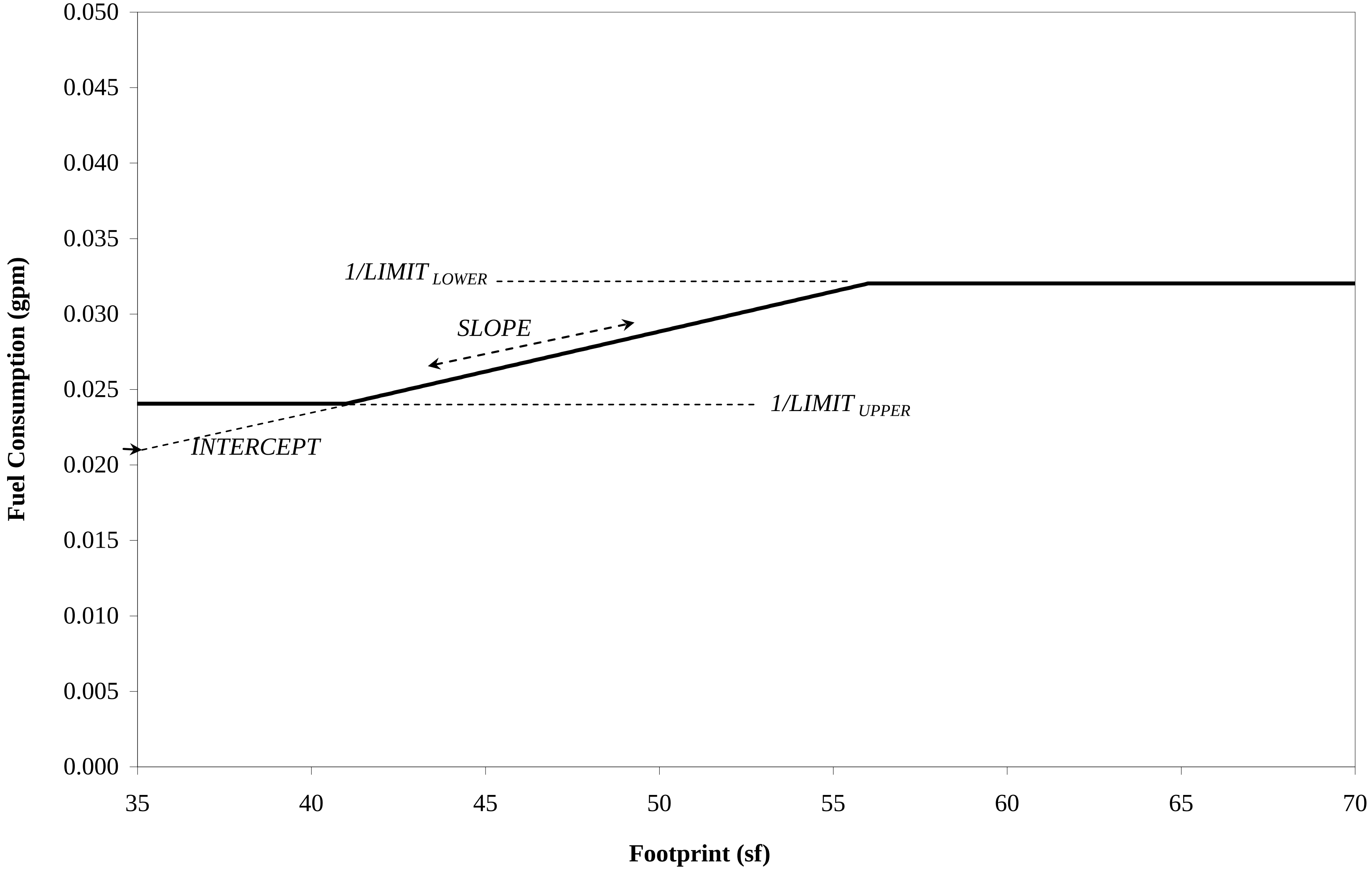

Figure V-1 The Shape of the Constrained Linear Form

The specific form and stringency for each fleet (passenger car and light trucks) and model year are defined through specific values for the four coefficients shown above.

For purposes of the final rules, NHTSA and EPA developed the basic curve shapes using methods similar to those applied by NHTSA in fitting the curves defining the MY 2011 standards. The first step involved defining the relevant vehicle characteristics in the form used by NHTSA's CAFE model (*e.g.*, fuel economy, footprint, vehicle class, technology) described in Section II.B of the Preamble and in Chapter 1 of the joint TSD. However, because the baseline fleet utilizes a wide range of available fuel saving technologies, NHTSA used the CAFE model to develop a fleet to which all of the technologies discussed in Chapter 3 of the joint TSD[63] were applied, except dieselization and strong hybridization. This was accomplished by taking the following steps: (1) treating all manufacturers as unwilling to pay civil penalties rather than applying technology, (2) applying any technology at any time, irrespective of scheduled vehicle redesigns or freshening, and (3) ignoring "phase-in caps" that constrain the overall amount of technology that can be applied by the model to a given manufacturer's fleet. These steps helped to increase technological parity among vehicle models, thereby providing a better basis (than the baseline or reference fleets) for estimating the statistical relationship between vehicle size and fuel economy.

In fitting the curves, NHTSA and EPA also continued to fit the sloped portion of the function to vehicle models between the footprint values at which the agencies continued to apply constraints to limit the function's value for both the smallest and largest vehicles. 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 leads to a function with an inherent absolute minimum level of performance, while remaining consistent with safety considerations.

Before fitting the sloped portion of the constrained linear form, NHTSA and EPA selected footprints above and below which to apply constraints (i.e., minimum and maximum values) on the function. The agencies believe that the linear form performs well in describing the observed relationship between footprint and fuel consumption or CO_2 emissions for vehicle models within the footprint ranges covering most vehicle models, but that the single (as opposed to piecewise) linear form does not perform well in describing this relationship for the smallest and largest vehicle models. For passenger

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[63] The agencies excluded diesel engines and strong hybrid vehicle technologies from this exercise (and only this exercise) because the agencies expect that manufacturers would not need to rely heavily on these technologies in order to comply with the proposed standards. NHTSA and EPA did include diesel engines and strong hybrid vehicle technologies in all other portions of their analyses.

cars, the agency noted that several manufacturers offer small, sporty coupes below 41 square feet, such as the BMW Z4 and Mini, Honda S2000, Mazda MX-5 Miata, Porsche Carrera and 911, and Volkswagen New Beetle. Because such vehicles represent a small portion (less than 10 percent) of the passenger car market, yet often have performance, utility, and/or structural characteristics that could make it technologically infeasible and/or economically impracticable for manufacturers focusing on such vehicles to achieve the very challenging average requirements that could apply in the absence of a constraint, EPA and NHTSA proposed to "cut off" the linear portion of the passenger car function at 41 square feet. For consistency, the agency proposed to do the same for the light truck function, although no light trucks are currently offered below 41 square feet. The agencies further noted that above 56 square feet, the only passenger car model 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. NHTSA and EPA therefore also proposed to "cut off" the linear portion of the passenger car function at 56 square feet. Finally, the agencies noted that although public information is limited regarding the sales volumes of the many different configurations (cab designs and bed sizes) of pickup trucks, most of the largest pickups (e.g., the Ford F-150, GM Sierra/Silverado, Nissan Titan, and Toyota Tundra) appear to fall just above 66 square feet in footprint. EPA and NHTSA therefore proposed to "cut off" the linear portion of the light truck function at 66 square feet.

Having developed a set of vehicle emissions and footprint data which represent the benefit of all non-diesel, non-hybrid technologies, we determined the initial values for parameters *c* and *d* were determined for cars and trucks separately. *c* and *d* were initially set at the values for which the average (equivalently, sum) of the absolute values of the differences was minimized between the "maximum technology" fleet fuel consumption (within the footprints between the upper and lower limits) and the straight line of the function defined above at the same corresponding vehicle footprints. That is, *c* and *d* were determined by minimizing the average absolute residual, commonly known as the MAD (Mean Absolute Deviation) approach, of the corresponding straight line.

Finally, NHTSA calculated the values of the upper and lower parameters (*a* and *b*) based on the corresponding footprints discussed above (41 and 56 square feet for passenger cars, and 41 and 66 square feet for light trucks).

The result of this methodology is shown below in Figures V-2 and V-3 for passenger cars and light trucks, respectively. The fitted curves are shown with the underlying "maximum technology" passenger car and light truck fleets. For passenger cars, the mean absolute deviation of the sloped portion of the function was 14 percent. For trucks, the corresponding MAD was 10 percent.

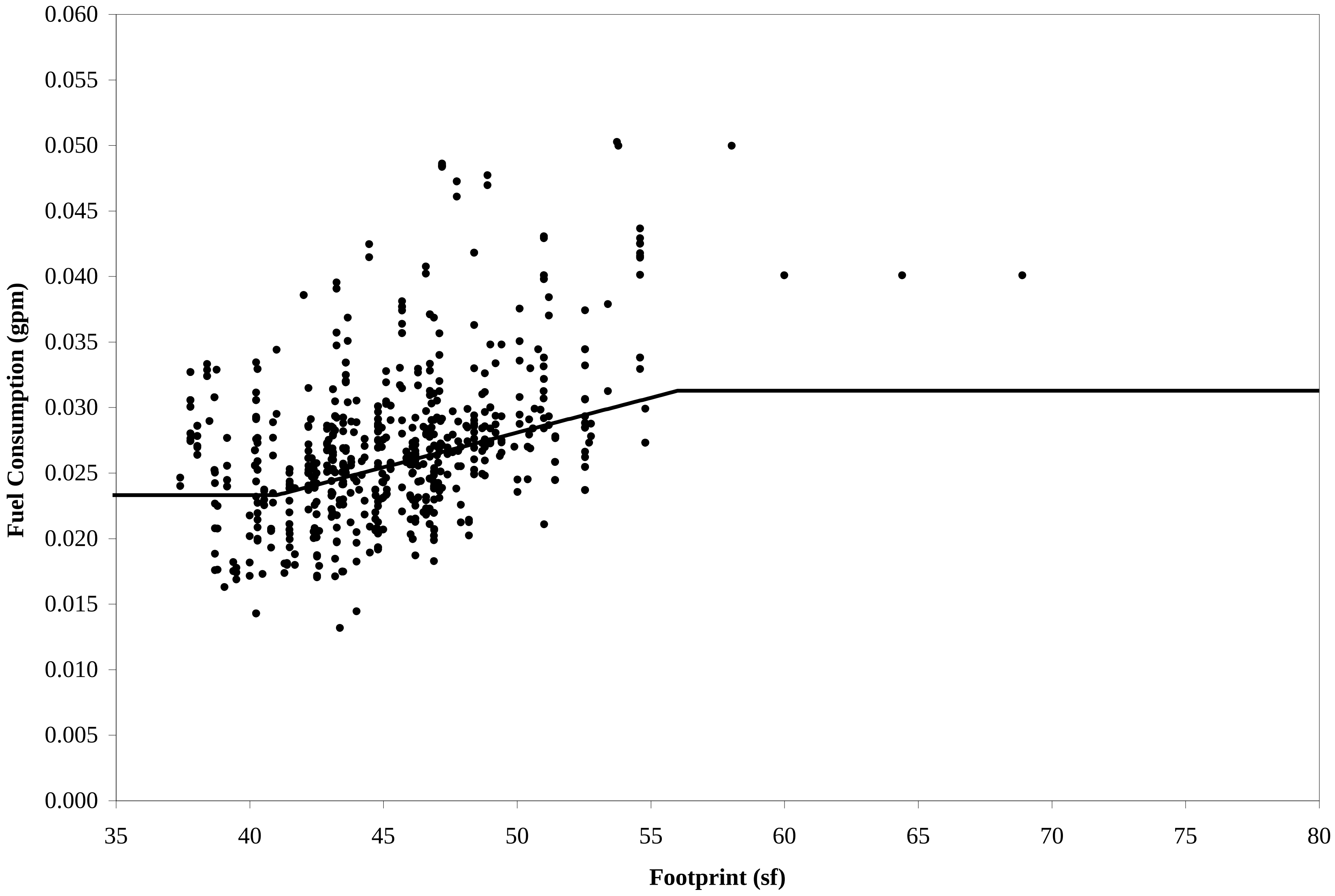

Figure V-2 “Maximum Technology” Passenger Fleet with Fitted Constrained Linear Function

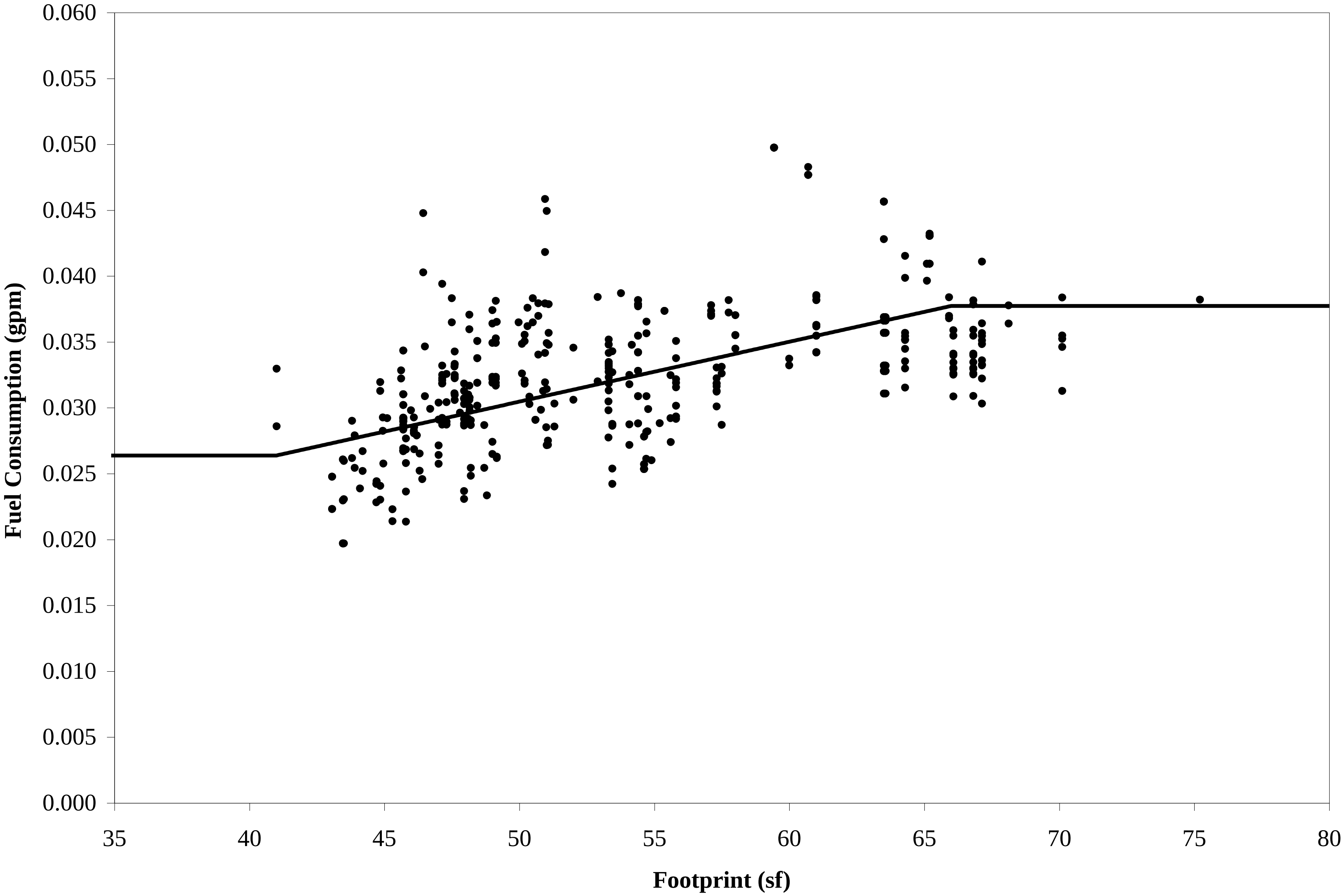

Figure V-3 “Maximum Technology” Light Truck with Fitted Constrained Linear Function

The agencies used these functional forms as a starting point to develop mathematical functions defining the actual proposed standards as discussed above. The agencies then transposed these functions vertically (i.e., on a gpm or CO_2 basis, uniformly downward) to produce the same fleetwide fuel economy (and CO_2 emission levels) for cars and light trucks described in the NPRM.

A number of public comments generally supported the agencies' choice of attribute-based mathematical functions, as well as the methods applied to fit the function. Ferrari indicated support for the use of a constrained linear form rather than a constrained logistic form, support for the application of limits on the functions' values, support for a generally less steep passenger car curve compared to MY 2011, and support for the inclusion of all manufacturers in the analysis used to fit the curves. ICCT also supported the use of a constrained linear form. Toyota expressed general support for the methods and outcome, including a less-steep passenger car curve, and the application of limits on fuel economy targets applicable to the smallest vehicles. The UAW commented that the shapes and levels of the curves are reasonable.

Other commenters suggested that changes to the agencies' methods and results would yield better outcomes. GM suggested that steeper curves would provide a greater incentive for limited-line manufacturers to apply technology to smaller vehicles. GM argued that steeper and, in their view, fairer curves could be obtained by using sales-weighted least-squares regression rather than minimization of the unweighted mean absolute deviation. Conversely, students from UC Santa Barbara commented that the passenger car and light truck curves should be flatter and should converge over time in order to encourage the market to turn, as the agencies' analysis assumes it will, away from light trucks and toward passenger cars.

NADA commented that there should be no "cut-off" points (i.e., lower limits or floors), because these *de facto* "backstops" might limit consumer choice, especially for light trucks—a possibility also suggested by the Alliance. The Alliance and several individual manufacturers also commented that the cut-off point for light trucks should be shifted to 72 square feet (from the proposed 66 square feet), arguing that the preponderance of high-volume light truck models with footprints greater than 66 square feet is such that a 72 square foot cut-off point makes it unduly challenging for manufacturers serving the large pickup market and thereby constitutes a *de facto* backstop. Also, with respect to the smallest light truck models, Honda commented that the cut-off point should be set at the point defining the smallest 10 percent of the fleet, both for consistency with the passenger car cut-off point, and to provide a greater incentive for manufacturers to downsize the smallest light truck models (which provide greater functionality than passenger cars).

Other commenters focused on whether the agencies should have separate curves for different fleets or whether they should have a single curve that applied to both passenger cars and light trucks. This issue is related, to some extent, to commenters who discussed whether car and truck definitions should change. CARB, Ford, and Toyota supported separate curves for cars and trucks, generally stating that different fleets have different functional characteristics and these characteristics are appropriately addressed by separate curves. Likewise, AIAM, Chrysler, and NADA supported leaving the current definitions of car and truck the same. CBD, ICCT, and NESCAUM supported a single curve, based on concerns about manufacturers gaming the system and reclassifying passenger cars as light trucks in order to obtain the often-less stringent light truck standard, which could lead to lower benefits than anticipated by the agencies.

In addition, the students from UC Santa Barbara reported being unable to reproduce the agencies' analysis to fit curves to the passenger car and light truck fleets, even when using the model, inputs, and external analysis files posted to NHTSA's web site when the NPRM was issued.

Having considered public comments, NHTSA and EPA have re-examined the development of curves underlying the standards proposed in the NPRM, and are promulgating standards based on the same underlying curves. The agencies have made this decision considering that, while EISA mandates that CAFE standards be defined by a mathematical function in terms of one or more attributes related to fuel economy, neither EISA nor the CAA require that the mathematical function be limited to the observed or theoretical dependence of fuel economy on the selected attribute or attributes. As a means by which CAFE and GHG standards are specified, the mathematical function can and does properly play a normative role. Therefore, NHTSA and EPA have concluded that, as supported by comments, the mathematical function can reasonably be based on a blend of analytical and policy considerations, as discussed below and in the Joint Technical Support Document.

With respect to GM's recommendation that NHTSA and EPA use weighted least-squares analysis, the agencies find that the market forecast used for analysis supporting both the NPRM and the final rule exhibits the two key characteristics that previously led NHTSA to use minimization of the unweighted Mean Absolute Deviation (MAD) rather than weighted least-squares analysis. First, projected model-specific sales volumes in the agencies' market forecast cover an extremely wide range, such that, as discussed in NHTSA's rulemaking for MY 2011, while unweighted regression gives low-selling vehicle models and high-selling vehicle models equal emphasis, sales-weighted regression would give some vehicle models considerably more emphasis than other vehicle models.[64] The agencies' intention is to fit a curve that describes a technical relationship between fuel economy and footprint, given comparable levels of technology, and this supports weighting discrete vehicle models equally. On the other hand, sales weighted regression would allow the difference between other vehicle attributes to be reflected in the analysis, and also would reflect consumer demand.

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[64] For example, the agencies' market forecast shows MY 2016 sales of 187,000 units for Toyota's 2WD Sienna, and shows 27 model configurations with MY 2016 sales of fewer than 100 units. Similarly, the agencies' market forecast shows MY 2016 sales of 268,000 for the Toyota Prius, and shows 29 model configurations with MY 2016 sales of fewer than 100 units. Sales-weighted analysis would give the Toyota Sienna and Prius more than a thousand times the consideration of many vehicle model configurations. Sales-weighted analysis would, therefore, cause a large number of vehicle model configurations to be virtually ignored. *See* discussion in NHTSA's final rule for MY 2011 passenger car and light truck CAFE standards, 74 FR 14368 (Mar. 30, 2009), and in NHTSA's NPRM for that rulemaking, 73 FR 24423-24429 (May 2, 2008).

Second, even after NHTSA's "maximum technology" analysis to increase technological parity of vehicle models before fitting curves, the agencies' market forecast contains many significant outliers. As discussed in NHTSA's rulemaking for MY 2011, MAD is a statistical procedure that has been demonstrated to produce more efficient parameter estimates than least-squares analysis in the presence of significant outliers.[65] In addition, the agencies remain concerned that the steeper curves resulting from weighted least-squares analysis would increase the risk that energy savings and environmental benefits would be lower than projected, because the steeper curves would provide a greater incentive to increase sales of larger vehicles with lower fuel economy levels. Based on these technical considerations and these concerns regarding potential outcomes, the agencies have decided not to re-fit curves using weighted least-squares analysis, but note that they may reconsider using least-squares regression in future analysis.

NHTSA and EPA have considered GM's comment that steeper curves would provide a greater incentive for limited-line manufacturers to apply technology to smaller vehicles. While the agencies agree that a steeper curve would, absent any changes in fleet mix, tend to shift average compliance burdens away from GM and toward companies that make smaller vehicles, the agencies are concerned, as stated above, that steeper curves would increase the risk that induced increases in vehicle size could erode projected energy and environmental benefits.

NHTSA and EPA have also considered the comments by the students from UC Santa Barbara indicating that the passenger car and light truck curves should be flatter and should converge over time. The agencies conclude that flatter curves would reduce the incentives intended in shifting from "flat" CAFE standards to attribute-based CAFE and GHG standards—those being the incentive to respond to attribute-based standards in ways that minimize compromises in vehicle safety, and the incentive for more manufacturers (than primarily those selling a wider range of vehicles) across the range of the attribute to have to increase the application of fuel-saving technologies. With regard to whether the agencies should set separate curves or a single one, NHTSA also notes that EPCA requires NHTSA to establish standards separately for passenger cars and light trucks, and thus concludes that the standards for each fleet should be based on the characteristics of vehicles in each fleet. In other words, the passenger car curve should be based on the characteristics of passenger cars, and the light truck curve should be

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[65] *Id.* In the case of a dataset not drawn from a sample with a Gaussian, or normal, distribution, there is often a need to employ robust estimation methods rather than rely on least-squares approach to curve fitting. The least-squares approach has as an underlying assumption that the data are drawn from a normal distribution, and hence fits a curve using a sum-of-squares method to minimize errors. This approach will, in a sample drawn from a non-normal distribution, give excessive weight to outliers by making their presence felt in proportion to the square of their distance from the fitted curve, and, hence, distort the resulting fit. With outliers in the sample, the typical solution is to use a robust method such as a minimum absolute deviation, rather than a squared term, to estimate the fit (*see*, e.g., ''AI Access: Your Access to Data Modeling,'' at http://www.aiaccess.net/English/Glossaries/GlosMod/e_gm_O_Pa.htm#Outlier). The effect on the estimation is to let the presence of each observation be felt more uniformly, resulting in a curve more representative of the data (*see*, e.g., Peter Kennedy, *A Guide to Econometrics*, 3rd edition, 1992, MIT Press, Cambridge, MA).

based on the characteristics of light trucks—thus to the extent that those characteristics are different, an artificially-forced convergence would not accurately reflect those differences. However, such convergence could be appropriate depending on future trends in the light vehicle market, specifically further reduction in the differences between passenger car and light truck characteristics. While that trend was more apparent when car-like 2WD SUVs were classified as light trucks, it seems likely to diminish for the model year vehicles subject to these rules as the truck fleet will be more purely "truck-like" than has been the case in recent years.

NHTSA and EPA have also considered comments on the maxima and minima that the agencies have applied to "cut off" the linear function underlying the proposed curves for passenger cars and light trucks. Contrary to NADA's suggestion that there should be no such cut-off points, the agencies conclude that curves lacking maximum fuel economy targets (i.e., minimum CO_2 targets) would result in average fuel economy and GHG requirements that would not be technologically feasible or economically practicable for manufacturers concentrating on those market segments. In addition, minimum fuel economy targets (i.e., maximum CO_2 targets) are important to mitigate the risk to energy and environmental benefits of potential market shifts toward large vehicles. The agencies also disagree with comments by the Alliance and several individual manufacturers that the cut-off point for light trucks should be shifted to 72 square feet (from the proposed 66 square feet) to ease compliance burdens facing manufacturers serving the large pickup market. Such a shift would increase the risk that energy and environmental benefits of the standards would be compromised by induced increases in the sales of large pickups, in situations where the increased compliance burden is feasible and appropriate. Also, the agencies' market forecast suggests that most of the light trucks models with footprints larger than 66 square feet have curb weights near or above 5,000 pounds. This suggests, in turn, that in terms of highway safety, there is little or no need to discourage downsizing of light trucks with footprints larger than 66 square feet. Based on these energy, environmental, technological feasibility, economic practicability, and safety considerations, the agencies conclude that the light truck curve should be cut off at 66 square feet, as proposed, rather than at 72 square feet. The agencies also disagree with Honda's suggestion that the cut-off point for the smallest trucks be shifted to a larger footprint value, because doing so could potentially increase the incentive to reclassify vehicles in that size range as light trucks, and could thereby increase the possibility that energy and environmental benefits of the rule would be less than projected.

Finally, considering comments by the UC Santa Barbara students regarding difficulties reproducing NHTSA's analysis, NHTSA reexamined its analysis, and discovered some erroneous entries in model inputs underlying the analysis used to develop the curves proposed in the NPRM. These errors are discussed in NHTSA's final Regulatory Impact Analysis (FRIA) and have since been corrected. They include the following: incorrect valvetrain phasing and lift inputs for many BMW engines, incorrect indexing for some Daimler models, incorrectly enabled valvetrain technologies for rotary engines and Atkinson cycle engines, omitted baseline applications of cylinder deactivation in some Honda and GM engines, incorrect valve phasing codes for some 4-cylinder Chrysler engines, omitted baseline applications of advanced transmissions in some VW models, incorrectly enabled advanced electrification technologies for several hybrid vehicle models, and incorrect DCT effectiveness estimates for subcompact passenger cars. These errors, while not significant enough to impact the overall analysis of stringency, did affect the fitted slope for the passenger car curve and would have prevented precise replication of NHTSA's NPRM analysis by outside parties.

After correcting these errors and repeating the curve development analysis presented in the NPRM, NHTSA obtained the curves shown below in Figures V-4 and V-5 for passenger cars and light trucks, respectively. The fitted curves are shown with the underlying "maximum technology" passenger car and light truck fleets. For passenger cars, the mean absolute deviation of the sloped portion of the function was 14 percent. For trucks, the corresponding MAD was 10 percent.

Figure V-4 Revised “Maximum Technology” Passenger Fleet with Fitted Constrained Linear Function

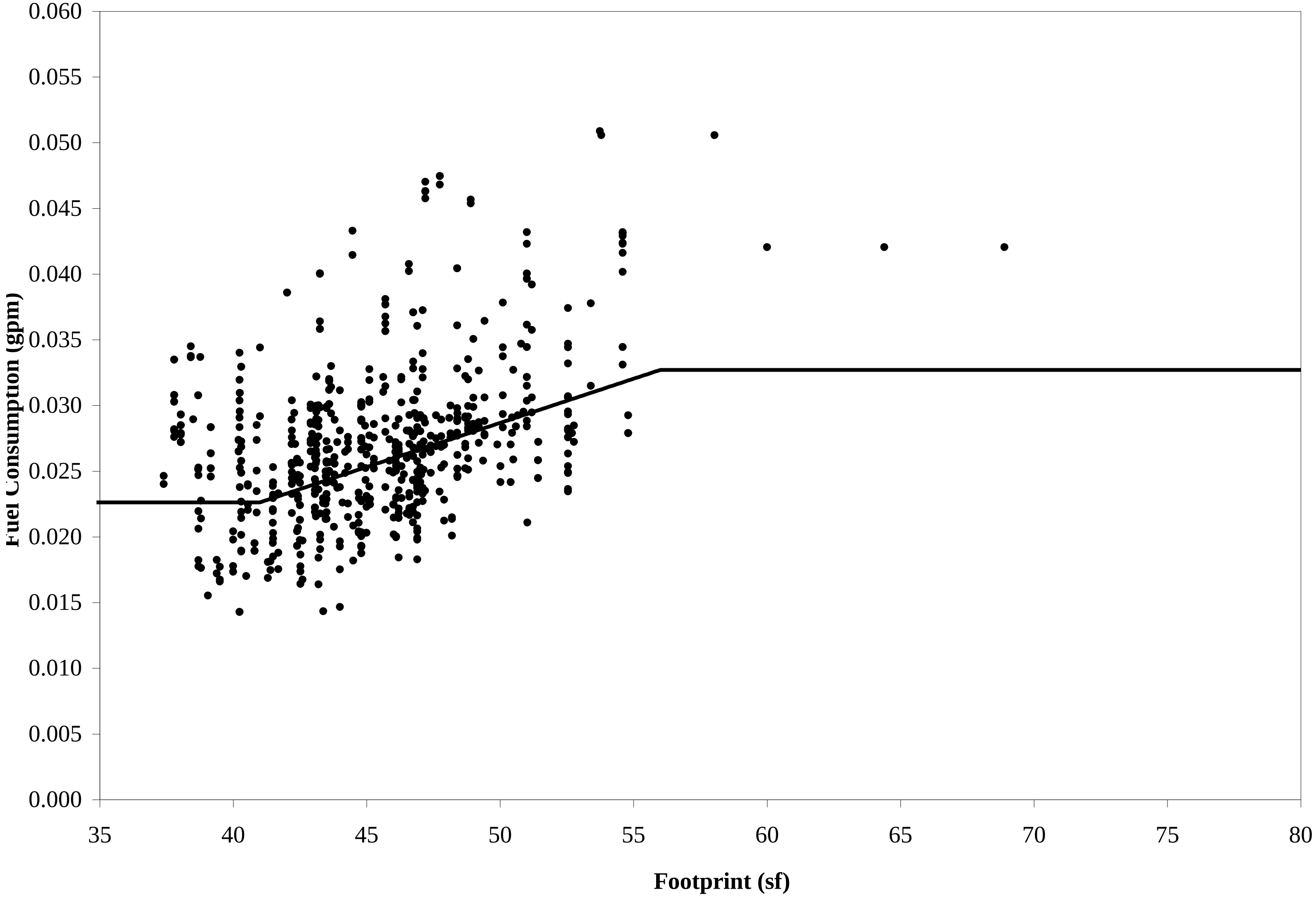
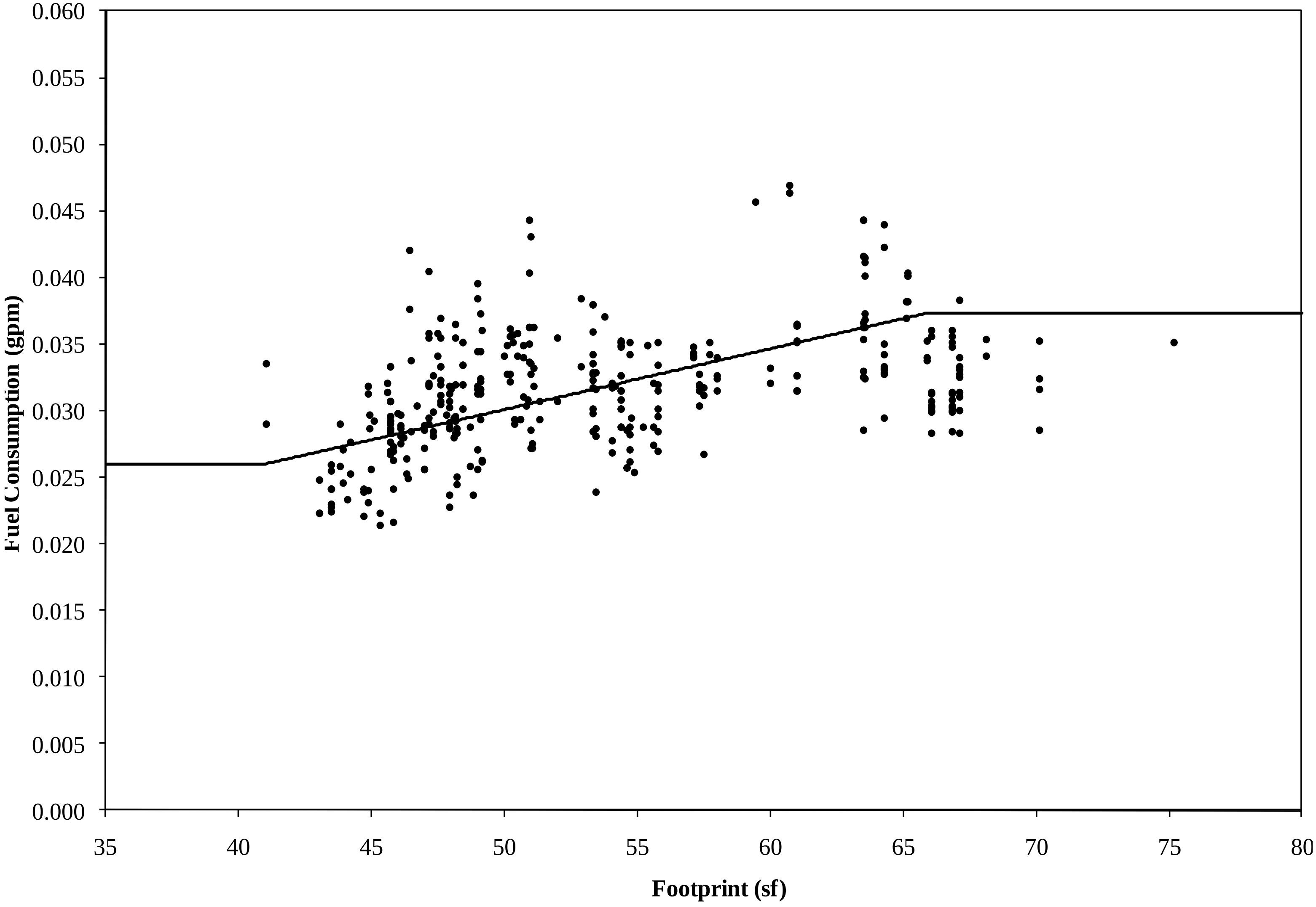


Figure V-5 Revised “Maximum Technology” Light Truck with Fitted Constrained Linear Function



This refitted passenger car curve is similar to that presented in the NPRM, and the refitted light truck curve is nearly identical the corresponding curve in the NPRM. However, the slope of the refitted passenger car curve is about 27 percent steeper (on a gpm per sf basis) than the curve presented in the NPRM. For passenger cars and light trucks, respectively, Figures V-6 and V-7 show the results of adjustment—discussed in the next section—of the above curves to yield the average required fuel economy levels corresponding to the final standards.

Figure V-6 MY 2016 Passenger Car Targets: NPRM, Final Rule, and if Using Re-Fitted Curve

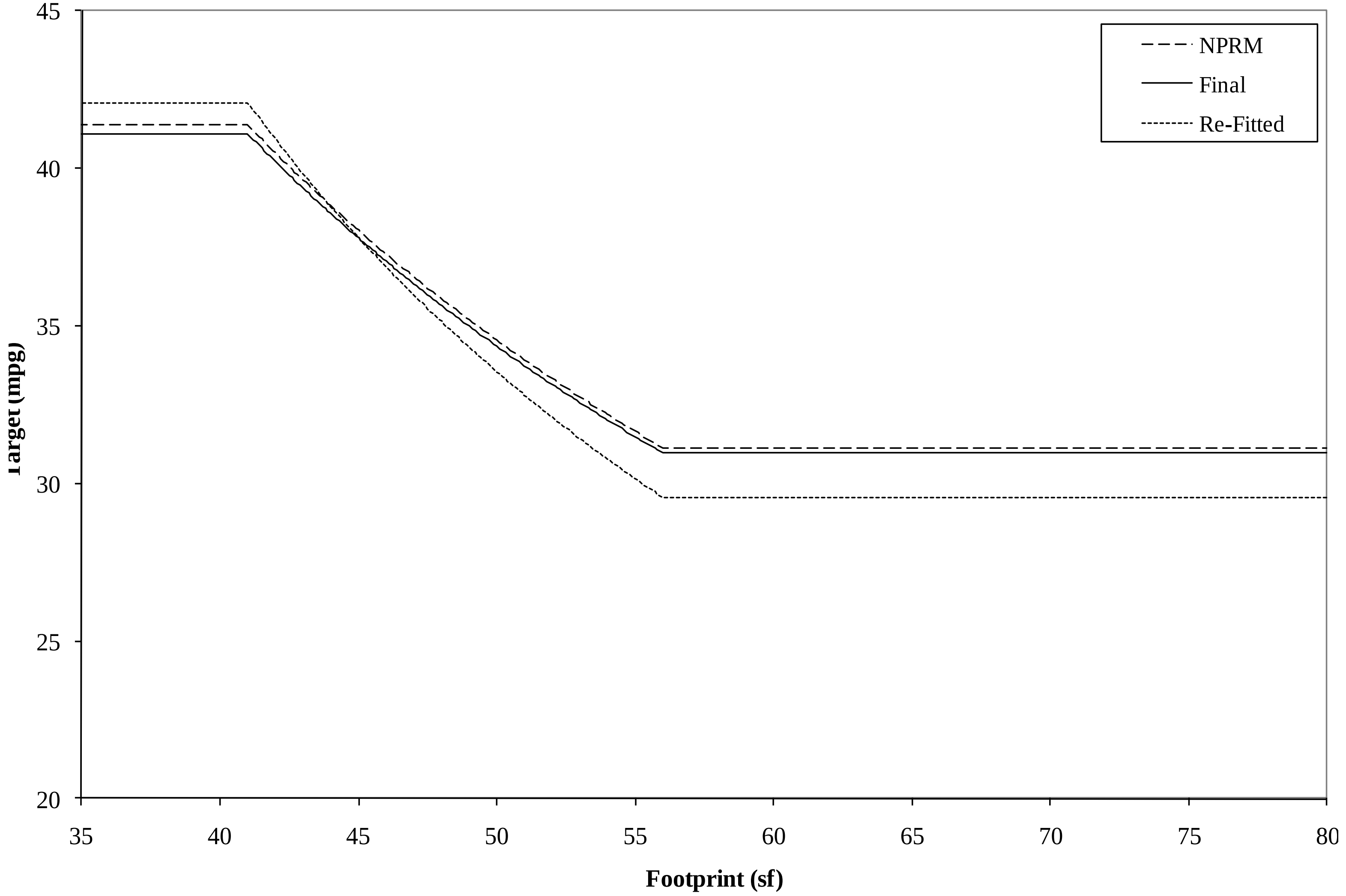
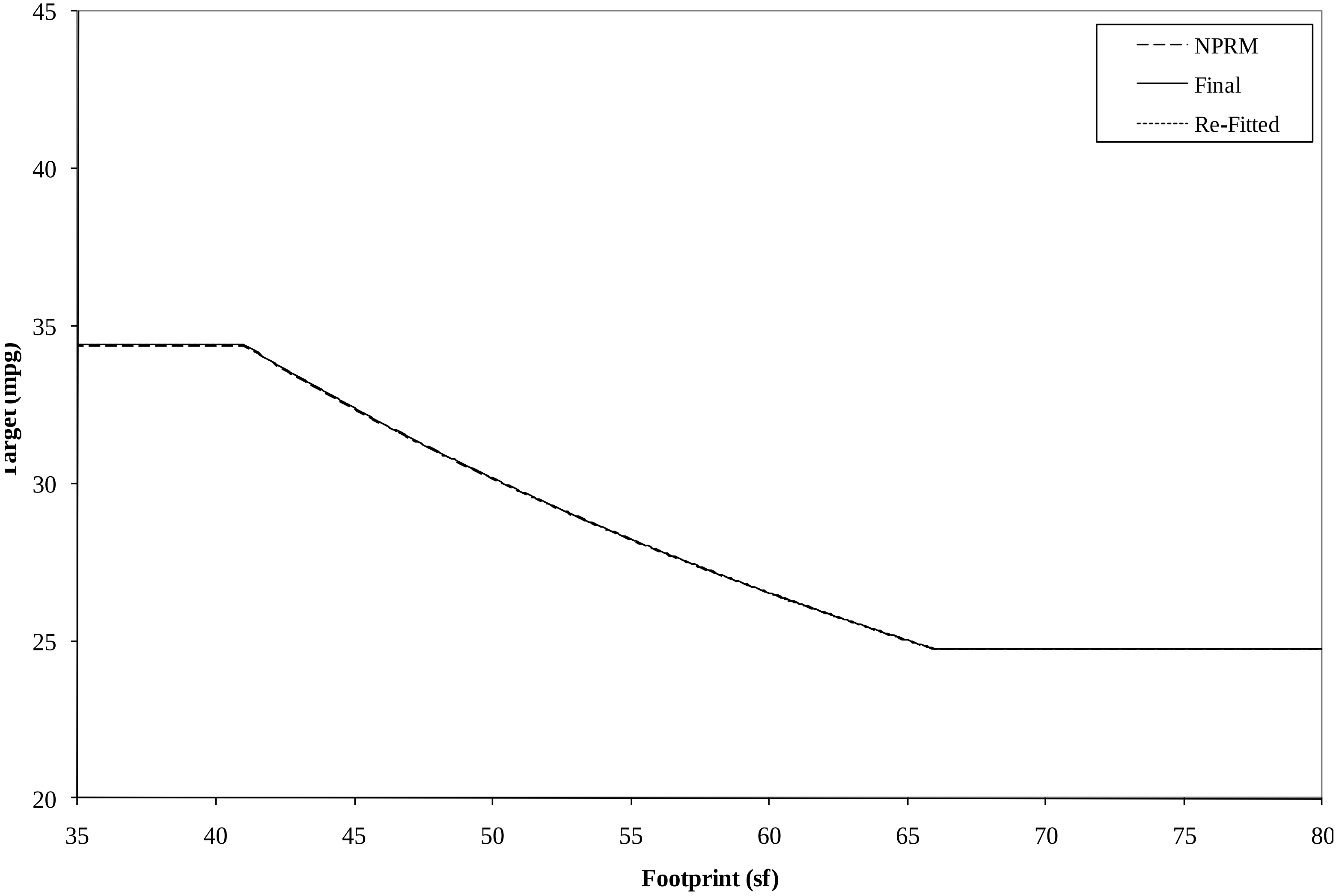


Figure V-7 MY 2016 Light Truck Targets: NPRM, Final Rule, and if Using Re-Fitted Curve



While the resultant light truck curves are visually indistinguishable from one another, the refitted curve for passenger cars would increase stringency for the smallest cars, decrease stringency for the largest cars, and provide a greater incentive to increase vehicle size throughout the range of footprints within which NHTSA and EPA project most passenger car models will be sold through MY 2016. The agencies are concerned that these changes would make it unduly difficult for manufacturers to introduce new small passenger cars in the United States, and unduly risk losses in energy and environmental benefits by increasing incentives for the passenger car market to shift toward larger vehicles.

Also, the agencies note that the refitted passenger car curve produces only a slightly closer fit to the corrected fleet than would the curve estimated in the NPRM; with respect to the corrected fleet (between the “cut off” footprint values, and after the “maximum technology” analysis discussed above), the mean absolute deviation for the refitted curve is 13.887 percent, and that of a refitted curve held to the original slope is 13.933 percent. In other words, the data support the original slope very nearly as well as they support the refitted slope.

Considering NHTSA’s and EPA’s concerns regarding the change in incentives that would result from a refitted curve for passenger cars, and considering that the data support the original curves about as well as they would support refitted curves, the agencies are finalizing CAFE and GHG standards based on the curves presented in the NPRM.

Finally, regarding some commenters’ inability to reproduce the agencies’ NPRM analysis, NHTSA believes that its correction of the errors discussed above and its release (on NHTSA’s web site) of the updated Volpe model and all accompanying inputs and external analysis files should enable outside parties to independently reproduce the agencies’ analysis. If outside parties continue to experience difficulty in doing so, we encourage them to contact NHTSA, and the agency will do its best to provide assistance.

Thus, in summary, the agencies’ approach to developing the attribute-based mathematical functions for MY 2012-2016 CAFE and CO_2 standards represents the agencies’ best technical judgment and consideration of potential outcomes at this time, and we are confident that the conclusions have resulted in appropriate and reasonable standards. The agencies recognize, however, that aspects of these decisions may merit updating or revision in future analysis to support CAFE and CO_2 standards or for other purposes. Consistent with best rulemaking practices, the agencies will take a fresh look at all assumptions and approaches to curve fitting, appropriate attributes, and mathematical functions in the context of future rulemakings.

The agencies also recognized in the NPRM the possibility that lower fuel prices could lead to lower fleetwide fuel economy (and higher CO_2 emissions) than projected in this rule. One way of addressing that concern is through the use of a universal standard—that is, an average standard set at a (single) absolute level. This is often described as a “backstop standard.” The agencies explained that under the CAFE program, EISA requires such a minimum average fuel economy standard for domestic passenger cars, but is silent with regard to similar backstops for imported passenger cars and light trucks, while under the CAA, a backstop could be adopted under section 202(a) assuming it could be justified under the relevant statutory criteria. NHTSA and EPA also noted that the flattened portions of the curves at the largest footprints directionally address the issue of a backstop (i.e., the mpg "floor" or gpm "ceiling" applied to the curves provides a universal and absolute value for that range of footprints). The agencies sought comment on whether backstop standards, or any other method within the agencies' statutory authority, should and can be implemented in order to guarantee a level of CO_2 emissions reductions and fuel savings under the attribute-based standards.

The agencies received a number of comments regarding the need for a backstop beyond NHTSA's alternative minimum standard. Comments were divided fairly evenly between support for and opposition to additional backstop standards. The following organizations supported the need for EPA and NHTSA to have explicit backstop standards: American Council for an Energy Efficient Economy (ACEEE), American Lung Association, California Air Resources Board (CARB), Environment America, Environment Defense Fund, Massachusetts Department of Environmental Protection, Natural Resources Defense Council (NRDC), Northeast States for Coordinated Air Use Management (NESCAUM), Public Citizen and Safe Climate Campaign, Sierra Club, State of Washington Department of Ecology, Union of Concerned Scientists, and a number of private citizens. Commenters in favor of additional backstop standards for all fleets for both NHTSA and EPA[66] generally stated that the emissions reductions and fuel savings expected to be achieved by MY 2016 depended on assumptions about fleet mix that might not come to pass, and that various kinds of backstop standards or "ratchet mechanisms"[67] were necessary to ensure that those reductions were achieved in fact. In addition, some commenters[68] stated that manufacturers might build larger vehicles or more trucks during MYs 2012-2016 than the agencies project, for example, because 1) any amount of slope in target curves encourages manufacturers to upsize, and 2) lower targets for light trucks than for passenger cars encourage manufacturers to find ways to reclassify vehicles as light trucks, such as by dropping 2WD versions of SUVs and offering only 4WD versions, perhaps spurred by NHTSA's reclassification of 2WD SUVs as passenger cars. Both of these mechanisms will be addressed further below. Some commenters also discussed EPA authority under the CAA to set backstops,[69] agreeing with EPA's analysis that section 202 (a) allows such standards since EPA has wide discretion under that section to craft standards.

The following organizations opposed a backstop: Alliance of Automobile Manufacturers (AAM), Association of International Automobile Manufacturers (AIAM), Ford Motor Company, National Automobile Dealers Association (NADA), Toyota Motor Company,

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[66] ACEEE, American Lung Association, CARB, Christopher Lish, Environment America, EDF, MA DEP, NRDC, NESCAUM, Public Citizen, Sierra Club *et al.*, SCAQMD, UCS, WA DE

[67] Commenters generally defined a "ratchet mechanism" as an automatic re-calculation of stringency to ensure cumulative goals are reached by 2016, even if emissions reductions and fuel savings fall short in the earlier years covered by the rulemaking.

[68] CBD, MA DEP, NJ DEP, Public Citizen, Sierra Club *et al.*, UCS

[69] CARB, Public Citizen, Sierra Club *et al.*

and the United Auto Workers Union. Commenters stating that additional backstops would not be necessary disagreed that upsizing was likely,[70] and emphasized the anti-backsliding characteristics of the target curves. Others argued that universal absolute standards as backstops could restrict consumer choice of vehicles. Commenters making legal arguments under EPCA/EISA[71] stated that Congress' silence regarding backstops for imported passenger cars and light trucks should be construed as a lack of authority for NHTSA to create further backstops. Commenters making legal arguments under the CAA[72] focused on the lack of clear authority under the CAA to create multiple GHG emissions standards for the same fleets of vehicles based on the same statutory criteria, and opposed EPA taking steps that would reduce harmonization with NHTSA in standard setting. Furthermore, AIAM indicated that EISA's requirement that the combined (car and truck) fuel economy level reach at least 35 mpg by 2020 itself constitutes a backstop.[73] One individual[74] commented that while additional backstop standards might be necessary given optimism of fleet mix assumptions, both agencies' authorities would probably need to be revised by Congress to clarify that backstop standards (whether for individual fleets or for the national fleet as a whole) were permissible.

In response, EPA and NHTSA remain confident that their projections of the future fleet mix are reliable, and that future changes in the fleet mix of footprints and sales are not likely to lead to more than modest changes in projected emissions reductions or fuel savings.[75] Both agencies thus remain confident in these fleet projections and the resulting

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[70] For example, the Alliance and Toyota said that upsizing would not be likely because (1) it would not necessarily make compliance with applicable standards easier, since larger vehicles tend to be heavier and heavier vehicles tend to achieve worse fuel economy/emissions levels; (2) it may require expensive platform changes; (3) target curves become increasingly more stringent from year to year, which reduces the benefits of upsizing; and (4) the mpg floor and gpm ceiling for the largest vehicles (the point at which the curve is "cut off") discourages manufacturers from continuing to upsize beyond a point because doing so makes it increasingly difficult to meet the flat standard at that part of the curve.

[71] AIAM, Alliance, Ford, NADA, Toyota

[72] Alliance, Ford, NADA, UAW

[73] NHTSA and EPA agree with AIAM that the EISA 35 mpg requirement in MY 2020 has a backstop-like function, in that it requires a certain level of achieved fleetwide fuel economy by a certain date, although it is not literally a backstop standard. Considering that NHTSA's MY 2011 CAFE standards increased projected average fuel economy requirements (relative to the MY 2010 standards) at a significantly faster rate than would be required to achieve the 35-in-2020 requirement, and considering that the standards being finalized today would increase projected average combined fuel economy requirements to 34.1 mpg in MY 2016, four years before MY 2020, the agencies believe that the U.S. vehicle market would have to shift in highly unexpected ways in order to put the 35-in-2020 requirement at risk, even despite the fact that due to the attribute-based standards, average fuel economy requirements will vary depending on the mix of vehicles produced for sale in the U.S. in each model year. The agencies further emphasize that both NHTSA and EPA plan to conduct and document retrospective analyses to evaluate how the market's evolution during the rulemaking timeframe compares with the agencies' forecasts employed for this rulemaking. Additionally, we emphasize that both agencies have the authority, given sufficient lead time, to revise their standards upwards if necessary to avoid missing the 35-in-2020 requirement.

[74] Schade

[75] For reference, NHTSA's March 2009 final rule establishing MY 2011 CAFE standards was based on a forecast that passenger cars would represent 57.6 percent of the MY 2011 fleet, and that MY 2011 passenger cars and light trucks would average 45.6 square feet (sf) and 55.1 sf, respectively, such that average required CAFE levels would be 30.2 mpg, 24.1 mpg, and 27.3 mpg, respectively, for passenger cars, light trucks, and the overall light-duty fleet. Based on the agencies' current market forecast, even as

emissions reductions and fuel savings from the standards. As explained in Section II.B of the Preamble, the agencies' projections of the future fleet are based on the most transparent information currently available to the agencies. In addition, there are only a relatively few model years at issue. Moreover, market trends today are consistent with the agencies' estimates, showing shifts from light trucks to passenger cars and increased emphasis on fuel economy from all vehicles.

Finally, the shapes of the curves, including the "flattening" at the largest footprint values, tend to avoid or minimize regulatory incentives for manufacturers to upsize their fleet to change their compliance burden. Given the way the curves are fit to the data points (which represent vehicle models' fuel economy mapped against their footprint), the agencies believe that there is little real benefit to be gained by a manufacturer upsizing their vehicles. As discussed above, the agencies' analysis indicates that, for passenger car models with footprints falling between the two flattened portions of the corresponding curve, the actual slope of fuel economy with respect to footprint, if fit to that data by itself, is about 27 percent steeper than the curve the agencies are promulgating today. This difference suggests that manufacturers would, if anything, have more to gain by reducing vehicle footprint than by increasing vehicle footprint. For light trucks, the agencies' analysis indicates that, for models with footprints falling between the two flatted portions of the corresponding curve, the slope of fuel economy with respect to footprint is nearly identical to the curve the agencies are promulgating today. This suggests that, within this range, manufacturers would typically have little incentive to either incrementally increase or reduce vehicle footprint.

At the same time, adding another backstop standard would have virtually no effect if the standard was weak, but a more stringent backstop could compromise the objectives served by attribute-based standards – that they distribute compliance burdens more equally among manufacturers, and at the same time encourage manufacturers to apply fuel-saving technologies rather than simply downsizing their vehicles, as they did in past decades under flat standards. This is why Congress mandated attribute-based CAFE standards in EISA. This compromise in objectives could occur for any manufacturer whose fleet average was above the backstop, irrespective of why they were above the backstop and irrespective of whether the industry as a whole was achieving the emissions and fuel economy benefits projected for the final standards, the problem the backstop is supposed to address. For example, the projected industry wide level of 250 gm/mile for MY 2016 is based on a mix of manufacturer levels, ranging from approximately 205 to 315 gram/mile[76] but resulting in an industry wide basis in a fleet average of 250 gm/mile. Unless the backstop was at a very weak level, above the high end of this range, then some percentage of manufacturers would be above the backstop even if the performance of the entire industry remains fully consistent with the emissions and fuel economy levels projected for the final standards. For these manufacturers and any other manufacturers

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soon as MY 2011, passenger cars will comprise a larger share (59.2 percent) of the light vehicle market; passenger cars and light trucks will, on average, be smaller by 0.5 sf and 1.3 sf, respectively; and average required CAFE levels will be higher by 0.2 mpg, 0.3 mpg, and 0.3 mpg, respectively, for passenger cars, light trucks, and the overall light-duty fleet.

[76] Based on estimated standards presented in tables III.B.1-1 and III.B.1-2.

who were above the backstop, the objectives of an attribute based standard would be compromised and unnecessary costs would be imposed. This could directionally impose increased costs for some manufacturers. It would be difficult if not impossible to establish the level of a backstop standard such that costs are likely to be imposed on manufacturers only when there is a failure to achieve the projected reductions across the industry as a whole. An example of this kind of industry wide situation could be when there is a significant shift to larger vehicles across the industry as a whole, or if there is a general market shift from cars to trucks. The problem the agencies are concerned about in those circumstances is not with respect to any single manufacturer, but rather is based on concerns over shifts across the fleet as a whole, as compared to shifts in one manufacturer's fleet that may be more than offset by shifts the other way in another manufacturer's fleet. However, in this respect, a traditional backstop acts as a manufacturer specific standard.

The concept of a ratchet mechanism recognizes this problem, and would impose the new more stringent standard only when the problem arises across the industry as a whole. While the new more stringent standards would enter into force automatically, any such standards would still need to provide adequate lead time for the manufacturers. Given the limited number of model years covered by this rulemaking and the short lead-time already before the 2012 model year, a ratchet mechanism in this rulemaking that would automatically tighten the standards at some point after model year 2012 is finished and apply the new more stringent standards for model years 2016 or earlier, would fail to provide adequate lead time for any new, more stringent standards

Additionally, we do not believe that the risk of vehicle upsizing or changing vehicle offerings to “game” the passenger car and light truck definitions is as great as commenters imply for the model years in question.[77] The changes that commenters suggest manufacturers might make are neither so simple nor so likely to be accepted by consumers. For example, 4WD versions of vehicles tend to be more expensive and, other things being equal, have inherently lower fuel economy than their 2WD equivalent models. Therefore, although there is a market for 4WD vehicles, and some consumers might shift from 2WD vehicles to 4WD vehicles if 4WD becomes available at little or no extra cost, many consumers still may not desire to purchase 4WD vehicles because of concerns about cost premium and additional maintenance requirements; conversely, many manufacturers often require the 2WD option to satisfy demand for base vehicle models. Additionally, increasing the footprint of vehicles requires platform changes, which usually requires a product redesign phase (the agencies estimate that this occurs on average once every 5 years for most models). Alternatively, turning many 2WD SUVs into 2WD light trucks would require manufacturers to squeeze a third row of seats in or significantly increase their GVWR, which also requires a significant change in the vehicle.[78] The agencies are confident that the anticipated increases in average fuel

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[77] We note that NHTSA’s recent clarification of the light truck definitions has significantly reduced the potential for gaming, and resulted in the reclassification of over a million vehicles from the light truck to the passenger car fleet.

[78] Increasing the GVWR of a light truck (assuming this was the only goal) can be accomplished in a number of ways, and must include consideration of: (1) redesign of wheel axles; (2) improving the vehicle

economy and reductions in average CO_2 emission rates can be achieved without backstops under EISA or the CAA. As noted above, the agencies plan to conduct retrospective analysis to monitor progress. Both agencies have the authority to revise standards if warranted, as long as sufficient lead time is provided.

The agencies acknowledge that the MY 2016 fleet emissions and fuel economy goals of 250 g/mi and 34.1 mpg for EPA and NHTSA respectively are estimates and not standards (the MY 2012-2016 curves are the standards). Changes in fuel prices, consumer preferences, and/or vehicle survival and mileage accumulation rates could result in either smaller or larger oil and GHG savings. As explained above and elsewhere in the rule, the agencies believe that the possibility of not meeting (or, alternatively, exceeding) fuel economy and emissions goals exists, but is not likely Given this, and given the potential complexities in designing an appropriate backstop, the agencies believe the balance here points to not adopting additional backstops at this time for the MYs 2012-2016 standards other than NHTSA's finalizing of the ones required by EPCA/EISA for domestic passenger cars. If, during the timeframe of this rule, the agencies observe a significant shift in the manufacturer's product mix resulting in a relaxation of their estimated targets, NHTSA and EPA will reconsider options, both for MYs 2012-2016 and future rulemakings.

B. How does NHTSA use the assumptions in its modeling analysis?

In developing today's final 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

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suspension; (3) changes in tire specification (which will likely affect ride quality); (4) vehicle dynamics development (especially with vehicles equipped with electronic stability control); and (5) brake redesign. Depending on the vehicle, some of these changes may be easier or more difficult than others.

also available in the docket for today's final rule, as are inputs for and outputs from analysis of today's final CAFE standards.

1. 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 market forecast discussed in Section IV.C.1 of the Preamble and Chapter 1 of the TSD, (b) technology-related estimates discussed in Section IV.C.2 of the Preamble and Chapter 3 of the TSD, (c) economic inputs discussed in Section IV.C.3 of the Preamble and Chapter 4 of the TSD, and (d) inputs defining baseline and potential new CAFE standards. 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 identify a set of technologies the manufacturer could apply in response to new CAFE standards. The model applies technologies to each of the projected individual vehicles in a manufacturer's fleet, until one of three things occurs:

(1) the manufacturer's fleet achieves compliance with the applicable standard;
(2) the manufacturer "exhausts"[79] 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.[80]

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[79] 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.

[80] 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 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).

As discussed below, the model has also been 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.

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.[81] The multi-year planning capability mentioned above increases 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.[82] It calculates costs by applying the cost estimation techniques discussed in Section IV.C.2 of the Preamble, 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 in Section IV.C.2 of the Preamble, and the vehicle survival and mileage accumulation forecasts, the rebound effect estimate and the fuel properties and emission factors discussed in Section IV.C.3 of the Preamble. Considering changes in travel demand and fuel consumption, the model estimates the monetized value of accompanying benefits to society, as discussed in Section IV.C.3 of the Preamble. 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. It can be used to fit a mathematical function forming the basis for an attribute-based CAFE standard, following the steps described below. It 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

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[81] 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.

[82] As for all of its other rulemakings, NHTSA is required by Executive Order 12866 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 February 21, 2010).

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.

2. Has NHTSA Considered Other Models?

Nothing in EPCA requires NHTSA to use the Volpe model. In principle, NHTSA could perform all of these tasks through other means. For example, in developing today's final standards, the agency did not use the Volpe model's curve fitting routines; rather, as discussed in Section II of the Preamble, the agency fitted curves outside the model (as for the NPRM) but elected to retain the curve shapes defining the proposed standards. In general, though, these model 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.

During its previous rulemaking, which led to the final MY 2011 standards promulgated earlier this year, NHTSA received comments from the Alliance and CARB encouraging NHTSA to examine the usefulness of other models. As discussed in that final rule, NHTSA, having undertaken such consideration, concluded that the Volpe model is a sound and reliable tool for the development and evaluation of potential CAFE standards.[83] Also, although some observers have criticized analyses the agency has conducted using the Volpe model, those criticisms have largely concerned inputs to the model (such as fuel prices and the estimated economic cost of CO_2 emissions), not the model itself. In comments on the NPRM preceding today's final rule, one of these observers, the Center for Biological Diversity (CBD), suggested that the revisions to such inputs have produced an unbiased cost-benefit analysis.[84]

One commenter, the International Council on Clean Transportation (ICCT) suggested that the Volpe model is excessively complex and insufficiently transparent. However, in NHTSA's view, the complexity of the Volpe model has evolved in response to the complex analytical demands surrounding very significant regulations impacting a large and important sector of the economy, and ICCT's own comments illustrate some of the potential pitfalls of model simplification. Furthermore, ICCT's assertions regarding model transparency relate to the use of confidential business information, not to the Volpe model itself; as discussed below in Section V.B.5, NHTSA and the Volpe Center have taken pains to make the Volpe model transparent by releasing the model and supporting documentation, along with the underlying source code and accompanying model inputs and outputs. Therefore, the agency disagrees with these ICCT comments.

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[83] 74 FR 14372 (Mar. 30, 2009).

[84] CBD, p. 2. (Docket NHTSA-2009-0050-0053.1)

In reconsidering and reaffirming this conclusion for purposes of this rule, NHTSA notes that the Volpe model not only has been formally peer-reviewed and tested 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.[85] 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.[86] 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. The first (2002) version of DOT's model treated each model year separately, and did not perform this type of explicit accounting. Manufacturers took strong exception to these shortcomings. For example, GM commented in 2002 that "although the table suggests that the proposed standard for MY 2007, considered in isolation, promises benefits exceeding costs, that anomalous outcome is merely an artifact of the peculiar Volpe methodology, which treats each year independently of any other…" In 2002, GM also criticized DOT's analysis for, in some cases, adding a technology in MY 2006 and then replacing it with another technology in MY 2007. GM (and other manufacturers) argued that this completely failed to represent true manufacturer product-development cycles, and therefore could not be technologically feasible or economically practicable.

In response to these concerns, and related concerns expressed by other manufacturers, 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. This was accomplished by limiting the application of many technologies to model years in which vehicle models are scheduled to be redesigned (or, for some technologies, "freshened"), and by causing the model to "carry forward" applied technologies from one model year to the next.

During the recent rulemaking for MY 2011 passenger cars and light trucks, DOT further modified the CAFE model to account for cost reductions attributable to "learning effects" related to volume (*i.e.*, economies of scale) and the passage of time (*i.e.*, time-based learning), both of which evolve on year-by-year basis. These changes were implemented in response to comments by environmental groups and other stakeholders.

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[85] 49 U.S.C. 32902(a).

[86] For example, the CAFE model "carries forward" technologies applied in earlier model years and, when evaluating standards in later model years, evaluates the potential to add "extra" technology in earlier model years if doing so will sufficiently facilitate compliance in later model years. However, because EPCA does not allow NHTSA to consider manufacturers' potential use of CAFE credits, NHTSA's analysis does not attempt to account for manufacturers' ability to earn credits in one year and apply them toward compliance in a different model year, even though this is an important flexibility actually allowed by EPCA.

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. Some commenters have previously suggested that manufacturers are most likely to broadly apply generic technology "packages," and the Volpe model does tend to form "packages" dynamically, based on vehicle characteristics, redesign schedules, and schedules for increases in CAFE standards. For example, under the final CAFE standards for passenger cars, the CAFE model estimated that manufacturers could apply turbocharged SGDI engines mated with dual-clutch AMTs to 2.4 million passenger cars in MY 2016, about 22 percent of the MY 2016 passenger car fleet. Recent modifications to the model, discussed below, to represent multi-year planning, increase the model's tendency to add relatively cost-effective technologies when vehicles are estimated to be redesigned, and thereby increase the model's tendency to form such packages.

On the other hand, some manufacturers have indicated that especially when faced with significant progressive increases in the stringency of new CAFE standards, they are likely to also look for narrower opportunities to apply specific technologies. By progressively applying specific technologies to specific vehicle models, the CAFE model also produces such outcomes. For example, under the final CAFE standards for passenger cars, the CAFE model estimated that in MY 2012, some manufacturers could find it advantageous to apply SIDI to some vehicle models without also adding turbochargers.

By following this approach of 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. For example, the model does not apply dual-clutch AMTs (or strong hybrid systems) to vehicle models with 6-speed manual transmissions. Some vehicle buyers prefer a manual transmission; this preference cannot be assumed away. The model's accounting for manual transmissions is also important for vehicles with larger engines: for example, cylinder deactivation cannot be applied to vehicles with manual transmissions, because there is no reliable means of predicting when the driver will change gears. By retaining cylinder deactivation as a specific technology rather than part of a pre-determined package and by retaining differentiation between vehicles with different transmissions, DOT's model is able to target cylinder deactivation only to vehicle models for which it is technologically feasible.

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.

3. What Changes Has DOT Made to the Model?

As discussed in the NPRM preceding today's final rule, the Volpe model has been revised since the 2011 CAFE rule to make some minor improvements, and to add one significant new capability: the ability to simulate manufacturers' ability to engage in "multi-year planning." Multi-year planning refers to the fact that when redesigning or freshening vehicles, manufacturers can anticipate future fuel economy or CO_2 standards, and add technologies accounting for these standards. For example, a manufacturer might choose to over-comply in a given model year when many vehicle models are scheduled for redesign, in order to facilitate compliance in a later model year when standards will be more stringent yet few vehicle models are scheduled for redesign.[87] Prior comments have indicated that the Volpe model, by not representing such manufacturer choices, tended to overestimate compliance costs. However, because of the technical complexity involved in representing these choices when, as in the Volpe model, each model year is accounted for separately and explicitly, the model could not be modified to add this capability prior to the statutory deadline for the MY 2011 final standards.

The model now includes this capability, and NHTSA has applied it in conducting analysis to support the NPRM and in analyzing the standards finalized today. Consequently, this new capability often produces results indicating that manufacturers could over-comply in some model years (with corresponding increases in costs and benefits in those model years) and thereby "carry forward" technology into later model years in order to reduce compliance costs in those later model years. NHTSA believes this better represents how manufacturers would actually respond to new CAFE standards, and thereby produces more realistic estimates of the costs and benefits of such standards.

The Volpe model has also been modified to accommodate inputs specifying the amount of CAFE credit to be applied to each manufacturer's fleet. Although the model is not currently capable of estimating manufacturers' decisions regarding the generation and use of CAFE credits, and EPCA does not allow NHTSA, in setting CAFE standards, to take into account manufacturers' potential use of credits, this additional capability in the Volpe model provides 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 some ability to examine outcomes more realistically than EPCA allows for purposes of setting new CAFE standards.

4. Does the Model Set the Standards?

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[87] Although a manufacturer may, in addition, generate CAFE credits in early model years for use in later model years (or, less likely, in later years for use in early years), EPCA does not allow NHTSA, when setting CAFE standards, to account for manufacturers' use of CAFE credits.

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. This is incorrect. 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. Although the model has been programmed in previous rulemakings to estimate at what stringency net benefits are maximized, it was not the model's decision to seek that level of stringency, it was the agency's, as it is always the agency's decision what level of CAFE stringency is appropriate. 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.

NHTSA considers the results of analyses conducted by the Volpe model and analyses conducted outside of the Volpe model, including analysis of the impacts of carbon dioxide and criteria pollutant emissions, analysis of technologies that may be available in the long term and whether NHTSA could expedite their entry into the market through these standards, and analysis of the extent to which changes in vehicle prices and fuel economy might affect vehicle production and sales. Using all of this information—not solely that from the Volpe model—the agency considers the governing statutory factors, along with environmental issues and other relevant societal issues such as safety, and promulgates the standards based on its best judgment on how to balance these factors.

This is why the agency considered eight regulatory alternatives, only one of which reflects the agency's final standards, based on the agency's determinations and assumptions. Others assess alternative standards, some of which exceed the final standards and/or the point at which net benefits are maximized.[88] These comprehensive analyses, which also included scenarios with different economic input assumptions as presented in the FEIS and FRIA, are intended to inform and contribute to the agency's consideration of the "need of the United States to conserve energy," as well as the other statutory factors. 49 U.S.C. 32902(f). Additionally, the agency's analysis considers the need of the nation to conserve energy by accounting for economic externalities of petroleum consumption and monetizing the economic costs of incremental CO_2 emissions in the social cost of carbon. NHTSA uses information from the model when considering what standards to propose and finalize, but the model does not determine the standards.

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[88] *See* Section IV.F of the Preamble for a detailed discussion of the alternatives.

5. How Does NHTSA Make the Model Available and Transparent?

Model documentation, which is publicly available in the rulemaking docket and on NHTSA's web site, explains how the model is installed, how the model inputs (all of which are available to the public)[89] 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 final 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.

NHTSA is aware of two attempts by commenters to install and use the Volpe model in connection with the NPRM. James Adcock, an individual reviewer, reported difficulties installing the model on a computer with Microsoft® Office 2003 installed. Also, students from the University of California at Santa Barbara, though successful in installing and running the model, reported being unable to reproduce NHTSA's results underlying the development of the shapes of the passenger car and light truck curves.

Regarding the difficulties Mr. Adcock reported encountering, NHTSA staff is aware of no attempts to contact the agency for assistance locating supporting material related to the MYs 2012-2016 CAFE rulemaking. Further, the model documentation provides specific minimum hardware requirements and also indicates operating environment requirements, both of which have remained materially unchanged for more than a year. Volpe Center staff members routinely install and run the model successfully on new laptops, desktops, and servers as part of normal equipment refreshes and interagency support activities. We believe, therefore, that if the minimum hardware and operating environment requirements are met, installing and running the model should be straightforward and successful. The model documentation notes that some of the development and operating environment used by the Volpe model (*e.g.*, the software environment rather than the hardware on which that software environment operates), particularly the version of Microsoft® Excel used by the model, is Microsoft® Office 2003. We recognize that some users may have more recent versions of Microsoft® Office. However, as in the case of other large organizations, software licensing decisions, including the version of Microsoft® Office, is centralized in the Office of the Chief Information Officer. Nonetheless, the Volpe Model is proven on both Microsoft® Office version 2003 and the newer 2007 version.

As discussed in Section II.C of the Preamble to today's final rule, considering comments by the UC Santa Barbara students regarding difficulties reproducing NHTSA's analysis, NHTSA reexamined its analysis, and discovered some erroneous entries in model inputs underlying the analysis used to develop the curves proposed in the NPRM. These errors are discussed in the FRIA and have since been corrected. Updated inputs and outputs

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[89] 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.

have been posted to NHTSA's web site, and should enable outside replication of the analysis documented in today's notice.

6. Estimating Market Effects Induced by New CAFE Standards

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 mix of vehicles in the new vehicle fleet. NHTSA agrees that a "market shift" model, also called a consumer vehicle choice model, could provide useful information regarding the possible effects of potential new CAFE standards. An earlier experimental version of the Volpe model included a multinomial logit model that estimated changes in sales resulting from CAFE-induced increases in new vehicle fuel economy and prices. A fuller description of this attempt can be found below. However, NHTSA has thus far been unable to develop credible coefficients specifying such a model. In addition, as discussed in Section II.H.4 of the Preamble, such a model is sensitive to the coefficients used in it, and there is great variation over some key values of these coefficients in published studies.

In the NPRM preceding today's final rule, NHTSA sought comment on ways to improve on this earlier work and develop this capability effectively. Some comments implied that the agency should continue work to do so, without providing specific recommendations. The Alliance of Automobile Manufacturers identified consumer choice as one of several factors outside the industry's control yet influential with respect to the agencies' analysis. Also, the University of Pennsylvania Environmental Law Project suggested that the rule would change consumers' vehicle purchasing decisions, and the California Air Resources Board expressed support for continued consideration of consumer choice modeling. On the other hand, citing concerns regarding model calibration, handling of advanced technologies, and applicability to the future light vehicle market, ACEEE, ICCT, UCS, and NRDC all expressed opposition to the possibility of using consumer choice models in estimating the costs and benefits of new standards.

Notwithstanding comments on this issue, NHTSA has been unable to further develop this capability in time to include it in the analysis supporting decisions regarding final CAFE standards. The agency will, however, continue efforts to develop and make use of this capability in future rulemakings, taking into account comments received in connection with today's final rule. An earlier experimental version of the Volpe model included a multinomial logit model that estimated changes in sales resulting from CAFE-induced increases in new vehicle fuel economy and prices, as well as an accompanying cost allocation algorithm to estimate how manufacturers might allocate compliance costs. However, the agency has thus far been unable to develop credible coefficients specifying such a model. The agency intends to continue seeking to develop such methods, and documents its prior attempts here in the interest of providing an overview of how they might be formulated and applied. The following description applies to an earlier experimental version of the Volpe model, not to the current version of the model. The latter does not have the capabilities discussed below.

a. Cost Allocation Assumptions

At the compliance simulation's conclusion, each represented vehicle model has some incurred technology cost (potentially zero), and each represented manufacturer has some zero or positive incurred CAFE fines (*i.e.*, civil penalties). We consider several cost allocation assumptions to distribute these compliance costs across each manufacturer's product line, following one of the following four strategies as specified as a user input for each manufacturer:

> <u>As-Incurred</u>: Based on the total technology costs incurred by each vehicle.
>
> <u>Price-Based</u>: Based on the initial price (MSRP) of each vehicle.
>
> <u>Elasticity-Based</u>: Based on the inverse of each vehicle's price elasticity of demand.
>
> <u>Uniform</u>: Based on uniform allocation across all vehicles.

A review of relevant literature did not reveal published studies that focus specifically on the relationship between CAFE compliance costs and vehicle prices. However, this review did reveal studies that generically address automotive price elasticities of demand and their influence on pricing decisions, as well as production costs and pricing strategies for some categories of automotive powertrain components. Interviews with selected industry experts suggest that manufacturers may shift compliance costs between vehicle models in order to maintain or improve competitiveness in profitable market segments. Specific information regarding the pricing strategies followed by individual manufacturers is unavailable. The pricing strategies provided by the cost allocation assumption portion of the model are intended to realistically bracket the potential range of strategies.

At the conclusion of the cost allocation assumption part of the system, each vehicle model is assigned a regulatory cost, which is reported as a price increase and used when applying the market share model discussed below.

b. Market Share Model

To provide the capability to analyze the market response to changes in vehicle prices and other attributes resulting from manufacturers' efforts to comply with CAFE regulation, we developed a statistical model to analyze the factors influencing new car buyers' choices among vehicle models. Our model focuses on buyers' decisions to choose specific vehicle types individual models, but does not analyze the factors influencing their choices to purchase a new vehicle during a specific model year.

i. Market Share Model Structure

The model uses a nested logit model to represent buyers' decisions about the type of vehicle to purchase and their choices among competing models of that type. As Figure V-8 illustrates, buyers are assumed to make decisions using a two-step process. First, a consumer chooses a type of vehicle, for example, a mid-size premium automobile, a small pickup truck, or a large sport-utility vehicle.[90] Conditioned on that decision, a buyer then selects an individual vehicle model from among those making up the chosen "market segment".

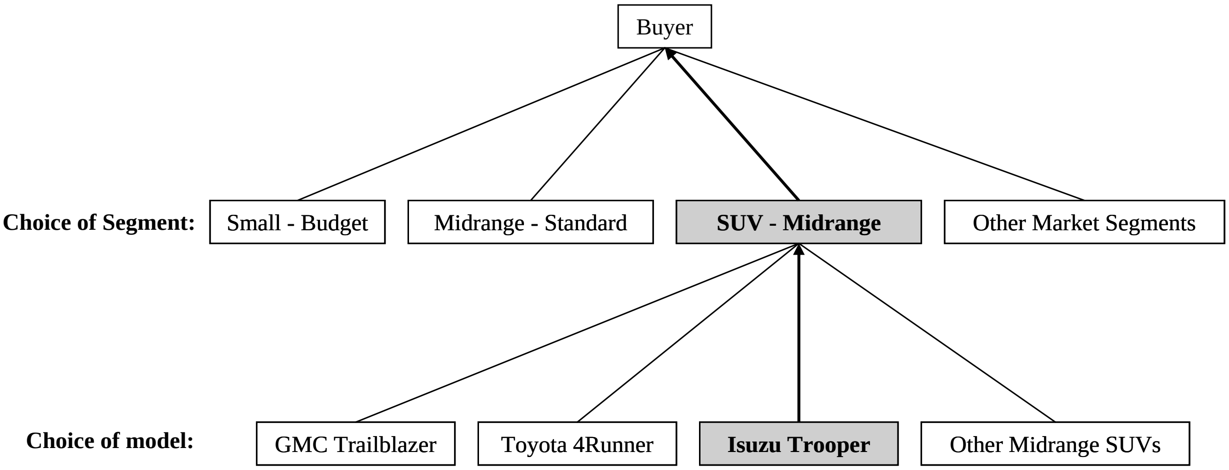

Figure V-8. Nested Logit Model

This model relies on several underlying assumptions; most important, that buyers derive utility from the attributes offered by different vehicle models, including characteristics such as its passenger- and cargo-carrying capacity, driving performance, fuel economy, comfort level, transmission and drive type (two- versus four-wheel drive). Individual buyers are assumed to choose the specific vehicle model whose purchase price and combination of attributes offers the maximum level of utility. Many of the attributes or characteristics that make individual vehicle models attractive to potential buyers have been well documented, and some of these can be readily measured and compared.

However, other characteristics that lead buyers to view particular models as closely competitive may be difficult to quantify, or may simply be unknown. The presence of these unobserved attributes means that vehicles are likely to form groups or market segments, and that models within each segment compete more closely with one another than with models belonging to other market segments. Our model uses the common assumption in automotive marketing that market segments consist of vehicle models of similar body type or style, overall size, luxury level, and performance.

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[90] Our model employs the market segmentation presented in *2002 Automotive News Car Market Classifications*, (Docket NHTSA-2009-0059-0159).

ii. Factors Affecting Vehicle Buyer's Behavior

Using the subscript *s* to designate market segments, *k* to designate individual vehicle models, and *n* to designate buyers, the probability that a representative buyer will choose a vehicle of type and luxury or performance level *s* is simply

$$P_n \;\; s \qquad (0.1)$$

In turn, the probability that buyer *n* will choose to purchase a specific brand and model *k* from within market segment, or $P_n(sk)$, is

$$P_n \;\; sk \;\; = P_n \;\; k|s \;\; P_n \;\; s \qquad (0.2)$$

Here, $P_n(k|s)$ represents the conditional probability that the representative buyer will select model *k*, having already decided to purchase a vehicle of the body type and luxury or performance level represented by segment *s*.

In choosing a market segment and a specific vehicle model, the probability that a buyer will choose a specific alternative depends on how the utility or benefits it provides compare to those supplied by the competing choices. Since buyers are assumed to choose the alternative that offers the maximum utility, the likelihood that any specific alternative will be chosen depends on the probability that it offers the maximum utility level among the choices available.

For example, the probability that a buyer will select a specific vehicle model from a given market segment depends on how the utility its attributes offer compares to the utility levels offered by other vehicle models within that same market segment. Similarly, a buyer's choice of the vehicle type, size, luxury, and performance level to shop for depends on how the composite utility of the various models making up that market segment compares to the composite utility offered by the vehicles included in the other market segments.

The observable or measurable component of utility offered by each vehicle model depends on the particular features or attributes it provides, such as its driving performance, fuel economy, and seating or luggage-carrying capacity, as well as on its purchase price.[91] The unobserved component of utility that each model offers arises partly from uncertainty about which observable attributes are important to buyers, as well as about the relationship between a vehicle's combination of attributes and the utility it offers to prospective buyers. Other sources of unobserved utility include errors in measuring or describing these attributes, and the potential existence of attributes that, though valued by buyers, are unknown or difficult to measure.

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[91] It may also be affected by characteristics of the buyers who choose the market segment containing that model, since certain characteristics of buyers may affect their preferences for or valuation of specific vehicle attributes.

http://www.epa.gov/QUALITY/informationguidelines/
By making a specific assumption about the probability distribution of these unobserved components of utility, the probability that a representative buyer will select a specific vehicle model can be expressed as a function of the utility it's measured attributes supply and of how it compares to the utility levels offered by competing models.[92] One common assumption is that the unobserved components of utility follow a specific probability distribution in which large values are rare (a Type I extreme value distribution, which somewhat resembles a normal distribution), and are thus unlikely to be sufficiently large to offset any difference in observed utilities between the preferred model and other competing choices.

Under this assumption, the probability that a representative buyer will purchase a vehicle model (*k*) from among those within a market segment (*s*) is an exponential function of its utility as well as those offered by the other models in that market segment:

$$P_n \quad k|s \quad = \frac{e^{U_{sk}}}{\sum_{k' \in s} e^{U_{sk'}}} \quad (0.3)$$

where U_{sk} represents the level of utility provided by the attributes of vehicle model *k*. In turn, the probability that a representative buyer will decide to purchase a vehicle from market segment *s* can be expressed as

$$P_n \quad s \quad = \frac{e^{\mu^{s} U_{s}}}{\sum_{s' \in s} e^{\mu^{s} U_{s'}}} \quad (0.4)$$

where

$$U_s = \log \; \sum_{k' \in s} e^{U_{sk'}} \quad (0.5)$$

The term $\sum_{k' \in s} e^{U_{sk'}}$, often referred to as the *expected maximum utility* provided by the choices available in market segment s, is a measure of the composite utility – *i.e.*, the overall attractiveness to potential buyers – offered by all of the vehicle models making up that market segment. Thus, Equation (0.4) states that the probability a buyer will purchase a vehicle from market segment *s* – say a small economy car – depends on how the composite utility (or combined attractiveness) of the models making up that category compares to the composite utility measures for each of the other market segments (sports

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[92] The specific probability distribution assumed for the unobserved utility components determines the form of the expression for the probability that an individual model will be chosen, because it determines the probability that a vehicle model offering the maximum observed or measured level of utility to a buyer would still represent that buyer's utility-maximizing choice if the unobserved component of utility were also reflected in the decision.

cars, large automobiles, midsize sport-utility vehicles, etc.), the sum of which appears in the denominator.

Equation (0.4) also shows that the expected maximum utility of each market segment is scaled by the parameter μ^s, which measures the variance in the unobserved component of utility shared by models in the same market segment relative to that of the remaining unobserved component of utility, which differs for each vehicle model. This parameter (sometimes referred to as the nesting coefficient) has the convenient property that the value of $[1 - (\mu^s)^2]$ measures how similarly buyers view the various vehicle models included within each market segment, thus indicating how closely the market segmentation used in the model matches shoppers' views of model groupings or segmentation in the new vehicle market.[93]

Our model assumes that the utility offered by an individual vehicle model is a linear function of the levels of various attributes that it offers, including its driving performance, seating capacity, fuel economy, transmission and drive type, and its purchase price. Denoting these attributes X_1, X_2, ..., X_n, vehicle model k within market segment s provides a utility level

$$U_{sk} = \beta_1 X_{1k} + \beta_2 X_{2k} + \ldots + \beta_n X_{nk} + \varepsilon_s + \varepsilon_{sk} \quad (0.6)$$

where, for example, X_{1k} denotes the level of attribute 1 – say, the ratio of horsepower to weight, a widely used index of driving performance – provided by vehicle model k.[94]

The relative importance or weight that buyers attach to each vehicle attribute is summarized by the value of its coefficient ($\beta_1, \beta_2, \ldots \beta_n$), while the terms ε_s and ε_{sk} respectively represent the unobserved components of utility shared by all vehicles in market segment s and unique to vehicle model k. As discussed previously, it is the presence of the term ε_s, which represents the unobserved component of utility that is shared by all vehicle models in market segments, that implies the hierarchical structure of buyers' decisions.

iii. Statistical Estimation of Model Parameters

Parameters specified in an input file define this model based on any of several candidate attributes. These parameters can be estimated statistically by using the market shares of total sales accounted for by each individual vehicle model during a recent model year to

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[93] Specifically, $[1 - (\mu^s)^2]$ measures the correlation between the utility levels offered by any two vehicle models that are included in the same market segment. The value of μ^s is theoretically restricted to the range from 0 to 1; values close to 0 indicate that the utilities offered by models in the same market segment are closely correlated, and thus that the market segmentation used in the model accurately reflects buyers' views about how closely different vehicle types and models compete with one another. In contrast, values closer to 1 indicate that the utilities of models in the same segment are not closely correlated, and thus that the market segmentation may be inaccurate.

[94] Thus in this model, the parameter μ^s in Equation (0.4) measures the variance in ε_s relative to the variance in ε_{sk}.

approximate the probabilities that a “typical” vehicle buyer would choose each model. We estimated the model’s parameters, including the coefficients (β_1, β_2, …β_n) in Equation (0.6) and the nesting parameter μ^s, using market share and attribute data for the approximately 1,300 automobile and light truck models that were produced and sold during model year 2002. Total automobile and light truck sales during that model year were about 17 million vehicles.

We assembled data on suggested retail and actual sales prices, horsepower, vehicle weight, seating capacity, fuel economy, fuel tank capacity, transmission and drive type, continent of origin, and brand name for each vehicle model produced and sold during model year 2002. These attributes were used to define additional vehicle characteristics such as the ratio of horsepower to vehicle weight and refueling range, and the resulting set of attributes was used to test a variety of different specifications for Equation (0.6).

iv. Using the Market Share Model

With a sufficiently large number of new vehicle sales, the model’s predicted probabilities that a representative buyer will choose each vehicle model can be interpreted as the share or fraction of total sales it is likely to account for. Thus the model can be used to estimate how the market shares of individual vehicle models would have differed during that period if one or more attributes of a specific model had been different. If data describing the attributes and prices of vehicles that manufacturers will offer for sale during future model years are available, this model can also be used to simulate how sales or market shares in future years would change in response to changes in attributes or prices for some models.

The change in the probability that an individual vehicle model *k* would have been chosen by a representative buyer – or in the aggregate, its market share of total new vehicle sales – in response to a change in one of its attributes $X_{i,k}$ is:

$$\frac{\partial P_n \;\; sk}{\partial X_{i,k}} = \frac{\partial P_n \;\; k|s}{\partial X_{i,k}} + \frac{\partial P_n \;\; s}{\partial X_{i,k}}$$

$$= \beta_i P_n \;\; k|s \; \left[1 - P_n \;\; k|s \;\right] P_n \;\; s \; + \mu^s \beta_i P_n \;\; k|s \;^2 \, P_n \;\; s \; \left[1 - P_n \;\; s \;\right] P_n \;\; s$$

(0.7)

Normalizing Equation (0.7) to measure the proportional (rather than absolute) change in a vehicle’s market share in response to a proportional change in one of its attributes gives the elasticity of its market share:

$$\frac{\partial P_n \;\; sk}{\partial X_{i,k}} \left[\frac{X_{i,k}}{P_n \;\; sk} \right] = \beta_i X_{i,k} \left[1 - P_n \;\; k|s \;\right] + \mu^s \beta_i X_{i,k} P_n \;\; k|s \; \left[1 - P_n \;\; s \;\right] \qquad (0.8)$$

The computed values of these elasticities, which depend on the estimated parameters (the β_is), the values of the attributes that change (the $X_{i,k}$s), and the initial market shares of individual vehicles (the values of P_{sk}), can be used in two ways. First, the elasticities of vehicle models' market shares with respect to their own selling prices can be used to implement the cost-sharing calculation that apportions a manufacturer's technology costs for improving the fuel economy of its fleet in inverse proportion to the price elasticity of demand for each of its models. Second, they can be used to estimate the resulting changes in market shares for individual models that results when these technology costs are "spread" among a manufacturer's fleet using this or any other cost allocation assumption.

However, certain attributes of at least some vehicle models – notably fuel economy, and possibly weight and performance – will also change as part of manufacturers' efforts to comply with stricter fuel economy standards. When prices and other attributes of a number of vehicle models change simultaneously, it is often simpler to estimate the new market shares that will result by inserting the changed prices and attribute values in the utility expression for these models and recalculate the new market shares of all models directly.

These new market shares can then be used to recalculate how each manufacturer's sales-weighted CAFE level would have changed once the technology costs for improving some of its models' fuel economy were reflected in vehicle prices. This revised CAFE level can then be used to assess each manufacturer's compliance with the revised standard, and thus its need to apply additional fuel economy technology to its vehicle models.

v. NML (Market Share) Model Specification

The system uses a 2-level nested multinomial logit (NML) model to recalculate market shares and sales volumes of different vehicle models after compliance costs have been estimated and allocated. Table V-1 lists the attributes accommodated by the system, and shows the inclusive value parameter the coefficients used in Equation (0.6) for a sample model using price and four other attributes. Other NML formulations may be specified, subject to the following constraints:

- The inclusive value parameter must be between 0 and 1.
- Coefficients must apply to attributes measured in the indicated units.
- The number of market segments must correspond to the vehicles input file.

Table V-1. Market Share Model Coefficients (Sample)

Inclusive Value Parameter	0.579638

Attribute	**Units**	**Coefficient**
Effective Price	**dollars (2003)**	-0.000061
Fuel Economy	**mpg**	
Seating Capacity (Max.)	**number of seat belts**	0.175729
Curb Weight	**pounds**	
4 Wheel Drive	**1=present**	0.075382
Automatic Transmission	**1=present**	
Power	**horsepower**	
Power/Weight	**horsepower/pound**	10.046800
Range	**miles**	
Weight-Specific Fuel Economy	**pound-miles per gallon**	

When developing an input file defining the initial state of the MY2002 fleet based on the structure shown in Table V-1 we estimated the annual sales volumes for the 1,355 individual vehicle models produced during model year 2002 using production data reported to NHTSA by manufacturers for the purpose of determining their CAFE compliance, supplemented with confidential and commercial data regarding vehicles with curb weights over 8,500 pounds.

As discussed above, we developed the vehicle attribute, price, and other data used to estimate the market share model using several sources. We initially obtained some vehicle attribute data through information requests to the automotive manufacturers, but because of inconsistent reporting the resulting data file was missing some or all attribute data for certain vehicle models. Wherever possible, we filled these gaps by collecting supplemental information from online sources of vehicle characteristics and related data such as Edmunds.com. As part of this process, we also obtained the Manufacturer's Suggested Retail Price (MSRP) for each vehicle model produced during model year 2002.

Because actual purchase prices for most vehicle models typically differ significantly from their suggested retail process, we adjusted each vehicle model's MSRP for model year 2002 by the ratio of its nationwide average "True Market Value" (TMV) during model year 2004, as estimated by Edmunds.com, to its MSRP during model year 2004.[95] This adjustment provided an estimate of its nationwide average actual selling price during model year 2002. For vehicle models produced in model year 2002 but no longer offered for sale during model year 2004, we used the ratio of Edmunds' estimated TMV to MSRP for the vehicle model in the same market segment we judged to be most similar (and where possible, produced by the same manufacturer).

To calculate an "effective price" that takes into account fuel costs, we combined this with the estimated value to the consumer of fuel outlays during a specific payback period. We

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[95] Edmunds' estimates of vehicles True Market Values for model year 2002 were no longer available at the time we developed the market share model.

calculated this value using the same methodology used in the compliance simulation model. The model-specific form applied here is as follows:

$$VALUE_{FUEL} = \sum_{v=0}^{v=PB} \frac{SURV_v MI_v FUELPRICE_{MY+v}}{FE(1-gap)\,(1+r)^{v+0.5}} \qquad (0.9)$$

where MI_v is the number of miles driven during the year when a vehicle produced in model year MY reaches age v, $SURV_v$ is the probability that a vehicle of that vintage (model year) will remain in service through age v, FE is the vehicle's fuel economy, $FUELPRICE_{MY+v}$ is the price of fuel in year $MY+v$, and PB is a "payback period", or number of years in the future the consumer is assumed to take into account when considering fuel savings. Payback periods of three and five years produced similar results.

Table V-2 lists the vehicle attributes for which we were able to obtain complete data using the combination of sources discussed above. We used the estimated market shares and attribute data for individual vehicle models to develop a two-level nested logit model of each vehicle model's market share. In this model, buyers first choose one of the 23 market segments developed by Automotive News to represent the new vehicle market, each of which represents one combination of vehicle type (automobile versus light truck), style (*e.g.*, sedan, pickup, or utility vehicle), size (small, mid-size, or large), and luxury level (standard, "upscale," etc.). Table V-2 gives examples of vehicles that fall into each of these segments.[96] Buyers then choose to purchase one of the specific vehicle models within that market segment.

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[96] When using forward-looking product plans, it will be necessary to assign each new vehicle model to one of these market segments.

Table V-2. NML Market Segments and Example Vehicles

Segment	Name	Examples
1	Small - Budget	Hyundai Accent, Toyota Echo
2	Small - Economy	Dodge Neon, Saturn S Series, Toyota Corolla
3	Sporty - Touring	Mazda Miata, Toyota MR2 Spyder, Mini Cooper
4	Sporty - Premium	Audi TT Coupe, Porsche (all), BMW Z3
5	Sporty - Exotic	Ferrari (all), Lotus Esprit, Dodge Viper
6	Mid-Range - Lower	Chevrolet Malibu, Honda Civic, VW Golf
7	Mid-Range - Standard	Buick Century, Toyota Camry, Honda Accord
8	Mid-Range - Premium	Audi A4, Nissan Maxima, Saab 9-3
9	Traditional	Buick LeSabre, Ford Crown Victoria, Toyota Avalon
10	Upscale - Near Luxury	Acura TL, BMW 3-Series, Volvo 70 Series, Chrysler 300M
11	Upscale - Luxury	Acura RL, BMW 5-Series, Jaguar XJ, Mercedes-Benz E Class
12	Upscale - Premium	Bentley (all), Mercedes-Benz CL600, Rolls-Royce
13	Pickups - Small	Chevrolet S, Dodge Dakota, Mazda B-Series
14	Pickups - Full-Sized	Dodge Ram, Ford F-Series, Toyota Tundra
15	Vans - Mini	Honda Odyssey, Toyota Sienna, Dodge Caravan
16	Vans - Full-Sized	Chevrolet Express, Dodge Ram Van, Ford Econoline
17	SUV - Standard Sport Wagon	Honda CRV, Ford Escape, Toyota Highlander
18	SUV - Premium Sport Wagon	Acura MDX, BMW X5, Mercedes-Benz M-Class
19	SUV - Small	Chevrolet Tracker, Jeep Liberty, Nissan Xterra
20	SUV - Mid-Range	Chevrolet Trailblazer, Dodge Durango, Honda Passport
21	SUV - Large	Chevrolet Suburban, Ford Expedition, Toyota Sequoia
22	SUV - Premium	Cadillac Escalade, Land Rover Range Rover, Mercedes-Benz G Class, Lincoln Navigator
23	SUV - Sport-utility pickups	Chevrolet Avalanche, Lincoln Blackwood, Cadillac Escalade EXT
24	Hybrid	Toyota Prius, Honda Insight

We used the Gauss Mathematical and Statistical System produced by APTECH Systems, Inc., to estimate the parameters of the nested logit model of vehicle market shares described previously in the report. This system uses a conventional maximum-likelihood procedure to estimate the parameter values for the utility function and the associated inclusive value parameter. As indicated as previously in the text, the value of this parameter provides some indication of how accurately the nesting structure used in the model (the Automotive News market segmentation) reflects buyers' views of the new vehicle market.

We experimented with a large number of alternative specifications of the utility function shown in Equation (0.6) for individual vehicle models, each using different combinations of the vehicle attributes shown in the table. We selected the combination of attributes to include in the final model on the basis of the reasonableness of the signs and relative magnitudes of their estimated coefficients, the model's ability to replicate actual market shares for individual models, and the estimated value of the nesting coefficient or inclusive value parameter.[97] Table V-3 indicates the subset of attributes that were included in final model, and reports the estimated values of their coefficients.

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[97] The wide variation in the orders of magnitude of the estimated coefficients for the different attributes reflects similarly wide variation in their measurement scales.

Table V-3. NML Model Attributes and Coefficients

Attribute	**Measure**	**Best Model Specification**	
		Coefficient	**t-statistic**
Equivalent Price	Est. sale price plus est. fuel value over 5 years	-0.0000556	-847
Performance	Ratio of horsepower to curb weight	9.605	285
Weight	Curb weight		
Seating Capacity	Number of adults seated	0.171	688
Towing Capacity	Maximum trailer weight		
Payload	Maximum cargo weight		
Luggage Space	Enclosed cargo volume		
Fuel Economy	EPA combined MPG rating		
Fuel Tank Size	Capacity in gallons		
Refueling Range	Fuel tank capacity * MPG		
Transmission Type	Automatic =1; manual = 0		
Drive Type	2—wheel drive = 0; 4-wheel drive =1	0.054	81
Continent of Origin	Asia, Europe, or North America		
Brand	Manufacturer identity		

c. Model Convergence

After the market share model has concluded, the sales volumes of different vehicle models will typically have changed relative to values used to determine compliance with CAFE standards. Because this can cause changes in CAFE levels, the revised sales volumes are used to repeat the compliance simulation, cost allocation, and market share models. This process is repeated until the model converges, as determined by the magnitude of changes in CAFE levels and market share specific to each manufacturer and regulatory class. The process, for which Figure V-9 provides an overview, terminates if such changes are all less than 1% or if the sequence has been repeated 10 times.[98,99]

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[98] This cycling currently leads to “overcompliance” in some cases, which we are attempting to minimize by developing code to selectively “remove” technologies between iterations.

[99] A limit of 10 iterations is imposed to guard against indefinite repetition. The system typically converges within 5-6 iterations to changes smaller than 1%.

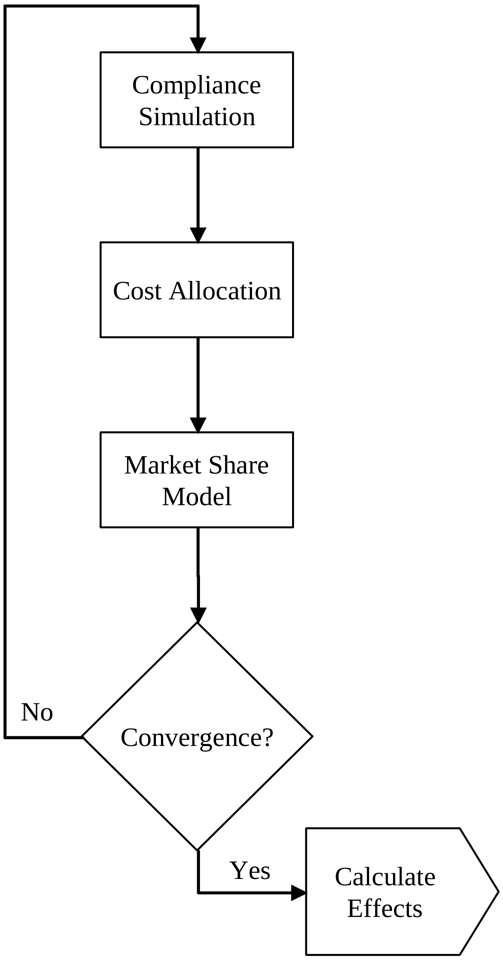

Figure V-9. Model Convergence Process

C. Technologies – Costs and Effectiveness

Technology assumptions, *i.e.*, assumptions about their availability, cost, effectiveness, and the rate at which they can be incorporated into new vehicles, are often very controversial as they have a significant impact on the levels of the standards. Agencies must, therefore, take great care in developing and justifying these assumptions. In developing technology inputs for MY 2012-2016 standards, NHTSA and EPA reviewed, as requested by President Obama in his January 26 memorandum, the technology assumptions that NHTSA used in setting the MY 2011 standards, the comments that NHTSA received in response to its May 2008 NPRM and the comments received in response to the NPRM for this rule. In addition, the agencies reviewed the technology input assumptions identified in EPA's July 2008 Advanced Notice of Proposed Rulemaking and 2008 Staff Technical Report[100] and supplemented the review with updated information from the FEV tear-down studies contracted by EPA, more current literature, new product plans and EPA certification testing data.

The following section details the availability, cost and effectiveness estimates completed for technologies deemed to be appropriate in the rulemaking timeframe. The estimates are drawn from an analysis conducted between NHTSA and EPA in 2009. The analysis was conducted by engineers from DOT and EPA and represents what the agencies believe to be the best available estimates for the MY 2012-2016 rulemaking timeframe.

A. NHTSA analyzes what technologies can be applied beyond those in the baseline vehicle fleet

One of the key statutory factors that NHTSA must consider in setting maximum feasible CAFE standards for each model year is the availability and feasibility of fuel saving technologies. The baseline vehicle fleet identifies the technologies already deployed for each vehicle model. The agency uses the baseline vehicle fleet data to ascertain the "baseline" capabilities and average fuel economy of each manufacturer. Given the agency's need to consider economic practicability in determining how quickly additional fuel saving technologies can be added to the baseline fleet, NHTSA researches and develops, based on the best available information and data, a list of technologies that the agencies believe will be ready for implementation during the model years covered by the rulemaking. This includes developing estimates of the costs and effectiveness of each technology and lead time needs. The resultant technology assumptions form an input into the Volpe model. The model simulates how manufacturers can comply with a given CAFE level by adding technologies beyond those included in the baseline vehicle fleet in a systematic, efficient and reproducible manner.

CBD commented that because many of the technologies considered in the NPRM are currently available, manufacturers should be able to attain mpg levels equivalent to the MY 2016 standards in MY 2009. In response, as discussed below, technology "availability" is not determined based simply on whether the technology exists, but

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[100] 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.

depends also on whether the technology has achieved a level of technical viability that makes it appropriate for widespread application. This depends in turn on component supplier constraints, capital investment and engineering constraints, and manufacturer product cycles, among other things. Moreover, even if a technology is available for application, it may not be available for every vehicle. Some technologies may have considerable fuel economy benefits, but present significant technical changes related to NVH and drivability issues when applied to some vehicles within the model years covered by this rule – for example, applying cylinder deactivation to 4-cylinder engine or on vehicles with manual transmissions. The agencies have provided for increases over time to reach the mpg level of the MY 2016 standards precisely because of these types of constraints, because they have a real effect on how quickly manufacturers can apply technology to vehicles in their fleets. The following sections describe NHTSA's fuel-saving technology assumptions and methodology for estimating them, and their applicability to MY 2012-2016 vehicles.

B How NHTSA decides which technologies to include

1. How NHTSA did this historically, and how for the MY 2011 Final Rule

In two of the agency's past CAFE rulemakings, which established light truck CAFE standards for MYs 2005-2007 and MYs 2008-2011, NHTSA relied on the 2002 National Academy of Sciences' report, "Effectiveness and Impact of Corporate Average Fuel Economy Standards"[101] ("the 2002 NAS Report") for estimating potential fuel economy effectiveness values and associated retail costs of applying combinations of technologies in 10 classes of production vehicles. The NAS study was commissioned by the agency, at the direction of Congress, in order to provide independent and peer reviewed estimates of cost and effectiveness numbers. The NAS list was determined by a panel of experts formed by the National Academy of Sciences, and was then peer-reviewed by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the Report Review Committee of the National Research.

In the 2008 NPRM, NHTSA explained that there has been substantial advancement in fuel-saving automotive technologies since the publication of the 2002 NAS Report. New technologies, *i.e.*, ones that were not assessed in the NAS report, have appeared in the market place or are expected to appear in the timeframe of the rulemaking. Also, new studies have been conducted and reports issued by several other organizations providing new or different information regarding the fuel economy technologies that will be available and their costs and effectiveness values. To aid the agency in assessing these developments, NHTSA contracted with the NAS to update the fuel economy section, Chapter 3, of the 2002 NAS Report. However, as NHTSA explained, the NAS update was not available in time for this rulemaking.

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[101] National Research Council, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Academy Press, Washington, DC (2002). *Available at* http://www.nap.edu/openbook.php?isbn=0309076013 (last accessed March 15, 2010).

Accordingly, NHTSA worked with EPA staff to update the technology assumptions, and used the results as a basis for its NPRM. EPA staff published a related report and submitted it to the NAS committee.[102]

For the MY 2011 final rule, NHTSA hired an international consulting firm, Ricardo, to aid the agency in analyzing the comments the agency received in response to its 2008 NPRM. Ricardo's role was as a technical advisor to NHTSA staff. In this capacity, Ricardo helped NHTSA undertake a comprehensive review of the NPRM technology assumptions and all comments received on those assumptions, based on both old and new public and confidential manufacturer information. Relying on the technical expertise of Ricardo and taking into consideration all the information available, NHTSA revised its estimates of the availability and applicability of many technologies. While NHTSA sought Ricardo's expertise and relied significantly on their assistance as a neutral expert in developing its technical assumptions, it retained responsibility for the final assumptions. The agency believed that the assumptions of availability and applicability for the MY 2011 final rule were more accurate than those used in the NPRM, and were the best available for purposes of that rulemaking.

C. What technology assumptions has NHTSA used for the final rule?

1. How do NHTSA's technology assumptions in the final rule differ from those used in the NPRM?

In developing this final rule, and in working in conjunction with the EPA, NHTSA has revised some of the inputs used by the Volpe model to assess the appropriate stringency for future CAFE standards. The following section discusses the more important changes and revisions, and also advises where more information can be found on these and other changes.

Baseline and Market Data File:

As described in detail above in Section III.b. of the Preamble, the agencies relied on CSM forecast data to assist us with establishing the baseline and the market data file. After the NPRM had been published, the agencies noticed that the standard CSM forecast included heavy duty class 2b and class 3 vehicles. These vehicles are unregulated by CAFE (e.g., Ford F-350). The forecast from CSM used in the NPRM was from the 2nd quarter of 2009. The agencies requested that CSM to make a custom 4th quarter forecast with these vehicles removed for the final rule making. The customized forecast from CSM has allowed the agencies to correct this error and we now believe the estimates included in the baseline fleet to be accurate for all classes of vehicles.

More information on the advantages and disadvantages of the current approach and the agencies' decision to follow it is available in Section II.B.3 of the Preamble, and Section

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[102] EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions, EPA 420-R-08-008, March 2008. (Docket NHTSA-2009-0059-0027)

I of the joint TSD describes in greater detail the process the agencies used in sourcing the data for the baseline fleet and developing it into a representation of a future fleet.

Revisions to Technologies and Their Estimates:

Specific to its modeling, NHTSA has revised two technologies used in the final rule analysis from those considered in the NPRM. These revisions were based on comments received in response to the NPRM and the identification of area to improve accuracy. In the NPRM, a diesel engine option (DSLT or DSLC) was not available for small vehicles because it did not appear to be a cost-effective option. However, based on comments received in response to the NPRM, the agency added a diesel engine option for small vehicles. Additionally, in the NPRM, the mass reduction/material substitution technology, MS1, assumed engine downsizing. However, for purposes of the final rule, engine downsizing is no longer assumed for MS1, thus slightly lowering the effectiveness estimate, to better reflect how manufacturers might implement small amounts of mass reduction/material substitution. These changes are discussed in greater detail below and Chapter 3 of the joint TSD.

Building on NHTSA's estimates developed for the MY 2011 CAFE final rule and EPA's Advanced Notice of Proposed Rulemaking, which relied on EPA's 2008 Staff Technical Report,[103] the agencies took a fresh look at technology cost and effectiveness values and incorporated FEV tear-down study results for purposes of this joint final rule under the National Program. Generally speaking, while NHTSA found that much of the cost information used in the MY 2011 final rule and EPA's 2008 Staff Report was consistent to a great extent, the agencies, in reconsidering information from many sources, revised the component costs of several major technologies including: turbocharging/downsizing, mild and strong hybrids, diesels, SGDI, and Valve Train Lift Technologies for purposes of the NPRM. In addition, based on FEV tear-down studies, the costs for turbocharging/downsizing, 6-, 7-, 8-speed automatic transmissions, and dual clutch transmissions were revised for this final rule.

Most effectiveness estimates used in both the MY 2011 final rule and the 2008 EPA Staff Report were determined to be accurate and were carried forward without significant change into this rulemaking. When NHTSA and EPA's estimates for effectiveness diverged slightly due to differences in how the agencies apply technologies to vehicles in their respective models, we report the ranges for the effectiveness values used in each model. For purposes of the final rule analysis, NHTSA made only a couple of changes to the effectiveness estimates. Specifically, in reviewing the NPRM effectiveness estimates for this final rule NHTSA discovered that the DCTAM effectiveness value for Subcompact and Compact subclasses was incorrect; the (lower) wet clutch effectiveness estimate had been used instead of the intended (higher) dry clutch estimate for these

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[103] 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-2009-0059-0027)

vehicle classes.[104] Thus, NHTSA corrected these effectiveness estimates. Additionally, as discussed above, the effectiveness estimate for MS1 was revised (lowered) to better represent the impact of reducing mass at a refresh. These revisions are discussed at length in the joint TSD and in this document below. NHTSA and EPA are confident that the thorough review which has been conducted has led to the best available conclusion regarding technology costs and effectiveness estimates for the current rulemaking and resulted in excellent consistency between the agencies' respective analyses for developing the CAFE and CO_2 standards.

2. How are technologies applied in the model?

As in the MY 2011 final rule and NPRM, 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.

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. 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 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 during the comment period 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 in the decision tree.

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[104] A dry clutch DCTAM is more efficient and cheaper than a wet clutch DCTAM because it doesn't require a wet clutch type hydraulic system, which is used to cool the clutches. However, due to this lack of cooling, a dry clutch DCTAM has a lower torque capacity. Dry clutch DCTAM's are ideal for smaller vehicles (i.e. Subcompact and Compact) with lower engine torque ratings.

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 this final rule 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 now 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.

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. In both the MY 2011 final rule and this final rule, as appropriate and feasible, previously-applied technologies are retained in combination with the new technology being applied, but this is not always the case. For instance, one exception to this would be the application of diesel technology, where the entire engine is assumed to be replaced, so gasoline engine technologies cannot carry over. This exception for 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 2011 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 final rule.[105] To help readers better understand the

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[105] 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 20 boxes

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 Electrification/Accessory decision tree sequentially applying the EPS, IACC, MHEV, BISG and CISG technologies to a subcompact vehicle using the cost and effectiveness estimates from its input sheet. As seen in Table V-4 below, the input sheet cost estimates have a lower and upper value which may be the same or a different value (*i.e.*, a single value or a range) as shown in columns two and three. The Volpe model first averages the values (column 4), and then sums the average values to calculate the net cost of applying each technology (column 5). Accordingly, the net cost to apply the MHEV technology for example would be ($106.00+ $128.00 + $288.00 = $522.00). Net costs are calculated in a similar manner for all the decision trees.

Table V-4 Sample Volpe Model Net Cost Calculation

Example Net Cost Calculation: Elect./Acc. Path, Subcompact Vehicle Subclass				
Tech. Abrev.	**Lower INCR Cost**	**Upper INCR Cost**	**Avg. INCR Cost**	**NET Cost**
EPS	$ 106.00	$ 106.00	$ 106.00	**$ 106.00**
IACC	$ 128.00	$ 128.00	$ 128.00	**$ 234.00**
MHEV	$ 288.00	$ 288.00	$ 288.00	**$ 522.00**
BISG	$ 286.00	$ 286.00	$ 286.00	**$ 808.00**
CISG	$ 2,791.00	$ 2,791.00	$ 2,791.00	***$ 3,599.00***

The same decision tree, technologies, and vehicle are used for the example demonstrating the model's net effectiveness calculation. Table V-5 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 EPS technology with incremental effectiveness of 1.5 percent (or 0.015 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 – 0.015) = 0.985,[106] or mathematically 0.985*X. To represent

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representing engine technologies, whereas the expanded engine decision tree requires a total of 45 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-2009-0059-0156. 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 information.

[106] 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.

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

As the IACC technology is applied, the vehicle's fuel consumption is already reduced to 0.985 of its original value. Therefore the reduction for an additional incremental 1.5 percent results in a new fuel consumption value of 0.9702, or a net 2.98 percent effectiveness, as shown in the table. Net effectiveness is calculated in a similar manner for the all decision trees. It should be noted that 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-5 Sample Volpe Model Net Effectiveness Calculation

Example Net Effectiveness Calculation: Elect./Acc. Path, Subcompact Vehicle Subclass				
Tech. Abrev.	**Avg. INCR Eff. %**	**Avg. INCR Eff. (decimal)**	**Multiplicative FC Reduction Current FC * (1-Avg INCR)**	**Net Effect. (1 - Red)**
EPS	1.50%	0.0150	1 * (1 - 0.015) = 0.985	1.50%
IACC	1.50%	0.0150	0.985 * (1 - 0.015) = 0.9702	2.98%
MHEV	2.50%	0.0250	0.9702 * (1 - 0.0250) = 0.9459	5.41%
BISG	5.00%	0.0500	0.99459* (1 - 0.0500) = 0.8986	10.14%
CISG	8.75%	0.0875	0.8986 * (1 - 0.0875) = 0.8200	18.00%

To improve the accuracy of accumulating net cost and effectiveness estimates, "path-dependent corrections" were employed in the MY 2011 final rule and are being utilized in this final rule. The prior NPRM analysis (2008) 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 correct this issue path-dependent correction tables were added to the input sheets. The model uses these tables 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.[107] Path-dependent corrections were used when applying cylinder deactivation (on the DOHC path), turbocharging and downsizing, diesel and strong hybrids. For the engine technologies listed in the preceding sentence, the fuel

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[107] The correction tables are used for path deviations within the same decision tree. However, there is one exception to this rule, specifically that the tables are used to keep the model from double-counting cost and effectiveness estimates when both the CBRST and MHEV are applied to the same vehicle. Both technologies try to accomplish the same goal of reducing fuel consumption, by limiting idle time, but through different means. If either of these technologies exists on a vehicle and the Volpe model applies the other, the correction tables are used to remove the cost and effectiveness estimates for CBRST, thus ensuring that double-counting does not occur.

consumption and cost estimates stated in following sections and the input sheets are for an SOHC engine. The correction tables discussed above are then used to adjust the estimates for the different paths (i.e. DOHC or OHV). Similarly, all strong hybrid fuel consumption and cost estimates stated in the following section and the input sheets are relative to a vehicle that is following the CVT path, discussed in the Electrification/Accessory Technology Decision Tree section below. For a vehicle that is following the 6-, 7- and 8-speed automatic transmission path into the strong hybrids, the correction tables are used to adjust the estimates from the CVT path.

3. Technology application decision trees

The following paragraphs explain, in greater detail, the decision tree logic and revisions to the decision trees from the MY 2011 final rule that have been incorporated for this final rule.

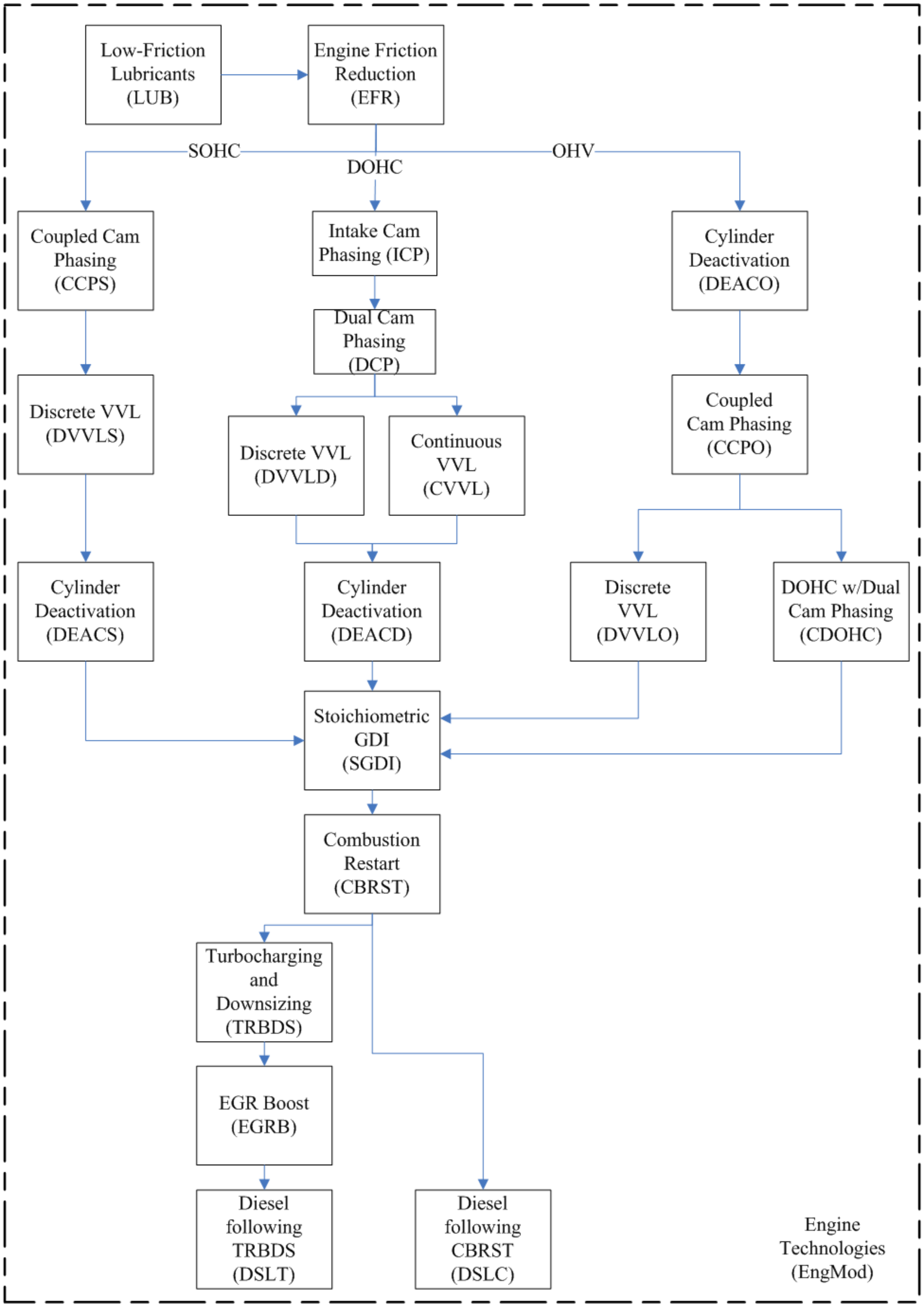
Engine Technology Decision Tree

For the NPRM and this final rule, NHTSA reviewed the engine decision tree and the model's technology application logic used in the MY 2011 final rule, and concluded that no revisions were necessary to the engine tree at this time. Figure V-10 below shows the decision tree for the engine technology category.

As in the MY 2011 final rule, NHTSA does not show Camless Valve Actuation (CVA), Lean-Burn GDI (LBDI), and Homogenous Charge Compression Ignition (HCCI) on the decision trees because these technologies were determined to be in the research phase of development; no new information to suggest these technologies are under development has been received at this time. As also discussed in the MY 2011 final rule, SOHC, DOHC and OHV engines 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. This approach also improves the accuracy of accounting for net cost and effectiveness compared to that used in the 2008 NPRM or prior rulemakings.

Also as in the MY 2011 final rule, the Turbocharging and Downsize technology (TRBDS) is considered to be a completely new engine that has been converted to DOHC (if not already a DOHC in the baseline vehicle) with LUB, EFR, DCP, SGDI and CBRST applied. Similarly, the conversion to Diesel (DSLC and DSLT) is considered to be a completely new engine that replaces the gasoline engine (although it carries over the LUB and EFR technologies). We note that the path-dependent variations of these three technologies (TRBDS, DSLC, and DSLT) all result in the same technology state for 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

FigureV-10. 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 MY 2011 final rule. Specifically, one of the 2011 technologies (HVIA) has been incorporated into a new mild hybrid technology (BISG), which allows the model to choose from a broader range of mild hybrid options before conversion to a strong hybrid, as shown in Figure V-11. Electric Power Steering (EPS) is the first technology in this decision tree, since it is a primary enabler for both mild and strong hybrids, and is followed by Improved Accessories (IACC), as in the MY 2011 final rule. Micro-Hybrid (MHEV), a 12-volt system that offers basic idle stop/start functionality only, continues to follow as the first of the mild hybrid technologies. However, while the Higher Voltage and Improved Alternator (HVIA) technology followed MHEV in the MY 2011 final rule, for purposes of the NPRM and this final rule, HVIA has been incorporated into the next technology, Belt Integrated Starter Generator (BISG). BISG represents a higher voltage, such as 42 volts, mild hybrid system with idle stop/start functionality, but with higher capability than MHEV including limited energy recovery through regenerative braking. BISG represents a mid-point option between MHEV and the next level of mild hybrid. BISG replaces the MHEV technology when it is applied, but EPS and IACC remain on the vehicle. Crank Integrated Starter Generator (CISG), the last of the mild hybrids, is also a higher voltage system with regenerative braking and limited motive power, primarily launch assist. Honda’s Integrate Motor Assist (IMA) system is a good example of a commercially realized version of this technology. CISG, which is the most capable of the mild hybrid options, is the final step necessary in order to convert the vehicle to a (full) strong hybrid; it replaces BISG when it is applied, but again, the final vehicle state contains both EPS and IACC. All Electrification/Accessory technologies can be applied to both automatic and manual transmission vehicles.

Transmission Technology Decision Tree

For the NPRM and this final rule, NHTSA reviewed the transmission technology decision tree and the model’s technology application logic used in the MY 2011 final rule, and concluded that no revisions to the transmission tree were necessary at this time. This decision tree, shown in Figure V-11, contains two paths: one for automatic transmissions and one for manual transmissions, that are identical to those used in the MY 2011 final rule.

On the automatic 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 before applying more expensive technologies. After IATC, the decision tree splits into a “Unibody only” and “Unibody or Ladder Frame” path, both of which result in conversion to new and fully optimized transmission designs. The Unibody only path contains the Continuously Variable Transmission (CVT) technology, while the Unibody or Ladder Frame path has 6/7/8-Speed Automatic Transmission with Improved Internals (NAUTO). The NAUTO technology is followed by Dual Clutch Transmission/Automated Manual Transmission (DCTAM) technology.

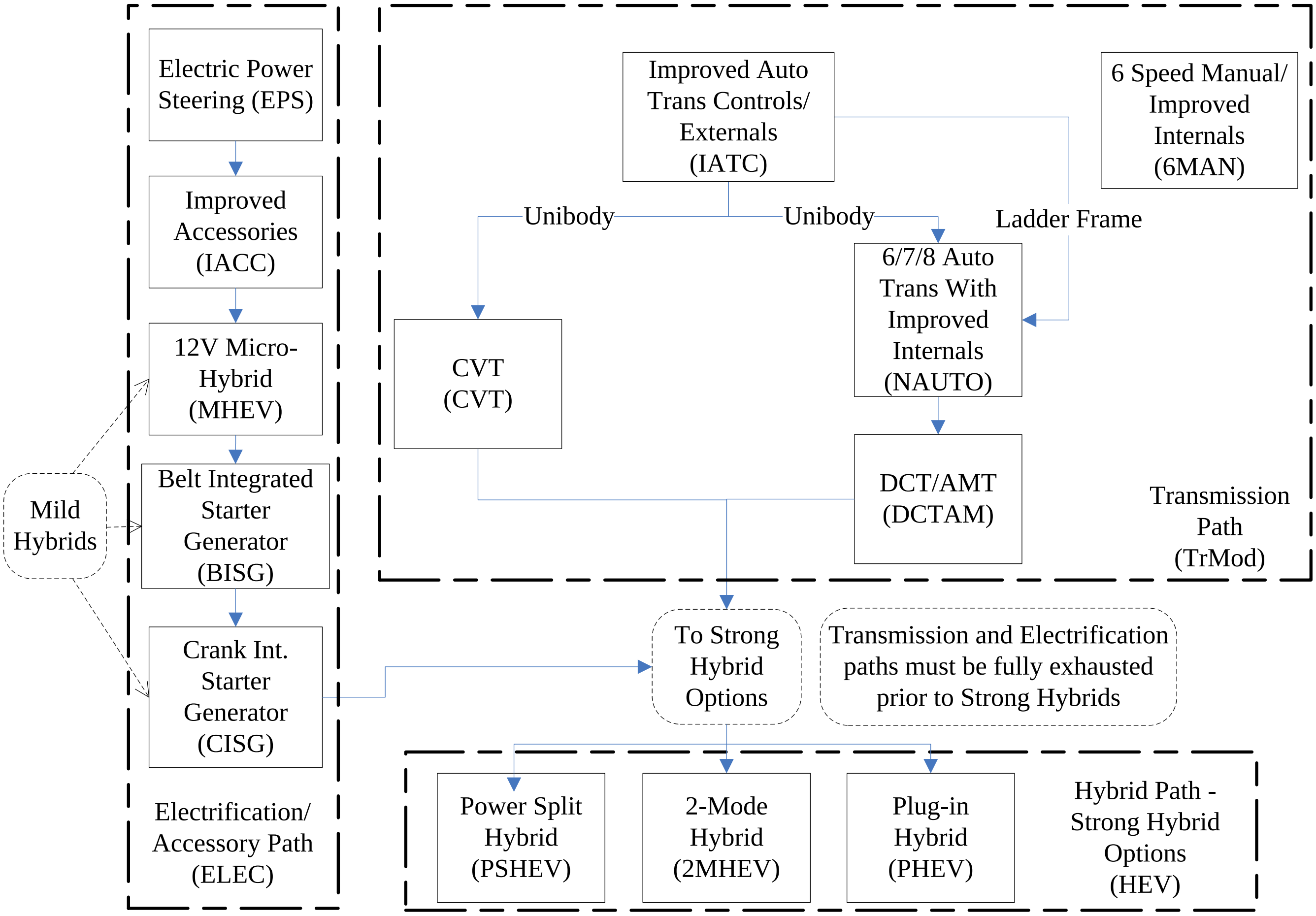
Dual Clutch Transmission (DCT) designs do not suffer torque interrupt when shifting; a characteristic associated with automated manual transmission (AMT) designs. In response to comments from manufacturers expressing concern that torque interrupt will not be acceptable to consumers, the DCTAM technology is intended to use a DCT-type transmission only.

The manual transmission path again has only one technology application; conversion to a 6-Speed Manual with Improved Internals (6MAN). NHTSA anticipates limited use of manual transmissions with more than 6 speeds within the MY 2012-2016 timeframe.

Hybrid Technology Decision Tree

NHTSA also reviewed the hybrid technology decision tree and the model's technology application logic used in the MY 2011 final rule, and concluded that no revisions were necessary for the hybrid tree for the NPRM and this final rule. The model continues to only apply strong hybrid technologies when both the Electrification/Accessory and Transmission (automatic transmissions only) technologies have been fully added to the vehicle, as seen in Figure V-11. When the CAFE model applies strong hybrids it takes into account that some of the fuel consumption reductions have already been included when technologies like EPS or IACC have been previously applied. When strong hybrids are required, the model chooses the most appropriate application of the Two Mode (2MHEV), Power Split (PSHEV) or Plug-in Hybrid Vehicle (PHEV), based on the vehicle's subclass and/or the most cost-effective application.

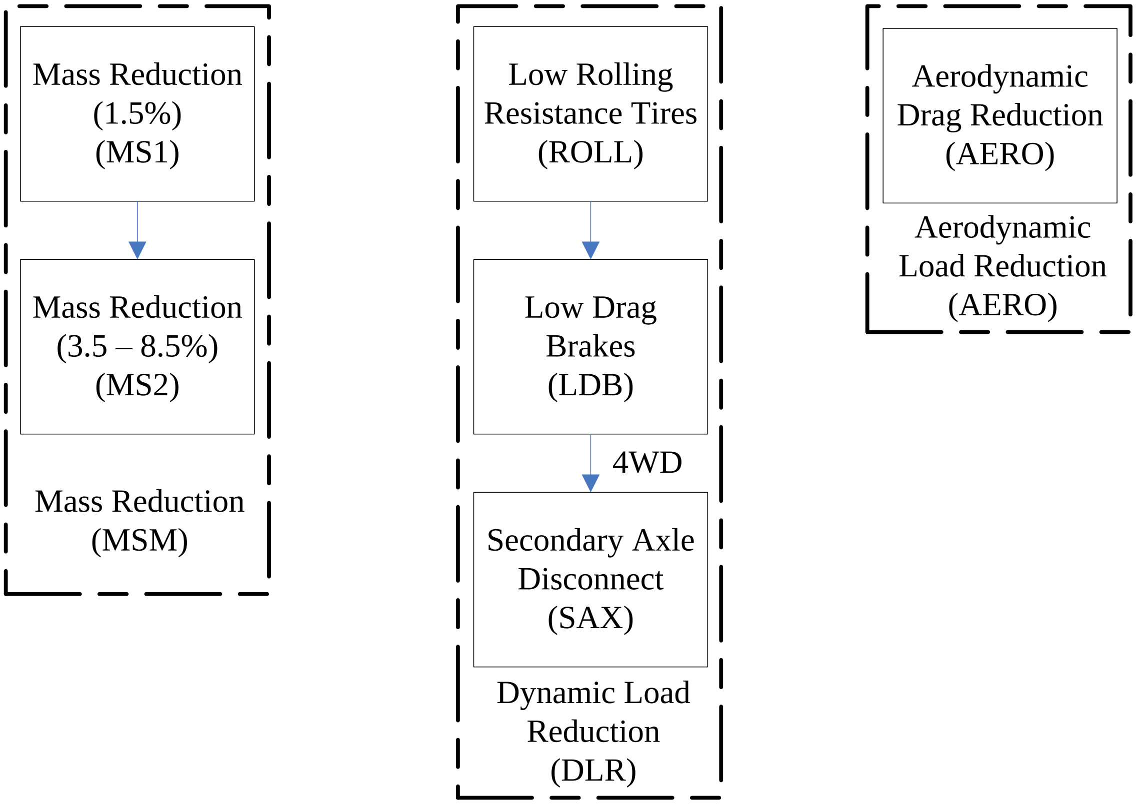
Figure V-11. Electrification/Accessory, Transmission and Hybrid Technology Decision Tree



Vehicle Technology Decision Tree

After reviewing this decision tree, NHTSA made some revisions to the vehicle technology tree from the version used in the MY 2011 final rule. The MY 2011 final rule utilized three Material Substitution (MS) technologies in a dedicated path in the Vehicle Technology Decision tree. These technologies have been reconsidered for purposes of the NPRM and this final rule as Mass Reduction and are discussed in greater detail below. As shown in Figure V-12, this rule uses two technologies, (MS1) and (MS2), and a dedicated path in the Vehicle Technology Decision Tree. Both have a different definition than was used in the prior rule. The Mass Reduction 1 (MS1) technology now represents a 1.5 percent (of vehicle curb weight) weight decrease that can be applied to any subclass of vehicle at the Refresh or Redesign cycle. The MS2 technology defines a 3.5 percent to 8.5 percent subclass-dependent mass reduction, which can only be applied at the Redesign cycle, with the lower reductions occurring in the smaller/lighter vehicles. MS2 is incremental to MS1, which means that the model may, subject to subclass and cycle constraints, potentially reduce vehicle weight by a total of 5 to 10 percent (of curb weight) within the rulemaking time frame. To allow manufacturers lead time to implement larger mass reductions, the MS2 technology is made unavailable until MY 2014. Low Rolling Resistance Tires (ROLL), Low Drag Brakes (LDB) and Secondary Axle Disconnect (SAX) all have the same definition and path as used in the MY 2011 final rule, with SAX applied to 4WD vehicles only. Aerodynamic Drag Reduction (AERO) remains a separate path.

Figure V-12. Vehicle Technology Decision Tree



4. Division of vehicles into subclasses based on technology applicability, cost and effectiveness

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. GM commented as to the applicability of technologies based on size and classification of vehicles, NHTSA agrees and applied technologies with this approach. The 2002 NAS Report differentiated technology application using ten vehicle "classes" (4 cars classes and 6 truck classes),[108] but did not determine how cost and effectiveness values differ from class to class. 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

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[108] The NAS classes included subcompact cars, compact cars, midsize cars, large cars, small SUVs, midsize SUVs, large SUVs, small pickups, large pickups, and minivans.

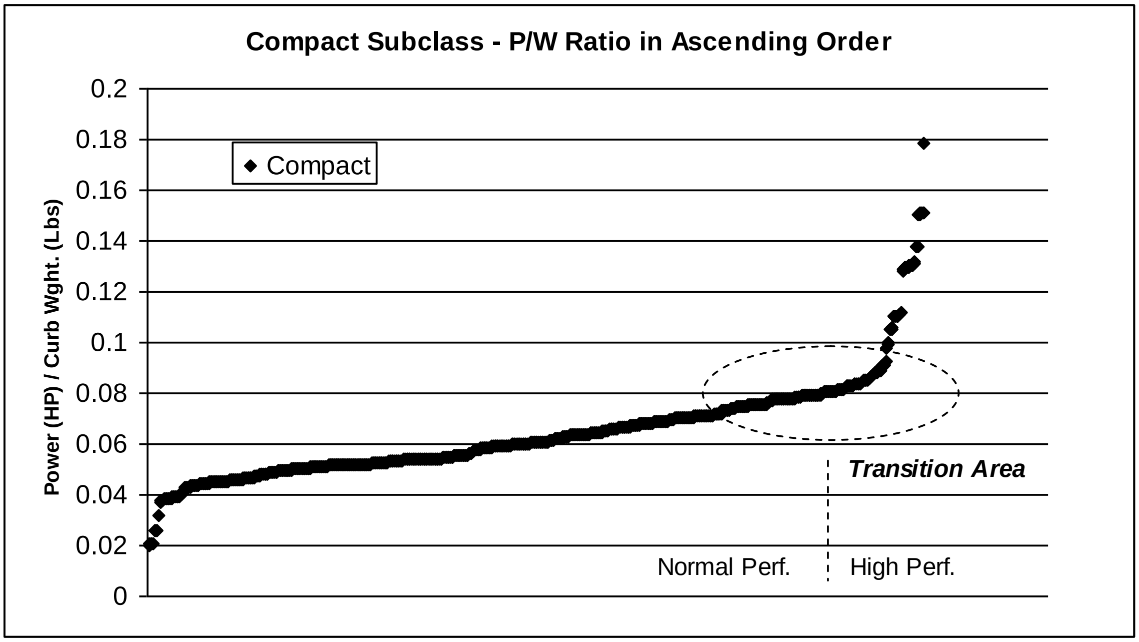
similar technologies are applicable. NHTSA similarly differentiates vehicles, referring to each grouping as a "subclass," for the purpose of applying technologies to vehicles and assessing their incremental costs and effectiveness. These technology subclasses should not be confused with the regulatory classifications pursuant to 49 CFR Part 523.

For this final rule as for the MY 2011 final rule, the CAFE model 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. Therefore, the model's estimates of the cost to improve the fuel economy and the amount of fuel economy improvement of each vehicle model depend upon the subclass to which the vehicle model is assigned.

NHTSA's analysis for the MY 2005-2007 and MY 2008-2011 light truck CAFE standards used the same vehicle classes defined by NAS in its 2002 Report. The 2008 NPRM for MY 2011-2015 also used those same vehicle classes, but included some differentiation in cost and effectiveness numbers between the various classes to account for differences in technology costs and effectiveness that are observed when technologies are applied on to different classes and subclasses of vehicles. The agency found it important to make that differentiation because it estimated that, for example, engine turbocharging and downsizing would have different implications for large vehicles than for smaller vehicles. However, for purposes of the NPRM and this final rule, NHTSA closely re-examined the subclasses used for the MY 2011 final rule and found that the methodology and subclasses used then, which had been developed in response to comments arguing insufficient differentiation, remain appropriate for the MY 2012-2016 vehicles under consideration. 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 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-13. 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-13. 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-6. 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 MY 2011 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 MY 2011 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-7. 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 final rule after reviewing the process used in the MY 2011 final rule and concluding that it continued to be a reasonable approach for purposes of this rulemaking. NHTSA believes that this method substantially improves 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.

5. How did NHTSA develop technology cost and effectiveness estimates for this final rule?

Building on NHTSA's estimates developed for the MY 2011 final rule and EPA's Advanced Notice of Proposed Rulemaking, which relied on the 2008 Staff Technical Report,[109] the agencies took a fresh look at technology cost and effectiveness values for purposes of the joint final rule under the National Program. For costs, the agencies reconsidered both the direct or "piece" costs and indirect costs of individual components of technologies. For the direct costs, the agencies followed a bill of materials (BOM) approach employed by NHTSA in NHTSA's MY 2011 final rule based on recommendation from Ricardo, Inc. Ricardo was hired by NHTSA, as discussed previously, to aid in the analysis of public comments on its proposed standards for MYs 2011-2015 because of its expertise in the area of fuel economy technologies A BOM, in a general sense, is a list of components that make up a system—in this case, an item of fuel economy-improving technology. The BOM approach is similar in concept to the approach used in tear down studies In order to determine what a system costs, one of the first steps is to determine its components and what they cost.

NHTSA and EPA estimated these components and their costs based on a number of sources for cost-related information. The objective was to use those sources of information considered to be most credible for projecting the costs of individual vehicle technologies. For example, while NHTSA and Ricardo engineers had relied considerably in the MY 2011 final rule on the 2008 Martec Report for costing contents of some technologies, upon further joint review and for purposes of the MY 2012-2016 standards, the agencies decided that some of the costing information in that report was no longer accurate due to downward trends in commodity prices since the publication of that report. The agencies reviewed, revalidated or updated cost estimates for individual components based on new information. Thus while NHTSA and EPA found that much of the cost information used in NHTSA's MY 2011 final rule and EPA's staff report was consistent

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[109] 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.

to a great extent, the agencies, in reconsidering information from many sources,[110] revised component costs of several major technologies (turbocharging downsizing, mild and strong hybrids, diesels, SGDI, Valve Train Lift Technologies, 6 speed automatic transmission and dual clutch transmission). These are discussed at length below.

For some technologies such as turbocharging/downsizing, SGDI, 6 speed automatic transmission and dual clutch transmission, the agencies relied, to the extent possible, on the tear down data available and scaling methodologies used in EPA's ongoing study with FEV Inc., an independent engine and powertrain systems research, design and development company. This study consists of complete system tear-down to evaluate technologies down to the nuts and bolts to arrive at very detailed estimates of the costs associated with manufacturing them.[111] For the NPRM, the agencies used a completed analysis to estimate costs of turbocharging with downsizing for I4 engines only. The NPRM stated that tear-down cost estimates from FEV for additional engine and transmission technologies became available shortly before the release of the NPRM, but not in time to be incorporated into the agencies' cost analysis of the proposed standards. These preliminary results were made available for review and the agencies stated they would consider this information for use in the final rule analysis.[112] The NPRM also stated that a detailed report would be submitted to the docket on these additional technologies during the public comment period for this rule. That deadline was not met but all additional technologies for which cost study tear downs have been completed from this study with FEV (studies have now been completed on turbocharging and downsizing for V6 and V8 engines, stoichiometric gasoline direct injection, 6/7/8-speed automatic transmission and dual clutch transmission technologies) have been considered for the final rule and details are contained in two reports placed in the docket.[113] [114] EPA and NHTSA reviewed all of the above information in order to develop the best estimates of availability, cost and effectiveness of these fuel-saving/CO_2-reducing technologies. The confidential information provided by manufacturer under their product plan submissions to the agencies or discussed in meetings between the agencies and the manufacturers and suppliers served largely as a check on publicly-available data.

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[110] The 2002 NAS Report, the 2004 study done by NESCCAF, the California Air Resources Board (CARB) Initial Statement of Reasons in support of their carbon rulemaking a 2006 study done by Energy and Environmental Analysis (EEA) for the Department of Energy, a study done by Martec for the Alliance of Automobile Manufacturers and the 2008 Martec Report which updated that study, and vehicle fuel economy certification data and confidential data submitted by manufacturers in response to the March 2009 request for product plans.

[111] "Draft Report – Light-Duty Technology Cost Analysis Pilot Study," U.S. Environmental Protection Agency, Contract No. EP-C-07-069, Work Assignment 1-3, September 3, 2009 (Docket NHTSA-2009-0059-0024).

[112] Memorandum from Don Kopinski, U.S. EPA, Docket No. EPA-HQ-OAR-2009-0472-0217, dated September 11, 2009.

[113] U.S. Environmental Protection Agency, "Draft Report – Light-Duty Technology Cost Analysis Pilot Study," Contract No. EP-C-07-069, Work Assignment 1-3, September 3, 2009, Docket EPA-HQ-OAR-2009-0472-0149.

[114] "Light-duty Technology Cost Analysis – Report on Additional Case Studies," EPA-420-R-10-010 for the FEV final report on additional case studies beyond the I4 to I4.

For the other technologies, because tear down studies were not yet available, the agencies decided to pursue the (BOM) approach considering all sources of information. The agencies worked together intensively during the summer of 2009 to determine component costs for each of the technologies and build up the costs accordingly. Where estimates differ between sources, we have used engineering judgment to arrive at what we believe to be the best cost estimate available today, and explained the basis for that exercise of judgment.

Once costs were determined, they were adjusted to ensure that they were all expressed in 2007 dollars using a ratio of GDP values for the associated calendar years,[115] and indirect costs were accounted for using the new approach developed by EPA for this rulemaking and explained in the joint TSD, rather than using the traditional Retail Price Equivalent (RPE) multiplier of 1.5. This report can be found in the docket for this notice. NHTSA and EPA also considered how costs should be adjusted by modifying or scaling content assumptions to account for differences across the range of vehicle sizes and functional requirements, and adjusted the associated material cost impacts to account for the revised content, although these adjustments were different for each agency due to the different vehicle subclasses used in their respective models.

Regarding estimates for technology effectiveness, NHTSA in coordination with EPA also reexamined the estimates from NHTSA's MY 2011 CAFE final rule and EPA's ANPRM and Staff Technical Report, which largely mirrored NHTSA's NPRM estimates in the 2008 proposed rule. The agencies also reconsidered other sources such as the 2002 NAS Report, the 2004 NESCCAF report and recent CAFE compliance data. Using the BOM framework utilized in MY 2011 CAFE final rule, NHTSA and EPA engineers reviewed effectiveness information from the multiple sources for each technology. Together, they compared the multiple estimates and assessed their validity, taking care to ensure that common BOM definitions and other vehicle attributes such as performance, refinement, and drivability were taken into account. However, because the agencies' respective models employ different numbers of vehicle subclasses and use different technology decision trees to arrive at the standards, direct comparison of technologies was somewhat more complicated. To address this and to assure an apples-to-apple comparison, NHTSA and EPA developed mapping techniques, devising technology packages and corresponding incremental technology estimates. This approach helped compare incremental and packaged estimates and derive results that are consistent and could be translated into the respective models of the agencies. In general, most effectiveness estimates used in both the MY 2011 CAFE final rule and the 2008 EPA staff report were determined to be accurate and were carried forward without significant change into this rulemaking. When NHTSA and EPA's estimates for effectiveness diverged slightly due differences in how agencies apply technologies to vehicles in their respective models, the agencies will report the ranges for the effectiveness values used in each model, as well as the reasons the range is reasonable.

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[115] NHTSA examined the use of the CPI multiplier instead of GDP for adjusting these dollar values, but found the difference to be exceedingly small – only $0.14 over $100.

6. Learning curves

In the MY 2011 CAFE final rule and its related 2008 proposal, NHTSA accounted for the cost reductions manufacturers realized through experiential learning achieved through applying technologies. NHTSA continues to account for these cost reductions in this final rule through the use of two mutually exclusive learning types, "volume-based" and "time-based," as discussed below.

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 the three parameters of 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. 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, NHTSA 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, NHTSA 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, and in response to comments, NHTSA revised its assumptions on learning threshold, basing them instead on an industry-wide production basis, and increasing the threshold to 300,000 units annually (and thus a technology is considered to be fully learned out at 1.2M annual units).

However commenters to the 2008 NPRM also described another type of learning factor which NHTSA, working in conjunction with its contractor Ricardo, Inc who assisted in finalizing the rule, adopted and implemented in 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 principal, 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), NHTSA adopted this type 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 Ricardo conducted for NHTSA, was used in the 2011 final rule.

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 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 agrees 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 the agencies were not able to investigate fully the use of a continuous cost-learning effects curve for each technology, but we will investigate the applicability of this approach for future rulemakings. For purposes of the final rule analysis, however, NHTSA believes that while more detailed cost learning approaches may eventually be possible, the approach taken for this final rule is valid.

Additionally, while the agencies agree that worldwide production volumes can impact learning curves, the agencies do not forecast worldwide vehicle production volumes in addition to the already complex task of forecasting the U.S. market. That said, the agencies do 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 the agencies. The agencies use "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 this final rule, NHTSA, taking into account comments received, has 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 NPRM, and has concluded that both learning factors continue to be accurate and appropriate. NHTSA therefore continues to implement both time- and volume-based learning in the analyses that supports this 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 principal 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 determined the learning factors shown in Table V-8 below. These factors, which were used in this analysis, closely resemble the settings used in the 2011 final rule with the exception of PSHEV which has been revised from time-based to volume-based learning. Note that no learning is applied to technologies which are potentially affected by commodity costs (LUB, ROLL) or that have loosely-defined BOMs (EFR, LDB) in the this analysis, as was also the case in the MY 2011 final rule analysis. Where volume-based learning has been applied, NHTSA has taken 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 have not defined 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 have 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 agencies did not believe it advantageous to define costs based on a finer level detail and believe the costs developed are the most appropriate for this rulemaking.

Table V-8. Application of learning-related cost reductions for technologies

Technology	Model Abbreviation	Learning Type	Learning Rate
Low Friction Lubricants	LUB		
Engine Friction Reduction	EFR		
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	TIME	3%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	TIME	3%
Cylinder Deactivation on SOHC	DEACS	TIME	3%
VVT - Intake Cam Phasing (ICP)	ICP	TIME	3%
VVT – Dual Cam Phasing (DCP)	DCP	TIME	3%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	TIME	3%
Continuously Variable Valve Lift (CVVL)	CVVL	TIME	3%
Cylinder Deactivation on DOHC	DEADD	TIME	3%
Cylinder Deactivation on OHV	DEACO	TIME	3%
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	TIME	3%
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	TIME	3%
Conversion to DOHC with DCP	CDOHC	TIME	3%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	TIME	3%
Combustion Restart	CBRST	TIME	3%
Turbocharging and Downsizing	TRBDS	TIME	3%
Exhaust Gas Recirculation (EGR) Boost	EGRB	TIME	3%
Conversion to Diesel following CBRST	DSLC	TIME	3%
Conversion to Diesel following TRBDS	DSLT	TIME	3%
6-Speed Manual/Improved Internals	6MAN	TIME	3%
Improved Auto. Trans. Controls/Externals	IATC	TIME	3%
Continuously Variable Transmission	CVT	TIME	3%
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	TIME	3%
Dual Clutch or Automated Manual Transmission	DCTAM	TIME	3%
Electric Power Steering	EPS	TIME	3%
Improved Accessories	IACC	TIME	3%
12V Micro-Hybrid	MHEV	TIME	3%
Belt Integrated Starter Generator	BISG	VOLUME	20%
Crank Integrated Starter Generator	CISG	VOLUME	20%
Power Split Hybrid	PSHEV	VOLUME	20%
2-Mode Hybrid	2MHEV	VOLUME	20%
Plug-in Hybrid	PHEV	VOLUME	20%
Mass Reduction 1 (1.5%)	MS1		
Mass Reduction 2 (3.5% – 8.5%)	MS2		
Low Rolling Resistance Tires	ROLL		
Low Drag Brakes	LDB		
Secondary Axle Disconnect 4WD	SAX	TIME	3%
Aero Drag Reduction	AERO	TIME	3%

7. Technology 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.[116] 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 individual effectiveness values in that set is referred to as a "synergy." Synergies may be positive (increased fuel consumption reduction compared to the product of the individual effects) or negative (decreased 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.

NHTSA determined synergistic impacts for this rulemaking using EPA's "lumped parameter" analysis tool, which EPA described at length in its March 2008 Staff Technical Report.[117] The lumped parameter tool is a spreadsheet model 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. Results of this analysis were generally consistent with those of

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[116] 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.

[117] 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-2009-0059-0027.

full-scale vehicle simulation modeling performed in 2007 by Ricardo, Inc. However, 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.

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).[118] Inputs to the Volpe model incorporate NEMS-identified pairs, as well as additional pairs from the set of technologies considered in the Volpe model. For this final rule, as was the case in the 2011 final rule, NHTSA used the lumped parameter tool to evaluate accurate synergy values. During the 2011 final rule analysis, and 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. Table V-9 below presents the types of losses that were analyzed.

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 Volpe model.

For applying incremental synergy factors in separate path technologies, i.e., between two or more decision trees, the Volpe model uses an input table (see Tables V-10 a-d) which 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 Volpe 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 Volpe model) are summed and applied to the fuel consumption improvement factor of the technology being applied. Synergies for the strong hybrid technology fuel consumption reductions are included in the incremental value for the specific hybrid technology since 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 hybrid technologies.

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[118] U.S. Department of Energy, Energy Information Administration, *Transportation Sector Module of the National Energy Modeling System: Model Documentation 2007*, May 2007, Washington, DC, DOE/EIA-M070(2007), at 29-30. *Available at* http://tonto.eia.doe.gov/ftproot/modeldoc/m070(2007).pdf (last accessed March 15, 2010).

NHTSA received only one comment regarding synergies, from MEMA, who commented that NHTSA's Volpe model adequately addressed synergistic effects. Having received no information to the contrary, NHTSA finalized the synergy approach and values for the final rule.

Table V-9 Loss Factors Considered in Synergy Analysis

Lumped Parameter Synergy Analysis

	VEHICLE Tractive Effort	TRANS Drivetrain Losses	ENGINE Mechanical Friction	ENGINE Pumping Losses	ENGINE Accessory Losses	ENGINE Indicated Efficiency
ENGINE						
Low Friction Lubricants			+			
Engine Friction Reduction			+			
VVT - Coupled Cam Phasing (CCP) on SOHC			-	+		+
Discrete Variable Valve Lift (DVVL) on SOHC			-	+		
Cylinder Deactivation on SOHC			+	+		
VVT - Intake Cam Phasing (ICP)			-	+		+
VVT - Dual Cam Phasing (DCP)			-	+		+
Discrete Variable Valve Lift (DVVL) on DOHC			-	+		
Continuously Variable Valve Lift (CVVL)			-	+		
Cylinder Deactivation on DOHC			+	+		
Cylinder Deactivation on OHV			+	+		
VVT - Coupled Cam Phasing (CCP) on OHV			-	+		+
Discrete Variable Valve Lift (DVVL) on OHV			-	+		
Conversion to DOHC with DCP			-	+		+
Stoichiometric Gasoline Direct Injection (GDI)						+
Combustion Restart			+	+	+	
Turbocharging and Downsizing			-	+		
Exhaust Gas Recirculation (EGR) Boost						+
Conversion to Diesel				+		+
TRANSMISSION (MANUAL)						
6-Speed Manual/Improved Internals		+		+		
TRANSMISSION (AUTOMATIC)						
Improved Auto. Trans. Controls/Externals		+		+		
Continuously Variable Transmission		-		+		
6/7/8-Speed Auto. Trans with Impr. Internals		+		+		
Dual Clutch/Automated Manual Transmission		+				
ELECTRIFICATION/ACCESSORY						
Electric Power Steering					+	
Improved Accessories					+	
12V Micro-Hybrid			+	+	+	
Belt Integrated Starter Generator			+	+	+	
Crank Integrated Starter Generator			+	+	+	
(STRONG) HYBRID						
Power Split Hybrid		+	+	+	+	
2-Mode Hybrid		+	+	+	+	
Plug-in Hybrid		+	+	+	+	
VEHICLE						
Mass Reduction 1 (1.5%)	+					
Mass Reduction 2 (3.5% - 8.5%)	+					
Low Rolling Resistance Tires	+					
Low Drag Brakes	+					
Secondary Axle Disconnect - 4WD		+				
Aero Drag Reduction	+					

+ Technology has a positive effect on fuel consumption
- Technology has a negative effect on fuel consumption

Table V-10a Synergy pairings and values

Synergies		Fuel Consumption Improvement Synergy values by Vehicle Subclass Positive values are positive synergies, negative values are dissynergies.					
Technology A	**Technology B**	**Subcompact PC**	**Subcompact Perf. PC**	**Compact PC**	**Compact Perf. PC**	**Midsize PC**	**Midsize Perf. PC**
CCPS	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
CCPS	IATC	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CCPS	CVT	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
CCPS	NAUTO	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
CCPS	MHEV	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
CCPS	BISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DVVLS	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
DVVLS	IATC	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
DVVLS	CVT	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
DVVLS	NAUTO	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
DVVLS	MHEV	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
DVVLS	BISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DEACS	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DEACS	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
DEACS	CVT	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
DEACS	NAUTO	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACS	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACS	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
ICP	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
ICP	IATC	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
ICP	CVT	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
ICP	NAUTO	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
ICP	MHEV	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
ICP	BISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DCP	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
DCP	IATC	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
DCP	CVT	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
DCP	NAUTO	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
DCP	MHEV	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
DCP	BISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLD	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DVVLD	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
DVVLD	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
DVVLD	NAUTO	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLD	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DVVLD	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACD	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DEACD	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
DEACD	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
DEACD	NAUTO	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DEACD	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACD	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CVVL	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CVVL	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
CVVL	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
CVVL	NAUTO	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
CVVL	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
CVVL	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACO	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
DEACO	IATC	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
DEACO	CVT	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
DEACO	NAUTO	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
DEACO	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACO	BISG	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%

Table V-10b Synergy pairings and values

Synergies		Fuel Consumption Improvement Synergy values by Vehicle Subclass Positive values are positive synergies, negative values are dissynergies.					
Technology A	**Technology B**	**Subcompact PC**	**Subcompact Perf. PC**	**Compact PC**	**Compact Perf. PC**	**Midsize PC**	**Midsize Perf. PC**
CCPO	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CCPO	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
CCPO	CVT	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
CCPO	NAUTO	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
CCPO	MHEV	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
CCPO	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DVVLO	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DVVLO	IATC	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
DVVLO	CVT	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%
DVVLO	NAUTO	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DVVLO	MHEV	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLO	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CDOHC	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CDOHC	IATC	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
CDOHC	CVT	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%
CDOHC	NAUTO	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CDOHC	MHEV	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
CDOHC	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CBRST	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
CBRST	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
CBRST	NAUTO	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	EPS	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CBRST	IACC	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
TRBDS	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
TRBDS	IATC	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
TRBDS	CVT	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%
TRBDS	NAUTO	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
TRBDS	MHEV	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
TRBDS	BISG	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
DSLC	6MAN	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
DSLC	IATC	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
DSLC	CVT	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
DSLC	NAUTO	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
DSLC	MHEV	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLC	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLT	6MAN	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
DSLT	IATC	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
DSLT	CVT	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
DSLT	NAUTO	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
DSLT	MHEV	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLT	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CCPS	CISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DVVLS	CISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DEACS	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
ICP	CISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DCP	CISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLD	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACD	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CVVL	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACO	CISG	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%
CCPO	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DVVLO	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CDOHC	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
TRBDS	CISG	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
DSLC	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLT	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%

Table V-10c Synergy pairings and values

Synergies		**Fuel Consumption Improvement Synergy values by Vehicle Subclass** **Positive values are positive synergies, negative values are dissynergies.**					
Technology A	**Technology B**	**Large PC**	**Large Perf. PC**	**Minivan LT**	**Small LT**	**Midsize LT**	**Large LT**
CCPS	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
CCPS	IATC	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CCPS	CVT	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
CCPS	NAUTO	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
CCPS	MHEV	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
CCPS	BISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DVVLS	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
DVVLS	IATC	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
DVVLS	CVT	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
DVVLS	NAUTO	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
DVVLS	MHEV	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
DVVLS	BISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DEACS	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DEACS	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
DEACS	CVT	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
DEACS	NAUTO	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACS	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACS	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
ICP	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
ICP	IATC	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
ICP	CVT	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
ICP	NAUTO	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
ICP	MHEV	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
ICP	BISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DCP	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
DCP	IATC	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
DCP	CVT	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
DCP	NAUTO	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
DCP	MHEV	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
DCP	BISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLD	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DVVLD	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
DVVLD	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
DVVLD	NAUTO	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLD	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DVVLD	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACD	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DEACD	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
DEACD	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
DEACD	NAUTO	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DEACD	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACD	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CVVL	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CVVL	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
CVVL	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
CVVL	NAUTO	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
CVVL	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
CVVL	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACO	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
DEACO	IATC	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
DEACO	CVT	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
DEACO	NAUTO	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
DEACO	MHEV	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DEACO	BISG	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%

Table V-10d Synergy pairings and values

Synergies		**Fuel Consumption Improvement Synergy values by Vehicle Subclass Positive values are positive synergies, negative values are dissynergies.**					
Technology A	**Technology B**	**Large PC**	**Large Perf. PC**	**Minivan LT**	**Small LT**	**Midsize LT**	**Large LT**
CCPO	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CCPO	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
CCPO	CVT	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
CCPO	NAUTO	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
CCPO	MHEV	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
CCPO	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DVVLO	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
DVVLO	IATC	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
DVVLO	CVT	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%
DVVLO	NAUTO	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DVVLO	MHEV	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLO	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CDOHC	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CDOHC	IATC	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
CDOHC	CVT	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%
CDOHC	NAUTO	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CDOHC	MHEV	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
CDOHC	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CBRST	IATC	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%
CBRST	CVT	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%
CBRST	NAUTO	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	EPS	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
CBRST	IACC	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
TRBDS	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
TRBDS	IATC	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
TRBDS	CVT	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%
TRBDS	NAUTO	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
TRBDS	MHEV	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
TRBDS	BISG	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
DSLC	6MAN	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
DSLC	IATC	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
DSLC	CVT	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
DSLC	NAUTO	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
DSLC	MHEV	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLC	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLT	6MAN	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
DSLT	IATC	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
DSLT	CVT	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
DSLT	NAUTO	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
DSLT	MHEV	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLT	BISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CCPS	CISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DVVLS	CISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DEACS	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
ICP	CISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
DCP	CISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
DVVLD	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACD	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CVVL	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DEACO	CISG	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%
CCPO	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DVVLO	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CDOHC	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
CBRST	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
TRBDS	CISG	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
DSLC	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%
DSLT	CISG	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%

9. Refresh and redesign schedule

Because of the complexities of the automobile manufacturing process, manufacturers are generally only able to add new technologies to vehicles on a specific schedule; just because a technology exists in the marketplace, does not mean that it is immediately available for application on all of a manufacturer's vehicles. In the automobile industry there are two terms that describe when technology changes to vehicles occur: redesign and refresh (*i.e.*, freshening). Vehicle redesign usually refers to significant changes to a vehicle's appearance, shape, dimensions, and powertrain. Redesign is traditionally associated with the introduction of "new" vehicles into the market, often characterized as the "next generation" of a vehicle, or a new platform. Vehicle refresh usually refers to less extensive vehicle modifications, such as minor changes to a vehicle's appearance, a moderate upgrade to a powertrain system, or small changes to the vehicle's feature or safety equipment content. Refresh is traditionally associated with mid-cycle cosmetic changes to a vehicle, within its current generation, to make it appear "fresh." Vehicle refresh generally occurs no earlier than two years after a vehicle redesign or at least two years before a scheduled redesign. For the majority of technologies discussed today, manufacturers will only be able to apply them at a refresh or redesign, because their application would be significant enough to involve some level of engineering, testing, and calibration work.[119]

Thus, in addition to developing methods that address limitations on the rates at which new technologies can feasibly penetrate manufacturers' fleets, which NHTSA refers to as phase-in caps, the agency has also developed methods to address the feasible scheduling of changes to specific vehicle models. In the Volpe model, which the agency used to support this final rule, these scheduling-related methods were first applied in 2003, in response to concerns that an early version of the model would sometimes add and then subsequently remove some technologies.[120] By 2006, these methods were integrated into a new version of the model, one which explicitly "carried forward" technologies added to one vehicle model to succeeding vehicle models in the next model year, and which timed the application of many technologies to coincide with the redesign or freshening of any given vehicle model.[121] In the 2008 NPRM and subsequent final rule for the MY 2011 CAFE standards, NHTSA tied the application of the majority of technologies to a vehicle's refresh/redesign cycle.

Even within the context of the phase-in caps discussed below, NHTSA considers these model-by-model scheduling constraints 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,

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[119] 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 vehicle's braking characteristics or how it performs in crash avoidance tests.

[120] 68 FR 16874 (Apr. 7, 2003).

[121] 71 FR 17582 (Apr. 6, 2006).

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.[122]

For purposes of the analysis supporting this final rule, NHTSA has employed, as inputs to the Volpe model, a redesign cycle of 5 years for all manufacturers, with a refresh cycle of 2-3 years. This is the schedule employed in the analysis that supported the MY 2011 final rule, and is consistent with the most recent manufacturer product plans received in response to NHTSA's March 2009 and September 2009 requests for updated plans. However, the application of the refresh/redesign cycle in the modeling analysis has changed in this final rule from the MY 2011 final rule due to the characteristics of the new joint approach for establishing the baseline fleet. The paragraphs below explain how NHTSA developed the refresh/redesign cycle, and how its application has changed for this final rule.

In the MY 2011 final rule NHTSA developed the redesign and refresh schedules based on a combination of manufacturers' confidential product plans and NHTSA's engineering judgment. In most instances, NHTSA reviewed manufacturers' planned redesign and refresh schedules as stated in their confidential submissions and incorporated them into the market data file, as done in past rulemakings. If companies did not provide product plan data, NHTSA used publicly available data to estimate the redesign and refresh schedules for the vehicles produced by these companies.[123] Unless a manufacturer submitted plans for a more rapid redesign and refresh schedule, NHTSA assumed that passenger cars would normally be redesigned every 5 years, consistent with industry trends over the last 10-15 years.[124] NHTSA also projected a 5-year redesign cycle for the majority of light trucks.[125] A fuller discussion of NHTSA's justification and rationale for the 5-year redesign cycle can be found in the MY 2011 final rule.[126]

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[122] 49 U.S.C. § 32902(a) requires that NHTSA set CAFE standards at the maximum feasible level for each fleet, for each model year.

[123] 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.).

[124] 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).

125 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 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.

[126] 74 FR 14265 (Mar. 30, 2009)

Some manufacturers commented in the last round of CAFE rulemaking, even before the economic crisis had reached today's levels that their vehicle redesign cycles take at least five years for cars and 6 years and longer for trucks because they rely on those later years to recover investments and earn a profit. They argued that they would not be able to sustain their businesses if forced by CAFE standards to a shorter redesign cycle. Expecting that those concerns may be magnified in the current economic climate, NHTSA recognizes that some manufacturers are severely stressed and may be delaying or hoping to delay planned vehicle redesigns in order to conserve financial resources. However, manufacturers must balance this concern against their interest in continuing to provide vehicles that the public wishes to purchase, which may be redesigned or refreshed vehicles. Consistent with its forecast of the overall size of the light vehicle market from MY 2011 on, the agency tentatively expects that the industry's status will improve and that manufacturers will typically redesign both car and truck models every 5 years in order to be competitive in the market.

NHTSA received comments from the Center for Biological Diversity (CBD) and Ferrari regarding redesign cycles. CBD stated that manufacturers do not necessarily adhere to the agencies' assumed five-year redesign cycle, and may add significant technologies by redesigning vehicles at more frequent intervals, albeit at higher costs. CBD argued that NHTSA should analyze the costs and benefits of manufacturers choosing to redesign vehicles more frequently than a 5-year average. Conversely, Ferrari agreed with the agencies that major technology changes are introduced at vehicle redesigns, rather than at vehicle freshenings, stating further that as compared to full-line manufacturers, small-volume manufacturers in fact may have 7 to 8-year redesign cycles. In response, NHTSA recognizes that not all manufacturers follow a precise five-year redesign cycle for every vehicle they produce,[127] but continues to believe that the five-year redesign cycle assumption is a reasonable estimate of how often manufacturers can make major technological changes for purposes of its modeling analysis.[128] NHTSA has considered

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[127] In prior NHTSA rulemakings, the agency was able to account for shorter redesign cycles on some models (*e.g.*, some sedans), and longer redesign cycles on others (*e.g.*, cargo vans), but has standardized the redesign cycle in this analysis using the transparent baseline.

[128] In the MY 2011 final rule, NHTSA noted that the CAR report submitted by the Alliance, prepared by the Center for Automotive Research and EDF, stated that "For a given vehicle line, the time from conception to first production may span two and one-half to five years," but that "The time from first production ("Job#1") to the last vehicle off the line ("Balance Out") may span from four to five years to eight to ten years or more, depending on the dynamics of the market segment," The CAR report then stated that "At the point of final production of the current vehicle line, a new model with the same badge and similar characteristics may be ready to take its place, continuing the cycle, or the old model may be dropped in favor of a different product." *See* NHTSA-2008-0089-0170.1, Attachment 16, at 8 (393 of pdf). NHTSA explained that this description, which states that a vehicle model will be redesigned or dropped after 4-10 years, was consistent with other characterizations of the redesign and freshening process, and supported the 5-year redesign and 2-3 year refresh cycle assumptions used in the MY 2011 final rule. *See id.*, at 9 (394 of pdf). Given that the situation faced by the auto industry today is not so wholly different from that in March 2009, when the MY 2011 final rule was published, and given that the commenters did not present information to suggest that these assumptions are unreasonable (but rather simply that different manufacturers may redesign their vehicles more or less frequently, as the range of cycles above indicates), NHTSA believes that the assumptions remain reasonable for purposes of this final rule analysis. *See also* "Car Wars 2009-2012, The U.S. automotive product pipeline", John Murphy, Research Analyst, Merrill

attempting to quantify the increased cost impacts of setting standards that rise in stringency so rapidly that manufacturers are forced to apply "usual redesign" technologies at non-redesign intervals, but such an analysis would be exceedingly complex and is beyond the scope of this rulemaking given the timeframe and the current condition of the industry. NHTSA emphatically disagrees that the redesign cycle is a barrier to increasing penetration of technologies as CBD suggests, but we also believe that standards so stringent that they would require manufacturers to abandon redesign cycles entirely would be beyond the realm of economic practicability and technological feasibility, particularly in this rulemaking timeframe given lead time and capital constraints. Manufacturers can and will accomplish much improvement in fuel economy and GHG reductions while applying technology consistent with their redesign schedules.

NHTSA has concluded that the 5-year redesign is still appropriate and is retaining the 5-year redesign with 2-3 year refresh cycle assumptions for the final rule, noting that, for the most part, the cycle times are supported by manufacturer's confidential responses to NHTSA's March and September 2009 product plan requests. With regard to how the refresh/redesign cycle was implemented in the modeling analysis for this final rule given the new joint baseline approach, as discussed in Section I of the Preamble, NHTSA previously used confidential manufacturer product plan information and the refresh and redesign dates contained therein for formulating the market data input file used by the Volpe model, or relied on other sources of information where that data did not exist. For purposes of this final rule, in contrast, the agencies developed a baseline vehicle fleet data file from MY 2008 CAFE certification data. As discussed above, the certification data represents an historical data source that is publicly available, which allows NHTSA to make the baseline market data file itself publicly available. The advantage to this approach is the greater transparency provided with a publicly-available baseline market data file as compared to one based on confidential manufacturer data, as also discussed at greater length in Section I of the Preamble.

However, using adjusted historical data rather than estimated future data impacts how NHTSA is able to model the refresh/redesign cycle in its analysis of year-by-year maximum feasible CAFE standards. For example, some vehicles that exist in the MY 2008 certification-data based fleet manufacturers have indicated (either publicly or in their product plans) they will be discontinued (*i.e.*, no longer produced or sold) prior to or within the rulemaking period. Conversely, some vehicle models will be first 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 (unavailable) in 2008, they do not exist in the MY 2008 certification data, and thus do not exist in the final rule's market data file.

To address this problem, NHTSA first determined redesign schedules for the baseline MY 2008 vehicles, using publicly-available data and its own engineering judgment, which required finding the date of most recent redesign for each vehicle. Next, the

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Lynch research paper, May 14, 2008 and "Car Wars 2010-2013, The U.S. automotive product pipeline", John Murphy, Research Analyst, Bank of America/Merrill Lynch research paper, July 15, 2009, available at http://www.autonews.com/assets/PDF/CA66116716.PDF (last accessed on March 15, 2010).

agency applied 5-year redesign cycles to obtain new redesign dates for each vehicle, starting with the date of most recent redesign and working forward. Thus, a vehicle that was determined to have been last redesigned in MY 2008 would be projected to be redesigned again in MY 2013. The assumption here is that future vehicles that are replacements for vehicles currently in the market will tend to follow the same cycles as their predecessors, so it is appropriate to reflect the MY 2013 date in the market data file. NHTSA tried to ensure that most if not all vehicles had a redesign scheduled in the analysis during the rulemaking time frame, consistent with the industry's response in confidential product plans to the estimated levels of stringency announced in the joint NOI preceding the NPRM and this final rule. Manufacturers appear to be redesigning the vast majority of today's vehicles, or replacing them with new models, between now and the end of MY 2016. Finally, the agency determined refresh dates in a similar fashion, based on those of the baseline fleet and using the 2 to 3 year cycle, also working to ensure that all vehicles underwent a refresh cycle within the rulemaking time frame.

NHTSA accounts for these changes in the vehicle fleet as follows. While each entry in the new baseline market data file, by definition, is a vehicle that was sold in MY 2008 (based on the MY 2008 certification data), for purposes of projecting that vehicle model forward into the future fleet in the rulemaking period, each entry can also be used to represent a vehicle in that particular market segment (*e.g.*, subcompact, SUV/CUV, pickup, etc.) of a manufacturer's future fleet. The particular vehicle model shown in the file may or may not be sold in the future vehicle fleet, and in fact some models are expected to be discontinued well before MY 2016, as discussed above.

However, 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. NHTSA also used manufacturers' product plans as a check on this approach, and found them fairly consistent with the resulting baseline market data file.

The baseline market data file, available on NHTSA's website, contains the refresh and redesign dates developed by NHTSA for this final rule. Table V-11 below provides whether particular technologies are "anytime" technologies, "redesign only" technologies, or "refresh or redesign" technologies, for purposes of this final rule.

Table V-11 Technology Refresh and Redesign Application

Technology	Redesign only	Redesign or Refresh	Anytime
Low Friction Lubricants			X
Engine Friction Reduction		X	
VVT - Coupled Cam Phasing (CCP) on SOHC		X	
Discrete Variable Valve Lift (DVVL) on SOHC	X		
Cylinder Deactivation on SOHC		X	
VVT - Intake Cam Phasing (ICP)		X	
VVT – Dual Cam Phasing (DCP)		X	
Discrete Variable Valve Lift (DVVL) on DOHC	X		
Continuously Variable Valve Lift (CVVL)	X		
Cylinder Deactivation on DOHC		X	
Cylinder Deactivation on OHV		X	
VVT - Coupled Cam Phasing (CCP) on OHV		X	
Discrete Variable Valve Lift (DVVL) on OHV	X		
Conversion to DOHC with DCP	X		
Stoichiometric Gasoline Direct Injection (GDI)	X		
Combustion Restart		X	
Turbocharging and Downsizing	X		
Exhaust Gas Recirculation (EGR) Boost	X		
Conversion to Diesel following CBRST	X		
Conversion to Diesel following TRBDS	X		
6-Speed Manual/Improved Internals	X		
Improved Auto. Trans. Controls/Externals		X	
Continuously Variable Transmission	X		
6/7/8-Speed Auto. Trans with Improved Internals	X		
Dual Clutch or Automated Manual Transmission	X		
Electric Power Steering		X	
Improved Accessories		X	
12V Micro-Hybrid	X		
Belt Integrated Starter Generator	X		
Crank Integrated Starter Generator	X		
Power Split Hybrid	X		
2-Mode Hybrid	X		
Plug-in Hybrid	X		
Mass Reduction 1 (1.5%)		X	
Mass Reduction 2 (3.5% – 8.5%)	X		
Low Rolling Resistance Tires		X	
Low Drag Brakes		X	
Secondary Axle Disconnect 4WD		X	
Aero Drag Reduction		X	

10. 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.[129] 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. At a high level, phase-in caps and refresh/redesign cycles 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, especially in years where many models may be scheduled for refresh or redesign. This helps to ensure technological feasibility and economic practicability in determining the stringency of the standards.

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.[130] In 2002, when NHTSA proposed MY 2005-2007 standards for light trucks using a predecessor modeling algorithm to the Volpe model, manufacturers commented extensively on the issue of lead time and the potential for the rapid and widespread application of new technologies in the agency's analysis. Specifically, GM's comment pointed to the most significant manufacturer concern, the algorithm's "application of technologies to all truck lines in a single model year."[131] In response, NHTSA modified the algorithm to moderate the rates at which technologies were estimated to penetrate manufacturers' fleets in the MY 2005-2007 CAFE standards. The modeling changes produced more realistic estimates of the technologies manufacturers could apply in response to new standards, and more realistic estimates of the costs of those standards.

Explicit phase-in caps were included in the Volpe model analysis for the next rulemaking, establishing standards for MY 2008-2011 light trucks. These phase-in caps constrained the rates at which each technology would be estimated to penetrate each manufacturer's fleet in response to new CAFE standards. The agency's final standards for those model years used phase-in caps of up to 25 percent (corresponding to full penetration of the fleet within 4 years) for most technologies, and up to 10 percent (full

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[129] 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.

[130] 74 FR 14268–14271 (Mar. 30, 2009)

[131] 68 FR 16874 (Apr. 7, 2003).

penetration of the fleet within 10 years) for more advanced technologies such as hybrid electric vehicles.[132] The agency based these rates on consideration of comments and on the 2002 NAS Committee's findings that "widespread penetration of even existing technologies will probably require 4 to 8 years" and that for emerging technologies "that require additional research and development, this time lag can be considerably longer."[133]

In its 2008 NPRM proposing new CAFE standards for passenger cars and light trucks sold during MYs 2011-2015, NHTSA considered manufacturers' planned product offerings and estimates of technology availability, cost, and effectiveness, as well as broader market conditions and technology developments. The agency concluded that many technologies could be deployed more rapidly than it had estimated during the prior rulemaking[134] and increased some of the estimates as it determined appropriate. However, as in its earlier CAFE rulemakings, the agency continued to recognize that myriad constraints prohibit most technologies from being applied across an entire fleet of vehicles within a single year, even if those technologies are readily available in the market.

The comments NHTSA received in response to the 2008 proposal asserted three basic concerns with the agency's adjustments to phase in caps; a) that the hybrid phase-in caps were much lower than manufacturer announcements would otherwise suggest, b) that the phase-ins were too high in the early years of the rulemaking and did not reflect the very small (from a manufacturing perspective) amount of lead-time between the final rule and the standards taking effect, and/or were too low in the later years of the rulemaking given the increased lead-time, or c) that NHTSA did not consider the resources (either in terms of capital or engineering) required to implement the number (quantities) of technologies implied by the phase-in caps simultaneously.

NHTSA responded to these comments in the final rule,[135] noting that a number of factors potentially impact a manufacturer's ability to implement new technologies, including commercial viability, infrastructure requirements, and resource and lead-time considerations.[136] The agency explained that evaluating all the factors involved would require an extraordinary effort and that the analysis would likely involve significant uncertainties that would raise questions about its accuracy and usefulness. Nevertheless, the agency concluded that its use of phase-in caps was still appropriate "to apply the agency's best judgment of the extent to which such factors combine to constrain the rates at which technologies may feasibly be deployed." NHTSA emphasized that the MY 2011 phase-in caps were based on assumptions for the full five year period of the proposal (2011-2015), and stated that it would reconsider the phase-in settings for all years beyond 2011 in future rulemaking analysis. Some phase-in caps for individual technologies were raised and some were lowered, and the Volpe model was revised to add the ability to define unique phase-in caps for each model year, allowing non-linear

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[132] 71 FR 17572, 17679 (Apr. 6, 2006).
[133] *Id*. at. 17572. *See also* 2002 NAS Report, at 5.
[134] 73 FR 24387-88 (May 2, 2008).
[135] 74 FR 14268-69 (Mar 30, 2009)
[136] 74 FR 14268 (Mar. 30, 2009)

technology application rates throughout the rulemaking period (lower in the early years and increased in later, or vice-versa) if required.

Table V-12 below outlines the phase-in caps for the technologies used in this rule by model year. As in the MY 2011 final rule, NHTSA combines phase-ins 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 manufacturers' vehicle fleet is limited to the value of the cap.[137] In contrast to the phase-in caps used in the MY 2011 final rule, NHTSA has increased the phase-in caps for most of the technologies, except those for diesels and stronger hybrid technologies, as discussed below.

In developing phase-in cap values for purposes of the NPRM and this final rule, NHTSA initially considered the fact that many of the technologies commonly applied by the model, those placed near the top of the decision trees, such as low friction lubes, valve phasing, electric power steering, improved automatic transmission controls, and others, have been commonly available to manufacturers for several years now. Many technologies, in fact, precede the 2002 NAS Report, which estimated that such technologies would take 4 to 8 years to penetrate the fleet. Since this final rule will take effect in MY 2012, nearly 10 years beyond the NAS report, and extends to MY 2016, NHTSA determined that higher phase-in caps were likely justified. Additionally, NHTSA considered the fact that manufacturers, as part of the agreements supporting the National Program, appear to be anticipating higher technology application rates than those used in the MY 2011 final rule. This also supported higher phase-in caps of commonly applied technologies for purposes of this final rule.

However, for a few of the more complex and intrusive (from an implementation perspective) technologies, specifically dieselization and stronger hybridization, NHTSA has retained the more stringent phase-in levels used in the 2011 final rule since these technologies represent, for the most part, a significant departure from the vehicle architectures commonly utilized by most OEMs today. As was the case in the 2011 rule, these more stringent phase-in caps limit technology application, i.e., due to the Volpe modeling process, to 3 percent per annum up to a maximum of 15 percent by the 2016 model year.[138] Additionally, for some technologies that are not available in certain model years, a phase-in cap of 0 percent is shown for those model years, such as the combustion restart technology that is not determined to be available until 2014; hence the values of 0 percent for MYs 2012 and 2013 shown in Table V-12 below.

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

[138] A 15 percent maximum application rate should not be confused with the overall penetration of the technology, i.e., the amount of the technology applied by the modeling process plus that which existed in the baseline or was installed at the discretion of the manufacturer. Penetration rates typically exceed application rates.

NHTSA received comments from the Alliance and ICCT relating to phase-in caps. The Alliance commented that the higher phase-in caps in the NPRM analysis (as compared to the MY 2011 final rule) "ignore OEM engine architecture differences/limitations," arguing that the agency must consider manufacturing investment and lead time implications when defining phase-in caps. The Alliance also commented that it seems the combining of technologies "isn't being considered" due to most technologies be "phased in at 85%/100% rates by the mid-decade." ICCT did not raise the issue of phase-in caps directly, but commented that the agencies had not provided information in the proposal documents explaining when each manufacturer can implement the different technologies and how long it will take the technologies to spread across the fleet. ICCT argued that this information was crucial to considering how quickly the stringency of the standards could be increased, and at what cost.

In response to the Alliance comments, the phase-in cap constraint is, in fact, exactly intended to account for manufacturing investment and lead time implications, as discussed above: phase-in caps are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), to help ensure that resource capacity is accounted for in the modeling process. Although the phase-in caps for the analysis supporting these standards are higher than the phase-in caps employed in the MY 2011 final rule, as stated above, the agencies considered the fact that manufacturers, as part of the agreements supporting the National Program, appear to be anticipating higher technology application rates during the rulemaking timeframe. Additionally, the agencies did not receive any comments from manufacturers indicating a concern with the proposed application rates after reviewing the detailed manufacturer level model outputs. The agencies believe that as manufacturers focus their resources (*i.e.*, engineering, capital investment, etc.) on fuel economy-improving technologies, many of which have been in production for many years, the application rates being modeled are appropriate for the timeframe being analyzed. Regarding the Alliance's comments about the consideration of technology combinations, the 85%/100% phase-in caps do not dictate the level of applied technologies. As stated above, phase-in caps are one of the constraints, in combination with other constraints, used to limit technology applications, they are not used to prescribe technology application rates. The model applies different combinations of technologies at differing rates, however most technologies never approach the levels of the phase-in caps.

In response to ICCT's comments, the combination of phase-in caps, refresh/redesign cycles, engineering constraints, etc., are intended to simulate manufacturers' technology application decisions, and ultimately define the technology application/implementation rates for each manufacturer. NHTSA notes that the PRIA and the FRIA do contain manufacturer-specific application/implementation rates for prominent technologies, and that manufacturer-specific technology application as employed in the agency's analysis is available in full in the Volpe model outputs available on NHTSA's website. The model outputs present the resultant application of technologies at the industry, manufacturer, and vehicle levels.

Theoretically, significantly higher phase-in caps, such as those used in the NPRM and this final rule as compared to those used in the MY 2011 final rule, should result in higher levels of technology penetration in the modeling results. Reviewing the modeling output does not, however, indicate unreasonable levels of technology penetration as shown in Tables V-48 and V-49. NHTSA believes that this is due to the interaction of the various changes in methodology applied for the NPRM analysis and carried into this final rule--changes to phase-in caps are but one of a number of revisions to the Volpe model and its inputs that could potentially impact the rate at which technologies are applied in the NPRM and this final rule as compared to prior rulemakings. Other revisions that could impact application rates include the use of transparent CAFE certification data in baseline fleet formulation and the use of other data for projecting it forward,[139] or the use of a multi-year planning programming technique to apply technology retroactively to earlier-MY vehicles, both of which may have a direct impact on the modeling process. Conversely the model and inputs remain unchanged in other areas that also could impact technology application, such as in the refresh/redesign cycle settings, or the effectiveness estimates used for the technologies, both of which remain largely unchanged from the MY 2011 final rule. These changes together make it difficult to predict how phase-in caps should be expected to function in the new modeling process.

Thus, after reviewing the output files, NHTSA believes that the higher phase-in caps, and the resulting technology application rates produced by the Volpe model, at both the industry and manufacturer level, are appropriate for this final rule, achieving a suitable level of stringency without requiring unrealistic or unachievable penetration rates.

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[139] The baseline fleet sets the starting point, from a technology point of view, for where the model begins the technology application process, so changes have a direct impact on the net application of technology.

Table V-12 Phase-in Caps from 2011 Final Rule and Current Rule

Technology	***Final Rule***	***2012-2016 Final Rule Phase-In Caps by Model Year ****				
	MY 2011	***2012***	***2013***	***2014***	***2015***	***2016***
Low Friction Lubricants	50%	100%	100%	100%	100%	100%
Engine Friction Reduction	20%	85%	85%	85%	100%	100%
VVT - Coupled Cam Phasing (CCP) on SOHC	15%	85%	85%	85%	100%	100%
Discrete Variable Valve Lift (DVVL) on SOHC	15%	85%	85%	85%	100%	100%
Cylinder Deactivation on SOHC	9%	85%	85%	85%	85%	85%
VVT - Intake Cam Phasing (ICP)	15%	85%	85%	85%	100%	100%
VVT – Dual Cam Phasing (DCP)	15%	85%	85%	85%	100%	100%
Discrete Variable Valve Lift (DVVL) on DOHC	15%	85%	85%	85%	100%	100%
Continuously Variable Valve Lift (CVVL)	15%	85%	85%	85%	100%	100%
Cylinder Deactivation on DOHC	9%	85%	85%	85%	85%	85%
Cylinder Deactivation on OHV	9%	85%	85%	85%	85%	85%
VVT - Coupled Cam Phasing (CCP) on OHV	15%	85%	85%	85%	100%	100%
Discrete Variable Valve Lift (DVVL) on OHV	15%	85%	85%	85%	100%	100%
Conversion to DOHC with DCP	9%	85%	85%	85%	85%	85%
Stoichiometric Gasoline Direct Injection (GDI)	3%	85%	85%	85%	85%	85%
Combustion Restart	0%	0%	0%	85%	85%	85%
Turbocharging and Downsizing	9%	85%	85%	85%	85%	85%
Exhaust Gas Recirculation (EGR) Boost	0%	0%	85%	85%	85%	85%
Conversion to Diesel following CBRST	3%	3%	6%	9%	12%	15%
Conversion to Diesel following TRBDS	3%	3%	6%	9%	12%	15%
6-Speed Manual/Improved Internals	33%	85%	85%	85%	100%	100%
Improved Auto. Trans. Controls/Externals	33%	85%	85%	85%	100%	100%
Continuously Variable Transmission	5%	85%	85%	85%	85%	85%
6/7/8-Speed Auto. Trans with Improved Internals	50%	85%	100%	100%	100%	100%
Dual Clutch or Automated Manual Transmission	20%	85%	100%	100%	100%	100%
Electric Power Steering	10%	85%	85%	85%	100%	100%
Improved Accessories	10%	85%	85%	85%	100%	100%
12V Micro-Hybrid	3%	85%	85%	85%	85%	85%
Belt mounted Integrated Starter Generator	n/a	85%	85%	85%	85%	85%
Crank mounted Integrated Starter Generator	n/a	3%	6%	9%	12%	15%
Power Split Hybrid	0%	3%	6%	9%	12%	15%
2-Mode Hybrid	0%	3%	6%	9%	12%	15%
Plug-in Hybrid	0%	3%	6%	9%	12%	15%
Mass Reduction (1.50%)	5%	85%	85%	85%	85%	100%
Mass Reduction (5% to 10% Cum)	5%	0%	0%	85%	85%	100%
Low Rolling Resistance Tires	20%	85%	85%	85%	100%	100%
Low Drag Brakes	20%	85%	85%	85%	100%	100%
Secondary Axle Disconnect - Ladder Frame	17%	85%	85%	85%	100%	100%
Aero Drag Reduction	17%	85%	85%	85%	100%	100%

* - a phase-in cap of 0% is shown for the years the technology is unavailable

D. Specific technologies considered for application and NHTSA's estimates of their incremental costs and effectiveness

1. What data sources did NHTSA evaluate?

NHTSA and EPA have done extensive research in identifying the most credible sources of information. These sources included: the 2002 NAS report on the effectiveness and impact of CAFE standards;[140] the 2004 study done by NESCCAF;[141] the California Air Resources Board (CARB) Initial Statement of Reasons in support of their carbon rulemaking;[142] a 2006 study done by Energy and Environmental Analysis (EEA) for the Department of Energy;[143] a study done by the Martec Group for the Alliance of Automobile Manufacturers, and an update by the Martec Group to that study;[144] and vehicle fuel economy certification data. Both agencies also reviewed the published technical literature which addressed the issue of CO_2 emission control and fuel economy, such as papers published by the Society of Automotive Engineers and the American Society of Mechanical Engineers. In addition, confidential data submitted by vehicle manufacturers in response to NHTSA's request for product plans,[145] and confidential information shared by automotive industry component suppliers in meetings with EPA and NHTSA staff held during the second half of the 2007 calendar year were used as a cross check of the public data mentioned above and not as a significant basis for this rulemaking.

EPA also has a contracted study ongoing with FEV that consists of complete system tear-downs to evaluate technologies down to the nuts and bolts to arrive at very detailed estimates of the costs associated with manufacturing them.[146] As a general matter, NHTSA and EPA believe the best way to derive technology cost estimates is to conduct real-world tear down studies. This position is supported by commenters such as ICCT and we received no comments to the contrary.[147] These studies are based to a large degree on tear downs of vehicles or vehicle systems that employ the new technologies, and of similar vehicles or systems without the new technologies. Analysts with expertise

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[140] "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Research Council, National Academy of Sciences, 2002.

[141] "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," Northeast States Center for a Clean Air Future, September 2004 (Docket NHTSA-2009-0059-0021).

[142] "Staff Report: Initial Statement of Reasons for Proposed Rulemaking," California Environmental Protection Agency, Air Resources Board, Regulations to Control Greenhouse Gas Emissions from Motor Vehicles, August 6, 2004 (Docket NHTSA-0059-0030).

[143] "Technology to Improve the Fuel Economy of Light Duty Trucks to 2015," Energy and Environmental Analysis, Inc., May 2006 (Docket NHTSA-2009-0059-0028).

[144] "Variable Costs of Fuel Economy Technologies," prepared for The Alliance of Automobile Manufacturers, June 1, 2008; and, "Variable Costs of Fuel Economy Technologies," prepared for The Alliance of Automobile Manufacturers, June 1, 2008, Amended December 10, 2008 (Docket NHTSA-2009-0059-0023).

[145] 74 FR 9185 (Mar. 3, 2009)

[146] "Draft Report – Light-Duty Technology Cost Analysis Pilot Study," U.S. Environmental Protection Agency, Contract No. EP-C-07-069, Work Assignment 1-3, September 3, 2009

[147] See comments from ICCT (EPA-HQ-OAR-2009-0472-7156), CARB (EPA-HQ-OAR-2009-0472-7189), NESCAUM (EPA-HQ-OAR-2009-0472-7235)

in automotive design, materials, and manufacturing then compare the tear down components and evaluate the differences. Using databases for materials, labor, manufacturing overhead and mark-up costs, the overall costs to manufacture individual parts are calculated and summed into final results. However, as such, tear down studies require a significant amount of time and are very costly. EPA has begun conducting tear down studies to assess the costs of 4-5 technologies under a contract with FEV Inc., an independent engine and powertrain systems research, design and development company. To date, four technologies (downsizing and turbocharging, stoichiometric gasoline direct-injection, dual clutch transmission and 6-speed automatic transmission) have been evaluated. The tear down study has been peer-reviewed and the report for these tear down studies and the peer-review report have been made public in the rulemaking docket. The agencies have considered these studies and the comments received on them, as practicable and appropriate, in developing technology cost assumptions for this final rule.

These recently completed tear-downs include the following technologies:

1. 3.0L V6 port fuel-injected (PFI) downsized and turbocharged to a 2.0L I4 gasoline direct injection (GDI)
2. 5.4L V8 PFI downsized and turbocharged to a 3.0L V6 twin-turbo GDI
3. 5-speed automatic transmission to 6-speed automatic transmission
4. 6-speed automatic transmission to 6-speed wet dual-clutch transmission

A comparison between costs reported in the NPRM and the final rule can be found in Table V-13 below.

Table V-13. A comparison of NPRM costs and the final rule for five updated technologies ($2007 in 2012).

Technology	Incremental To	NPRM Direct Manufacturing Cost	Final Rule Direct Manufacturing Cost	Change
2.0L I4 Turbo GDI	3.0L V6 MPFI	$248	$152	-$96
3.0L V6 twin-turbo GDI	5.4L V8 MPFI	$1,081	$964	-$117
5-speed auto trans	4-speed auto trans	$91	$91	$0
6-speed auto trans	4-speed auto trans	$153	$101	-$52
6-speed auto trans	5-speed auto trans	$62 *	$9	-$53
6-speed dual-clutch trans (wet)	6-speed auto trans	$126	-$11	-$137

* Calculated as the difference between the 4 to 6 speed trans ($153) and the 4 to 5 speed trans ($91).

FEV tear down cost analysis studies were conducted based on the assumption that the analyzed technologies and the manufacturing for those technologies were both fully "mature," in that designs and manufacturing processes have been reasonably optimized. The studies also assumed that manufacturing facilities have annual production levels of 450,000 units. EPA and NHTSA recognize that in early implementation years, designs and manufacturing processes may not be optimized to that extent, and investment cost may exceed those of fully mature technologies. To account for higher cost in the earlier implementation years of the rulemaking period, NHTSA and EPA estimated MY 2012 costs as the average of the FEV tear down study cost and the NPRM cost for technologies for which there were completed FEV tear down studies. Time-based learning is used to reflect cost in later years. This approach is applied to downsizing and turbocharging for V6 and V8, stoichiometric gasoline direct-injection for V6 and V8, dual clutch transmission and 6-speed automatic transmission. In the NPRM, the costs for turbocharging, downsizing and SGDI for I4 engines were based on an FEV teardown cost study that was completed prior to release of the NPRM. For the final rule, these costs were carefully reviewed and updated to better account for early year implementation costs.

EPA and NHTSA reviewed all this information in order to develop the best estimates of availability, cost and effectiveness of these fuel-saving/CO_2-reducing technologies. NHTSA and EPA are confident that the thorough review conducted, led to the best available conclusion regarding technology costs and effectiveness estimates for the current rulemaking and resulted in excellent consistency between the agencies' respective analyses for developing the CAFE and CO_2 standards.

The agencies would also like to note that per the Energy Independence and Security Act (EISA), the National Academies of Sciences is conducting an updated study to update chapter 3 of their 2002 NAS Report, which presents technology effectiveness estimates. The update will take a fresh look at that list of technologies and their associated cost and effectiveness values. Some of specific tasks that NAS will undertake in updating the technology chapter are to define and document specific methodologies and input parameters to account for the sequential application and incremental benefits and costs of technologies, including the methods used to account for variations in vehicle characteristics (*e.g.*, size, weight, engine characteristics). Some methodologies might involve simple mathematical relationships (*e.g.*, cost per cylinder). Others might involve matrices (*e.g.*, of effectiveness versus vehicle category or versus the presence of other technologies) or more complex structural representations (*e.g.*, decision trees). In addition, NAS will identify and assess leading computer models for projecting vehicle fuel economy as a function of additional technology. These models would include both lumped-parameter (or Partial Discrete Approximation) type models, where interactions between technologies are represented using energy partitioning and/or scalar adjustment factors (aka "synergy" factors), and full vehicle simulation, in which such interactions are analyzed using explicit drive cycle and engine cycle simulation, based on detailed vehicle engineering characteristics (*e.g.*, including engine maps, transmission shift points, etc.). Finally, NAS will examine the effectiveness and impacts of vehicle weight and engine size/horsepower reductions which will be limited to advances in structural design and lightweight materials.

The updated NAS report was expected to be available on September 30, 2009, but has not been completed and released to the public. The updated report is currently undergoing various levels of required review. It is anticipated that the final report will be published after the publication of this final rule, thus the results from this study thus are unavailable for this rulemaking. The agencies look forward to considering the results from this study as part of the next round of rulemaking for CAFE standard.

The Indirect Cost Methodology (ICM)

Indirect costs include production-related costs (research, development, and other engineering), business-related costs (corporate salaries, pensions and manufacturer profits), and retail-sales-related costs (dealer support, marketing and dealer profits). For this analysis, direct cost estimates were first developed for each technology or system at the auto manufacturer level, *i.e.*, the price paid by the manufacturer to a Tier 1 component supplier. To these costs, an indirect cost markup factor was then applied that varied by the best estimate of the particular technology's complexity. This section describes the approach to determining the indirect cost multipliers (ICM) used in this analysis and the specific multipliers used for each piece of technology.

Concept behind and development of indirect cost multipliers

If all desirable data were available, when a new technology is implemented, the costs of that technology would include the direct and indirect costs particular to that technology. For instance, some changes may involve new tooling, while others may not; some may affect the way the car is marketed, while others are of limited interest to consumers. In a world of full information, the indirect costs of a new technology would be calculated specifically for that technology. In practice, though, it is often difficult, if not impossible, to identify the indirect costs specific to a new technology.

The automotive industry, EPA, and NHTSA have commonly used retail price equivalent (RPE) multipliers to approximate the indirect costs associated with a new technology. The RPE is a ratio of total revenues to direct manufacturing costs. Because, by definition, total revenues = direct costs + indirect costs + profit, the RPE is the factor that, when multiplied by direct manufacturing costs, recovers total revenue.[148] This multiplication is accurate only in the aggregate; it does not in reality apply to any specific technology. The RPE is a way to estimate indirect costs on the assumption that indirect costs are constant across all technologies and processes in a company. In the MY 2011 CAFE final rule NHTSA utilized a 1.5 RPE multiplier.

In fact, however, the indirect costs of new technologies vary, both with the complexity of the technology and with the time frame. For instance, a hybrid-electric engine is likely to involve greater research and development and marketing costs per dollar of direct costs than low-rolling-resistance tires; the research and development costs of any technology are likely to decrease over time. In recognition of this concern, EPA contracted with RTI International to provide a current estimate of the RPE multiplier and to examine whether the indirect costs of new technologies are likely to vary across technologies. The report "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," by Alex Rogozhin, Michael Gallaher, and Walter McManus,[149] calculates the RPE multiplier as

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[148] Note that unlike the RPE, the ICM does not include profits.

[149] Rogozhin, Alex, Michael Gallaher, and Walter McManus, "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," EPA 420-R-09-003, February 2009, http://epa.gov/otaq/ld-hwy/420r09003.pdf (last accessed on March 15, 2010).

1.46 in 2007. The report then develops indirect cost (IC) multipliers that vary with the complexity of technology and the time frame. While any multiplier is only an approximation of the true indirect costs of a new technology, the IC multipliers in this report move away from the assumption that the proportion of indirect costs is constant across all technologies and take into account some of the variation in these costs. The multipliers developed in this report are presented in Table V-14.

The agencies received comments from The National Automobile Dealers Association (NADA) stating that all cost associated with dealer costs-of sales, including consumer finance costs, should be accounted for in "dealer profits." The agencies have included dealer costs-of-sales (selling costs) in the indirect cost multiplier (ICM)—which makes up part of the final technology costs—as a unique element. There is no compelling reason to include those costs in the "dealer profit" element of the ICM. As for the finance costs paid by consumers, it is important to note that from a social perspective, the costs of the rule are the technology costs themselves and do not include the finance costs. While those costs are incurred by consumers, they are merely transfer costs from the perspective of regulatory cost analysis. We have included financing costs in our consumer welfare analysis since costs there are not social costs but rather personal costs.

The indirect cost multipliers used adjustment factors, developed by a team of EPA engineers with expertise in the auto industry, which accounted for the differences in complexity of the specific technologies under study. To examine the sensitivity of the results to different technologies of the same complexity, and to provide more detailed documentation of the development of the adjustment factors, EPA convened a second panel,[150] with NHTSA's input, to develop adjustment factors for three different technologies. This latter process allowed for estimates of the variation in adjustment factors, and thus in the variation of indirect cost multipliers. These results are also presented in Table V-14.

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[150] "Memorandum: Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Gloria Helfand and Todd Sherwood, Office of Transportation and Air Quality, U.S. Environmental Protection Agency (Docket EPA-HQ-OAR-2009-00472-0158).

Table V-14. Indirect Cost Multipliers

STUDY	TECHNOLOGY COMPLEXITY							
	Short Run				Long Run			
	Low	Medium	High		Low	Medium	High	
RTI Report	1.05	1.20	1.45		1.02	1.05	1.26	
EPA Memo: Average	1.16	1.29	1.64		1.12	1.20	1.39	
Standard Deviation	0.14	0.15	0.21		0.14	0.13	0.15	
Median	1.12	1.26	1.66		1.06	1.20	1.40	
Max	1.43	1.53	2.15		1.42	1.45	1.69	
Min	1.00	1.02	1.37		1.00	1.01	1.12	
Multipliers Used in this Analysis	1.11	1.25	1.45	1.64	1.07	1.13	1.26	1.39

The table shows minor differences in the multipliers for low- and medium-complexity technologies (roughly 0.1), but larger differences in the high-complexity technologies. The EPA and NHTSA engineers who reviewed the results believed that the differences reflected actual differences in the technologies under study. In particular, for low complexity, low-rolling-resistance tires (the application in the RTI Report) would involve lower indirect costs than aerodynamic improvements (the application in the EPA memo); and, for medium complexity, dual-clutch transmissions (the application in the RTI Report) should have a smaller multiplier than engine downsizing done in conjunction with turbocharging (the application in the EPA Memo). For these two cases, EPA and NHTSA considered these technologies to span the range of technologies assigned to those classes; the costs in this study, then, use the averages of the values of the two reports, as shown in the last line of Table V-14. For high complexity technologies, the agencies felt the technologies assigned to these categories—hybrid-electric vehicles in the RTI Report; plug-in hybrid electric vehicles in the EPA Memo—were sufficiently different that each deserved a different category. This is discussed in more detail in the next section which highlights the multipliers used for each specific technology.

Application of specific indirect cost multipliers to each technology

As noted in the previous section and in the NPRM a different ICM was applied to each technology's direct cost to arrive at its compliance cost. These different ICMs were chosen based on the complexity of integrating the technology into the vehicle in the opinions of staff engineers at EPA and NHTSA, most of whom have several years of experience in the auto industry. As shown in Table V-14, ICMs were developed via two separate processes: that presented in the RTI report; and that presented in the EPA Memo. While all of the ICMs generated via these two processes were in general agreement, some differences did exist. In determining how to deal with these differences, EPA and NHTSA agreed that, for the low and medium complexity technologies, a simple average of the two values would be used. However, for the high complexity technologies, it was decided that two separate high-multipliers should be used. The lower multiplier, deemed high, would be applied to those technologies of high complexity but with some level of use in the marketplace today. Such technologies would be power-split and 2-mode hybrid electric vehicles. The higher multiplier, deemed high+, would be applied to those technologies of high complexity but with no, or essentially no, use in the current fleet. Such technologies would be plug-in hybrids and full electric vehicles.

Table V-15 shows the complexity level for each technology considered in this analysis.

Table V-15. Complexity Levels of Technologies

LOW COMPLEXITY	MEDIUM COMPLEXITY	HIGH COMPLEXTIY	HIGH+ COMPLEXITY
Low friction lubes (LUB)	Combustion Restart (CBRST)	Continuously variable valve lift (CVVL)	Plug-in hybrid
Engine friction reduction (EFR)	Exhaust gas recirculation boost (EGRB)	2-mode hybrid (2MHEV)	Full electric vehicle
Intake cam phasing (ICP)	Belt integrated starter generator (BISG)	Power-split hybrid (PSHEV)	
Coupled cam phasing (CCPO) and (CCPS)	Turbocharge with downsize (TRBDS)	Crankshaft integrated starter generator (CISG)	
Dual cam phasing (DCP)	Conversion to diesel (DSLC) and (DSLT)		
Cylinder deactivation (DEACS), (DEACD), and (DEACO)	Dual clutch transmission (DCTAM)		
Discrete variable valve lift (DVVLS), (DVVLO) and (DVVLD)	Continually variable transmission (CVT)		
Stoichiometric gasoline direct injection (SGDI)	12 volt micro hybrid (MHEV)		
Conversion to DOHC with DCP (CDOHC)			
6/7/8-speed auto transmission (NAUTO)			
Improved auto transmission (IATC)			
6-speed manual transmission (6MAN)			
Improved accessories (IACC)			
Electric power steering (EPS)			
Low rolling resistance tires (ROLL)			
Low drag brakes (LDB)			
Secondary axle disconnect (SAXU/SAXL))			
Improved aerodynamics (AERO)			
Mass reduction (MS1) 1.5%			
Mass reduction (MS2) 3.5 - 8.5%			

ICCT commented that the integration aspect of a technology needs to be considered when defining technology complexity levels for purposes of ICM applications. While assigning ICM complexity levels to each technology used in the NPRM the agencies took into account the integration challenges with each technology. After considering the comments and evaluating the complexity levels of each technology relative to assigned complexity levels of other technologies the agencies still believe the complexity levels assigned in the NPRM to be valid. Thus for purposes of this final rule the complexity level assignments will be the same as those in the NPRM. For future rulemakings that agencies will re-evaluate the current list of technologies and emerging technologies to determine the appropriate technology complexity levels.

The estimates of vehicle compliance costs cover the years of implementation of the program – 2012 through 2016. In EPA's analysis, compliance costs have also been estimated for the years following implementation to shed light on the long term – 2022 and later – cost impacts of the rule. The year 2022 is used by EPA because the short-term and long-term markup factors described above are applied in five year increments with the 2012 through 2016 implementation span and the 2017 through 2021 span both representing the short-term.

One of the sensitivity analyses performed by NHTSA for this final rule was to evaluate the effects of using the Retail Price Equivalent (RPE) multiplier employed in the MY 2011 CAFE final rule and in other NHTSA rulemakings, instead of using the Indirect Cost Multiplier (ICM) developed for this rulemaking. The RPE methodology multiplies variable costs by 1.5 to estimate consumer costs. The 1.5 multiplier is a general increase that is applied consistently to every technology and consists of fixed costs and profits for the manufacturer and automobile dealers. The indirect cost multiplier is estimated depending upon the complexity of the technology and in the aggregate for the technologies utilized in the model results in a multiplier in the 1.2 to 1.25 range and does not include profits. The sensitivity analysis indicates that using 1.5 RPE multiplier would result in noticeably higher costs compared to the final rule costs incorporating the ICM multiplier, although we note that even with those higher costs the 1.5 RPE analysis still resulted in significant net benefits for the rulemaking as a whole[151]. The agency plans to investigate this issue further for future rulemakings.

2. Individual technology descriptions and cost/effectiveness estimates

The technology cost and effectiveness estimates used in the Volpe Model are defined in this section and are summarized in the tables at the end of the section. Related to costs the Volpe Model handles learning effects within the model itself so that individual technology costs in the 2016 model year would be lower than those in previous years. The costs in this section and the summary tables are for model year 2012 vehicles and, therefore, represent fully learned costs in the context of EPA's analysis. For technologies added in years prior to 2016, EPA has backed out the learning effects relative to the costs shown in the tables. For example, the small car stop-start vehicle cost is $351 in 2016. In the 2012 model year, this cost would be higher since the volume-based learning reflected in the 2016 cost would not have occurred yet. Backing out two volume-based learning steps (*i.e.*, dividing $351 by 80% twice) would result in a 2012 cost estimate of $548.

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[151] *See* Section X. below for the results of the sensitivity analyses.

(a) Gasoline Engine Technologies

(i) Overview

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, as shown in Table V-16 below.

Table V-16. Technology Characterization by Type of Loss Reduced

Technology	**Heat Loss Reduction**	**Exhaust Energy Reduction**	**Gas Exchange Reduction**	**Friction Reduction**
Low Friction Lubricants				✓
Engine Friction Reduction				✓
VVT - Coupled Cam Phasing (CCP) on SOHC			✓	
Discrete Variable Valve Lift (DVVL) on SOHC			✓	
Cylinder Deactivation on SOHC			✓	
VVT - Intake Cam Phasing (ICP)			✓	
VVT - Dual Cam Phasing (DCP)			✓	
Discrete Variable Valve Lift (DVVL) on DOHC			✓	
Continuously Variable Valve Lift (CVVL)			✓	
Cylinder Deactivation on DOHC			✓	
Cylinder Deactivation on OHV			✓	
VVT - Coupled Cam Phasing (CCP) on OHV			✓	
Discrete Variable Valve Lift (DVVL) on OHV			✓	
Conversion to DOHC with DCP			✓	
Stoichiometric Gasoline Direct Injection (GDI)		✓		
Combustion Restart				✓
Turbocharging and Downsizing			✓	✓
Exhaust Gas Recirculation (EGR) Boost		✓	✓	✓
Conversion to Diesel	✓	✓	✓	

✓ Represents area of primary influence

As Table V-16 shows, 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.

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. The latter is not considered to be at the emerging technology point yet due to the non-availability of lean NO_x aftertreatment, as discussed below. However, the compression ratio may potentially be raised by 1 to 1.5 ratios using stoichiometric direct fuel injection.

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 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 it is important to note that 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 revised decision trees, the effectiveness value shown for additional technologies targeting pumping loss depends on the existing technology combination already present on the engine.

a. Engine Technologies

NHTSA and EPA have reviewed the engine technology estimates used in NHTSA’s MY 2011 CAFE final rule and EPA’s 2008 Staff Report and available comments to the NPRM. In doing so NHTSA and EPA reconsidered all available sources and updated estimates as appropriate. The section below describes each of the engine technologies considered for this rulemaking.

(1) 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. For purposes of this final rule, NHTSA is using an effectiveness estimate within this range. Therefore 0.5 percent is used.

The 2002 NAS study estimated the low friction lubricant RPE at $8 to $11 using a 1.4 markup factor. The NESCCAF study showed an RPE of $5 to $15 with a 1.4 markup. The EEA report to DOE showed manufacturer costs of $10 to $20 with no markup. Confidential Business Information (CBI) data estimates an average incremental cost of $3 for the use of low friction lubricants. EPA's 2008 Staff Report also confirms this $3 cost (2006$). NHTSA believes that manufacturer's estimates are the most accurate, and thus continues to believe that the $3 cost estimate is appropriate and independent of vehicle class since the engineering work required should apply to any engine size. Applying an indirect cost multiplier (ICM) of 1.11, for a low complexity technology, results in a compliance cost of $3.33 per vehicle (2007 Dollars) for a MY 2012 through MY 2016 vehicle. The costs developed for low friction lubricants reflect the costs associated with any engine changes that would be required as well as any durability testing.

Neither volume-based cost reductions nor time-based cost reductions are applied to low friction lubricants. This technology is presumed to be significantly dependent on commodity raw material prices and to be priced independent of particular design or manufacturing savings. This technology can be applied to any vehicle class with a phase-in of 100 percent starting in MY 2012.

(2) Engine Friction Reduction (EFR)

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.[152] 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-

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[152] "Impact of Friction Reduction Technologies on Fuel Economy," Fenske, G. Presented at the March 2009 Chicago Chapter Meeting of the 'Society of Tribologists and Lubricated Engineers' Meeting, March 18th, 2009. Available at: http://www.chicagostle.org/program/2008-2009/Impact%20of%20Friction%20Reduction%20Technologies%20on%20Fuel%20Economy%20-%20with%20VGs%20removed.pdf (last accessed March 15, 2010).

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. The 2002 NAS, NESCCAF and EEA reports as well as confidential manufacturer data suggested a range of effectiveness for engine friction reduction to be between 1 to 3 percent. NHTSA continues to believe that this range is accurate. Because of the incremental nature of the Volpe model, NHTSA needed to continue to use the narrower range of 1-2 percent, which was also used in the MY 2011 CAFE final rule.

In the MY 2011 CAFE final rule, NHTSA estimated a range from $13 to $49 using a 1.5 RPE on a per cylinder basis, or $9 to $33 without RPE (2007 Dollars). In the 2008 NPRM engine friction reduction was estimated to cost up to $14 without RPE on a per cylinder basis. After review, NHTSA believes that the cost estimate is closer to the lower end of the MY 2011 CAFE final rule range and thus for this rulemaking has a compliance cost of $13 per cylinder (2007 Dollars), including the low complexity ICM markup value of 1.11, for a MY 2012 vehicle. This cost is multiplied by the number of engine cylinders for Volpe modeling purposes. Thus a cost of $50 was used for a 4-cylinder engine, $75 for a 6-cylinder engine and $101 for an 8-cylinder engine for this final rule.

Engine friction-reducing technologies may be applied to all vehicle classes. No learning factors were applied to costs as the technology has a loosely defined BOM which may in part consist of materials (surface treatments, raw materials) that are commodity based. As confirmed by manufacturers' comments, NHTSA has maintained as it did in the MY 2011 final rule, that engine friction reduction may only be applied in conjunction with a refresh or redesign cycle. Engine friction has phase-in cap of 85 percent from MY 2012 to 2014 and then increases to 100 percent for the rest of this rule making period.

(3) Variable Valve Timing (VVT)

Variable valve timing (VVT) classifies 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 the 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 2007, over half of all new cars and light trucks had engines with some method of variable valve timing.[153] GM has

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[153] "Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2007", EPA420-S-07-001, September 2007. Available at http://www.epa.gov/oms/cert/mpg/fetrends/fetrends-archive.htm (last accessed March 15, 2010).

commented that variable valve timing is in production on most of its engine families. 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 the proper level of VVT technology, if any, is applied. The three major types of VVT are listed below.

Each of the three implementations of VVT uses a cam phaser to adjust the camshaft angular position relative to the crankshaft position, referred to as "camshaft phasing." The phase adjustment results in changes to the pumping work required by the engine to accomplish the gas exchange process. The majority of current cam phaser applications use hydraulically-actuated units, powered by engine oil pressure and managed by a solenoid that controls the oil pressure supplied to the phaser.

In response to the NPRM, NHTSA received comments from GM that included a description of technical considerations, concerns, limitations and risks that need to be considered when implementing variable valve timing or variable valve lift. NHTSA judges that the expressed technical considerations, concerns, limitations and risks are well recognized within the industry and it is standard industry practice to address each during the design and development phases of applying variable valve timing or variable valve lift technologies. Cost and effectiveness estimates used in the final rule are based on analysis that assumes each of these factors is addressed prior to production implementation of the technologies.

(a) ***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.

NHTSA's MY 2011 CAFE final rule and EPA's 2008 Staff Report estimated an effectiveness of 1 to 2 percent for ICP, which was supported by the NESCCAF report and a majority of confidential manufacturer comments. NHTSA has found no additional sources to suggest strongly that this estimate is inaccurate, and so have continued to employ it for this rulemaking.

As for costs, NHTSA's MY 2011 CAFE final rule estimated a $61 RPE ($41 non-RPE) cost per cam phaser, based on the 2008 Martec Report and confidential manufacturer data. NHTSA believes that this number remains accurate. Using the new indirect cost multiplier of 1.11, for a low complexity technology, the compliance cost per cam phaser

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would be $45 per bank, yielding a $45 cost for and in-line engine configurations and $90 for V-engine configurations for a MY 2012 vehicle.

ICP is applicable to all vehicle classes, can be applied at the refresh or redesign cycles and is eligible for time-based learning. For this rulemaking and as it did for the MY 2011 final rule, NHTSA has combined the phase-in caps for ICP, CCPS, CCPO and DCP. This combined phase-in cap is 85 percent from MY 2012 to 2014 and then increases to 100 percent for the rest of this rule making period.

(b) ***<u>Coupled Cam Phasing (CCPS and CCPO)</u>***

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.[154]

Based on NHTSA's MY 2011 CAFE final rule, previously-received confidential manufacturer data, and the NESCCAF report, NHTSA estimated the effectiveness of CCP to be between 1 to 4 percent. NHTSA reviewed this estimate for purposes of the NPRM, and continue to find it accurate. Due to the incremental nature and decision tree logic of the Volpe model, NHTSA estimated the effectiveness for CCPS to be 1 to 3 percent and 1 to 1.5 percent for CCPO.

The same cam phaser has been assumed for ICP and CCP applications, thus CCP's cost per cam phaser is identical to ICP's. This results in a cost of $45 for in-line SOHC and OHV engines and $90 for SOHC V-engine configurations for a MY 2012 vehicle with time-based learning applied.

CCP is applicable to all vehicle classes and can be applied at refresh or redesign. For purposes of this rulemaking as in the MY 2011 final rule, NHTSA has combined the phase-in caps for ICP, CCPS, CCCPO and DCP. This combined phase-in cap is 85 percent from MY 2012 to 2014 and then increases to 100 percent for the rest of this rule making period.

(c) ***<u>Dual Cam Phasing (DCP)</u>***

The most flexible VVT design is dual (independent) cam phasing, where the intake and exhaust valve opening and closing events are controlled independently. This option 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

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[154] It is also noted that coaxial camshaft developments would allow other VVT options to be applied to OHV engines. However, since they would potentially be adopted on a limited number of OHV engines NHTSA did not include them in the decision tree.

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.

In the MY 2011 final rule, NHTSA estimated the effectiveness of DCP to be between 2 to 3 percent relative to an engine with ICP. NHTSA believes that this estimate remains applicable for this rulemaking.

As with CCP, the same cam phaser has been assumed for ICP and DCP applications. Thus, DCP’s cost per cam phaser is identical to ICP’s. DCP requires two cam phasers per cylinder bank, one to control the intake valves and one to control the exhaust valves. This results in a cost of $90, relative to an engine without ICP, or $45 relative to an engine with ICP, minus $6 for the removal of the EGR valve, ultimately yielding costs of $84 and $39 respectively for in-line DOHC configurations. For V-configuration engines, the cost is $180 relative to an engine without ICP, or $90 relative to an engine with ICP, minus $6 for the removal of the EGR valve, ultimately yielding costs of $174 and $84, respectively. These costs are appropriate for a MY 2012 vehicle application.

DCP can be applied to all of the vehicle classes at vehicle refresh. Time-based leaning is applied and NHTSA has combined the phase-in caps of ICP, CCPS, CCPO and DCP with a combined cap of 85 percent for MY 2012 to 2014 and increases to 100 percent for the rest of this rule making period.

In response to the NPRM, NHTSA received comments from a manufacturer that included confidential business information related to the effectiveness of variable valve timing technology. Analysis of the data, that used assumptions similar to those used in the NPRM and final rule, showed that effectiveness values are similar to those used in the NPRM and final rule.

(4) Variable Valve Lift (VVL)

Controlling the lift of the valves provides a potential for further efficiency improvements. By optimizing the valve-lift profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. By moving the throttling losses further downstream of the throttle valve, the heat transfer losses that occur from the throttling process are directed into the fresh charge-air mixture just prior to compression, delaying the onset of knock-limited combustion processes. Variable valve lift control can also be used to induce in-cylinder mixture motion, which improves fuel-air mixing and can result in improved thermodynamic efficiency. Variable valve lift control can also potentially reduce overall valvetrain friction. At the same time, such systems may also incur increased parasitic losses associated with their actuation mechanisms. A number of manufacturers have already implemented VVLT 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, described below:

Discrete Variable Valve Lift (DVVLS, DVVLD, DVVLO)

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.

NHTSA's MY 2011 CAFE final rule, previously-received confidential manufacturer data, and the NESCCAF report, all estimate the effectiveness of DVVL to be between 1 to 4 percent above that realized by VVT systems. NHTSA believes this estimate continues to be applicable for the final rule. Taking into account the incremental nature and decision tree logic of Volpe modeling, NHTSA has estimated an incremental reduction in fuel consumption for DVVLS and DVVLD of 1 to 3 percent. On OHV engines, DVVLO is applied following both VVT and cylinder deactivation, therefore the effectiveness estimate is at a slightly lower range of 0.5 to 2.5 percent.

In the MY 2011 CAFE final rule, NHTSA estimated an RPE (1.5 markup factor) cost of $201 for an inline 4-cylinder engine, $306 for a V6 engine and $396 for a V8 engine or without RPE $134, $204, $264, respectively (all in 2007 Dollars). After review, NHTSA, in consultation with EPA, has chosen to use the NESCCAF report as the basis for the discrete variable valve lift cost. The NESCCAF estimates were converted to 2007 dollars, updated for a MY 2012 application, increased by $25 for additional controls hardware and multiplied by the low complexity ICM markup factor or 1.11. For this final rule, NHTSA is using a compliance cost estimate of $141 for an inline 4-cylinder engine, $205 for a V6 engine and $293 for a V8 engine.

In response to the NPRM, NHTSA received comments from GM that implementation of either 2-step or continuously variable lift must be timed to coincide with changes to the engine cylinder head. In the NPRM and final rule, NHTSA limits application of these technologies to vehicle redesign, which is judged to approximate the frequency of engine cylinder head changes. This technology may be applied to any class of vehicles. NHTSA has combined the phase-in caps for DVVLS, DVVLD, DVVLO and CVVL, as it did in the MY 2011 final rule, and capped the joint penetration allowed at 85 percent in MY 2012 to 2014 and increases to 100 percent for the rest of this rule making period with time-based learning applied.

1. *Continuously Variable Valve Lift (CVVL)*

In CVVL systems, valve lift is varied by means of a mechanical linkage, driven by an actuator controlled by the engine control unit. The valve opening and phasing vary as the lift is changed and the relation depends on the geometry of the mechanical system. BMW has considerable production experience with CVVL systems and has sold port-injected "Valvetronic" engines since 2001. 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.

NHTSA's MY 2011 CAFE final rule estimated the effectiveness for CVVL at 1.5 to 3.5 percent over an engine with DCP, but also recognized that it could go up as high as 5% above and beyond DCP to account for the implementation of more complex CVVL systems such as BMW's "valvetronic" engines. This coincides with EPA Staff Report estimates of the contribution of CVVL, which were based on the NESCCAF report, in which CVVL could improve effectiveness by 4 percent (minivans) and up to 6 percent (large cars) over dual cam phasing. For this rulemaking, NHTSA has continued to use the 1.5 to 3.5 percent range from the MY 2011 final rule. However, due to the complexity and cost of this technology, the Volpe model projected very limited applications of this technology (*i.e.*, 2 out of 1100 vehicles). The most recent submission of manufacturers' product plans confirmed that this technology will not be applied by most manufacturers.

In the MY 2011 CAFE final rule, NHTSA estimated and RPE (1.5) cost of continuously variable valve lift to be $306 for an inline 4-cylinder engine, $432 for a V6 engine and $582 for a V8 engine or without RPE $204, $287, $388, respectively. After review, NHTSA in consultation with EPA has chosen to use the NESCCAF report as the basis for the discrete variable valve lift cost. The NESCCAF estimates were converted to 2007 dollars, updated for a MY 2012 application, increased by $25 for additional controls hardware and multiplied by the low complexity ICM markup factor or 1.45 For this rulemaking, NHTSA estimated a cost of $277 for an inline 4-cylinder engine, $509 for a V6 engine and $554 for a V8 engine with time-based learning applied.

There are no class specific applications of this technology, although it appears in only the DOHC portion of the decision tree. Due to the changes required to implement CVVL on an engine the Volpe model allows it to be applied at redesign model years only with time-based learning applied. NHTSA has combined the phase-in caps for DVVLS, DVVLD, DVVLO and CVVL, as in the MY 2011 final rule, and capped the joint penetration allowed at 85 percent in MY 2012 to 2014 and the increases to 100 percent for the rest of this rule making period.

In response to the NPRM, NHTSA received comments from GM that the introduction of additional technologies such as 2-step variable lift will be highly dependent on the cost-effectiveness of the technology from a fuel economy benefit standpoint. The Volpe model provides one solution that manufacturers could use to meet CAFE regulations to demonstrate the feasibility of regulatory standards. It is expected that in many cases, manufacturers will identify and implement other combinations of technologies to achieve CAFE regulatory compliance, based on their unique circumstances.

In response to the NPRM, NHTSA received comments from a manufacturer that included confidential business information related to the effectiveness of variable valve lift technology. Analysis of the data, that used assumptions similar to those used in the NPRM and final rule, showed that effectiveness values are similar to those used in the NPRM and final rule.

(5) 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 reduce the operating range to which cylinder deactivation is allowed, although manufacturers are exploring vehicle changes that enable the possibility of 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. Manufacturers have stated that use of DEAC on 4 cylinder engines would cause unacceptable NVH issues; therefore cylinder deactivation has not been applied to 4-cylinder engines.

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 (Odyssey, Pilot) offers V6 models with cylinder deactivation.

Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently.

NHTSA reviewed the MY 2011 CAFE estimates and confirmed their appropriateness for this rulemaking. The Volpe model, due to its incremental nature, uses a range depending on the engine valvetrain configuration. For example, for DOHC engines which are already equipped with DCP and DVVLD, there is little benefit that can be achieved from adding cylinder deactivation since the pumping work has already been minimized and internal Exhaust Gas Recirculation (EGR) rates are maximized, so the effectiveness range for DEACD is 0.0 to 0.5 percent. For SOHC engines which have CCP and DVVLS applied, effectiveness ranged from 2.5 to 3 percent for DEACS. For OHV engines, without VVT or VVL technologies, the effectiveness for DEACO ranged from 3.9 to 5.5 percent.

NHTSA considered a range of $28 to $190 depending on whether an engine already has lost motion devices, oil control valves and camshaft position sensors. This is a departure from NHTSA's 2011 final rule, which uses a range of $306 to $400. That range was primarily based on 2008 Martec Report and applied a higher RPE value. In reviewing these assumptions, NHTSA in consultation with EPA amended the MY 2011 CAFE estimates and adjusted the estimates to include the new ICM low complexity markup of 1.11. The EPA staff report and NHTSA's MYs 2011-2015 NPRM showed estimates of a $170 for a 6-cylinder engine and $190 for an 8-cylinder engine when adjusted for 2007 dollars and using the new ICM multipliers for engines that do not have lost motion devices. These numbers were within the ranges described by the 2002 NAS and NESCCAF reports. For Volpe modeling purposes, these costs are appropriate for DEACO on OHV engines. If lost motion devices are on the engine, as is the case for SOHC and DOHC engines based on the decision tree logic, the cost of DEACS and DEACD ranges from $0 to $56. This $0 to $56 range[155] accounts for the potential additional application of active engine mounts on SOHC and DOHC engines and can only be applied on 50 percent of the vehicles.

This technology may be applied only to V-6 and V-8 engines, as discussed above, and so does not apply to vehicle classes with I-4 engines. DEAC can be applied during a redesign or refresh model year with time-based learning. NHTSA has combined the phase-in caps for DEACS, DEACD and DEACO, as it did in MY 2011 final rule, and capped the joint penetration allowed at 85 percent for MY 2012 and beyond.

(6) Conversion to Double Overhead Camshaft Engine with Dual Cam Phasing (CDOHC)

Double overhead camshaft engines achieve increased airflow at high engine speeds, improve volumetric efficiency and reductions of the valvetrain's moving mass. Such

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[155] The $28 is an adjustment from the $75 estimate used in the MY 2011 final rule to account for the new ICM markup factor and the fact that it could only be applied on up to 50 percent of the vehicles.

engines typically develop higher power at high engine speeds. Manufacturers may choose to replace OHV engines with DOHC engine designs with dual cam phasing (DCP). NHTSA continues to use the fuel consumption reduction estimate of 1 to 2.5 percent, as it did in the MY 2011 final rule.

As for costs, NHTSA's MY 2011 CAFE final rule assumed that CDOHC would have an RPE cost of $746 ($497 non-RPE) for a V8 engine, $590 ($393 non-RPE) for a V6 engine and $373 ($249 non-RPE) for inline 4-cylinder engine. For purposes of this rulemaking, NHTSA revised the costs only by identifying this technology as a low complexity technology and applying an indirect cost multiplier of 1.11 resulting in a compliance cost of $552 for V8 engine, $436 for a V6 and $276 for an inline 4-cylinder engine.

There are no vehicle class-specific applications of this technology. The phase-in cap for CDOHC has been set at 85 percent per year for the 2012-2016 timeframe. The conversion from OHV to DOHC engine architecture with DCP is a major engine redesign that can be applied in redesign model years only with time-based learning applied.

(7) Stoichiometric Gasoline Direct Injection (SGDI)

Gasoline direct injection (GDI) 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 have recently introduced vehicles with SGDI engines, including VW/Audi, BMW, Toyota (Lexus IS 350) and General Motors (Chevrolet Impala and Cadillac CTS 3.6L). BMW, GM, Ford and VW/Audi have announced their plans to increase dramatically the number of SGDI engines in their portfolios.

NHTSA's MY 2011 CAFE final rule estimated the effectiveness of SGDI to be between 2 and 3 percent. In developing these estimates, NHTSA reviewed estimates from the Auto Alliance of American Manufacturers, which projects 3 percent gains in fuel efficiency and a 7 percent improvement in torque. The torque increase provides the opportunity to mildly downsize the engine allowing an increase in efficiency of up to a 5.8 percent. NHTSA also reviewed other published literature, reporting 3 percent effectiveness for SGDI.[156] Another source reports a 5 percent improvement on the NEDC drive cycle.[157] Confidential manufacturer data reported an efficiency effectiveness range of 1 to 2 percent. In response to the NPRM, NHTSA received comments from Porsche stating that Gasoline Direct Injection improves fuel economy up to 3%. NHTSA determined that the range of 2 to 3 percent continues to be appropriate. However, NHTSA notes that combined with other technologies (*i.e.*, boosting, downsizing, and in some cases, cooled EGR), SGDI can achieve greater reductions in fuel consumption compared to engines of similar power output.

In response to the NPRM, NHTSA received comments from MECA stating that Gasoline Direct Injection offers CO2 emissions reductions ranging from 5% to 20% depending on how it is implemented and the base engine to which it is compared. The 5% to 20% range in MECA's comments is not specific as to the technology level of the base engine for the comparison, nor the accompanying technologies that have been incorporated along with GDI. Therefore, there is insufficient information presented in MECA's comments to enable comparison of effectiveness to the effectiveness range for SGDI in the NPRM and final rule. However, it should be noted that if MECA's intended to include turbocharging, downsizing, and cooled EGR along with SGDI, that the 5 percent to 20 percent effectiveness improvement range would be consistent with effectiveness estimates in the final rule.

In reviewing the MY 2011 estimates, NHTSA in coordination with EPA revised the cost estimates for SGDI to take into account the changes required to the engine hardware, engine electronic controls, ancillary and Noise Vibration and Harshness (NVH) mitigation systems. Through contacts with industry NVH suppliers, and manufacturer press releases, the agency believes that the NVH treatments will be limited to the mitigation of fuel system noise, specifically from the injectors and the fuel lines. In the final rule, NHTSA, in coordination with EPA, revised the SGDI costs based on the FEV work that was not yet available for the NPRM. Focusing on direct manufacturing costs, the NPRM estimates, the FEV values, and the final values are shown in Table V-17. FEV did not directly estimate the SGDI costs shown here. Instead, FEV estimated costs associated with downsizing and turbocharging a V8 and V6 engine to a V6 and I4 engine, respectively, and simultaneously converting the PFI fuel system to a SGDI fuel system. The agencies, working closely with FEV, then "binned" the costs into three distinct bins: downsize, turbocharge, and SGDI. As such, the FEV results shown in Table V-17 cannot be found in the FEV reports, but instead are detailed in a memo to the docket which also

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[156] 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. Available at http://www.erc.wisc.edu/symposiums/2005_Symposium/June%208%20PM/Whitaker_Ricardo.pdf (last accessed March 15, 2010).

[157] Stefan Trampert, FEV Motorentechnik GmbH, "Engine and Transmission Development Trends - Rising Fuel Cost Pushes Technology," Symposium on International Automotive Technology, Pune, India, January 2007.

provides details of this binning process.[158] Because the methodology used by FEV presumes high volume production, instead of using the FEV results directly the agencies have averaged those results with the NPRM results to estimate the final values (this is noted above in section V.C.C.5 and in TSD sections 3.3.2.2, 3.4.2.1.9, and 3.4.2.2.5). Note that the costs for the I4 engine has changed since the NPRM but have not been averaged with the NPRM values. The costs changed based on a more rigorous binning process than that conducted for the NPRM, but were not averaged because they are based on the I4 to I4 teardown conducted by FEV which was, in fact, used in the NPRM. While the final value of $213 is lower than the NPRM value of $226, the $13 difference has simply been shifted from SGDI to the downsizing bin.

Table V-17. Direct Manufacturing Costs for SGDI (2007 Dollars in 2012)

Technology	NPRM	FEV Results	Final Rule
I4	$226	$213	$213
V6	$293	$321	$307
V8	$318	$386	$352

For the final rule marked up costs, the agencies estimate SGDI costs at $236 for an inline 4-cylinder and $341 for V6 and $391 for V8 including the low complexity ICM markup value of 1.11. As noted above, all of these costs differ slightly from those used in the NPRM analysis. These costs were not changed in response to public comments, but instead were changed due to updated information from the FEV teardown studies. [159]

SGDI systems are regarded as mature technology with minimal technical risk and are expected to be increasingly incorporated into manufacturers' product lineups. Time-based learning has been applied to this technology due to the fact that over 1.5 million vehicles containing this technology are now produced annually. Due to the changes to the cylinder head and combustion system and the control system development required to adopt SGDI technology, which are fairly extensive, SGDI can be applied only at redesign model years. There are no limitations on applying SGDI to any vehicle class. The phase-in cap for SGDI is applied at an 85 percent rate for MY 2012 and beyond.

(8) Combustion Restart (CBRST)

Combustion restart allows "start-stop" functionality of DI engines through the implementation of an upgraded starter with bi-directional rotation to allow precise crankshaft positioning prior to subsequent fuel injection and spark ignition, allowing engine restart. This method of implementing engine stop/start functionality allows not only save fuel from not idling the engine, but also reduces fuel consumption as the engine

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[158] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA-HQ-OAR-2009-0472 or NHTSA-2009-0059-0223, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

[159] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA-HQ-OAR-2009-0472 or NHTSA-2009-0059-0223, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

speeds up to its operational speed. A Direct Injection (DI) fuel system is required for implementation of this technology.

NHTSA reviewed the MY 2011 CAFE final rule assumptions and determined that due to technical risks implementation of combustion restart would likely not be feasible prior to MY 2014. Some of the risks are associated with unresolved issues regarding the impact of very high or very low ambient air temperatures on the ability to start the engine in the described manner. Although the starter motor can provide fail-safe starting capability in these temperature limited areas, strategies must be developed to manage the transitions. Others relate to production readiness.

Additional hardware is required to implement combustion restart, beyond SGDI. This includes a battery sensor, incremental wiring and high current switching, an incremental crank position sensor, and, in the case of an automatic transmission applications, a transmission oil pump to allow for torque converter continuity.

BMW has published a 3.5 percent fuel consumption effectiveness over the NEDC drive cycle for combustion restart,[160] and AVL a 4.8 percent effectiveness.[161] However, these reported effectiveness levels could potentially be reduced significantly on the EPA combined drive cycle, as combustion restart does not save fuel on the highway drive cycle. Therefore, NHTSA estimates the fuel consumption effectiveness for CBRST to range from 2 to 2.5 percent.

Regarding the cost estimate, NHTSA determined that the estimate of $118 from the 2008 Martec Report cost estimates for individual pieces was the best available. The total RPE cost (excluding transmission pump) is $141 at high volumes, which includes $70 for upgrading the starter, $10 for a battery sensor and wiring, $10 for high current switch and $4 for crank sensor a totaling $94 (non-RPE) cost. Applying an indirect cost multiplier of 1.25, for a medium complexity technology, results in a compliance cost of $118 for a MY 2012 vehicle and will be reduced in future years with the application of time-based learning.

CBRST is first available in MY 2014 and is applicable to all vehicle classes. Confidential product plan data indicates CBRST to be at high volume by 2014 so time-based learning is applied. CBRST can be applied a vehicle refresh.

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[160] Stefan Wolff, Dirk Abendroth, Werner Weigl, Claus-Peter Linner, Rupert Neudecker, Michael Schneider, Wolfgang Huber, and Andreas Rau, BMW, "Introducing The Automatic Start-Stop (ASS) Function In Series Models," 7th Stuttgart Automotive Vehicle and Engine Symposium, Organised by FKFS, Mar 2007, Vol. 1.

[160] G.K. Fraidl, P.E. Kapus, and H. Friedl, AVL List GmbH, "Future Gasoline Engine Technologies for 130 g/Km

[161] G.K. Fraidl, P.E. Kapus, and H. Friedl, AVL List GmbH, "Future Gasoline Engine Technologies for 130 g/Km CO2," VKM-THD 11th Symposium on the Working Process of Combustion Engines, TU Graz, Sept. 2007.

(9) Turbocharging and Downsizing (TRBDS)

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

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 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 conservatively be downsized roughly 30 percent to achieve 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. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

In response to the NPRM, NHTSA received comments from GM that included a description of technical considerations, concerns, limitations and risks that need to be considered when implementing turbocharging and downsizing technologies on full size trucks. These include concerns related to engine knock, drivability, control of boost pressure, packaging complexity, enhanced cooling for vehicles that are designed for towing or hauling, and noise, vibration and harshness. NHTSA judges that the expressed technical considerations, concerns, limitations and risks are well recognized within the industry and it is standard industry practice to address each during the design and development phases of applying turbocharging and downsizing technologies. Cost and effectiveness estimates used in the final rule are based on analysis that assumes each of these factors is addressed prior to production implementation of the technologies. In comments related to full size trucks, GM commented that potential to address knock limit concerns through various alternatives, which include use of higher octane premium fuel and/or the addition of a supplemental ethanol injection system. For this rulemaking, NHTSA has not assumed that either of these approaches is implemented to address knock limit concerns, and these technologies are not included in assessment of turbocharging and downsizing feasibility, cost or effectiveness.[162] In addition, NHTSA has received confidential business information from a manufacturer that supports that turbocharging and downsizing is feasible on a full size truck product during the rulemaking period.

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.[163]

Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption indicate that the potential for reducing fuel consumption for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines.[164] [165] [166] [167] [168] Confidential manufacturer data suggest an incremental range of fuel consumption of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection

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[162] Note that for one of the teardown analysis cost studies of turbocharging and downsizing conducted by FEV, in which a 2.4L I4 DOHC naturally aspirated engine was replaced by a 1.6L I4 DOHC SGDI turbocharged engine, the particular 1.6L turbocharged engine chosen for the study was a premium octane fuel engine. For this rulemaking, NHTSA intends that a turbocharged and downsized engine achieve comparable performance to a baseline engine without requiring premium octane fuel. For the FEV study of the 1.6L turbocharged engine, this could be achieved through the specification of an engine with a displacement of slightly greater than 1.6L. NHTSA judges that a slightly larger engine would have small effect on the overall cost analysis used in this rulemaking. For all other teardown studies conducted by FEV, both the naturally aspirated engine and the replacement turbocharged and downsized engine were specified to use regular octane fuel.

[163] "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-2009-0472-2860.1).

[164] 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).

[165] Tim Lake, John Stokes, Richard Murphy, and Richard Osborne of Ricardo and Andreas Schamel of Ford-Werke, "Turbocharging Concepts for Downsized DI Gasoline Engines," VKA/ika Aachen Colloquium 2003. *Available at* http://cat.inist.fr/?aModele=afficheN&cpsidt=16973598 (last accessed Nov. 9, 2008).

[166] "Interim Report: New Powertrain Technologies and Their Projected Costs," October 2005, EPA420-R-05-012. Docket EPA-HQ-OAR-2009-0472-0138.

[167] "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.

[168] "Electric Cars: Plugged In, Batteries must be included," Deutsche Bank Global Markets Research Company, June 9, 2008. Docket EPA-HQ-OAR-2009-0472-0154

using a wall-guided direct injection system;[169] a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection;[170] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[171] These reported fuel economy benefits show a wide range depending on the SGDI technology employed.

In response to the NPRM, NHTSA received comments from several sources related to the effectiveness of turbocharging and downsizing. Honeywell commented that they used four methods to estimate the fuel economy benefits for turbocharging, and each of those methods showed an improvement of 15 to 20 percent in fuel economy and, in addition, engine displacement could be reduced 30 to 40 percent. A fuel economy improvement of 15 to 20 percent converts to a fuel consumption effectiveness improvement of 13 to 17 percent. Porsche commented turbocharging improves fuel economy up to 1.9%.

Honeywell also commented “that turbo downsizing enables significant fuel economy improvement when engine performance is maintained”. For analysis of the effectiveness of technologies, NHTSA uses a constraint to maintaining performance at a level that is as similar to baseline as possible, such that vehicle performance attributes are affected to the smallest possible extent. Effectiveness estimates in the final rule are based on use of this constraint. This approach is consistent with the Honeywell comment.

For the NPRM and final rule, NHTSA estimates a turbocharged and downsized engine will improve fuel consumption by 0.3 percent to 6.7 percent incrementally over a comparable performance naturally-aspirated SGDI engine taking into account previously applied technologies (e.g., VVT and VVL) as defined on the decision tree. The range of incremental fuel consumption improvement for each engine is also based on which decision tree path (i.e. SOHC, DOHC or OHV) the engine is following. This is similar to estimates used in the 2011 final rule. This would equate to a 12 to 14 effectiveness improvement over baseline fixed-valve engine, similar to the estimate for Ford’s Ecoboost. When accounting for overall effectiveness for combined engine technologies that may be implemented along with turbocharging and downsizing, as defined in the NPRM and final rule decision trees, the NPRM and final rule estimated <u>cumulative</u> fuel consumption effectiveness is 11.2 to 17.4 percent which converts to 14 to 21 percent on a fuel economy improvement basis. This is similar to the 15 to 20 percent range estimated by Honeywell. The Porsche estimate for fuel economy improvement is consistent with the incremental effectiveness values used in the NPRM and final rule. In response to the

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[169] 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 March 15, 2010).

[170] 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.

[171] 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.

NPRM, one manufacturer provided confidential business information related to turbocharging and downsizing effectiveness which was similar to NPRM and final rule estimates when using similar assumptions for technology application.

As noted above NHTSA, in coordination with EPA, relied on engine teardown analyses conducted by EPA, FEV and Munro to develop costs for turbocharged SGDI engines.[172] Teardown studies are the one of the most effective ways to estimate technology costs. For the proposal, only the 2.4L I4 DOHC to 1.6L I4 DOHC teardown study had been completed in time for inclusion in the NPRM, and results from that study were used as the cost in the 2012 model year. For other turbo-downsize costs, the NPRM primarily used values developed for the 2008 EPA staff report. Since issuing the NPRM, two more teardown studies have been completed and those results are being used in the final analysis with some adjustment. NHTSA, in coordination with EPA, has adjusted the I4 to I4 turbo-downsize costs slightly to reflect an updated burden rate[173] employed by FEV and an updated binning approach employed by the agencies to distinguish turbo-related costs from downsize-related costs.[174] NHTSA and EPA modified the other FEV estimated costs as well. FEV made the assumption that these technologies would be mature when produced in large volumes (450,000 units or more). The agencies believe that there is potential for near term supplier-level engineering, design, and testing (ED&T) costs to be in excess of those considered in the FEV analysis (as existing equipment and facilities must be converted to production of new technologies). The agencies have therefore decided to average the FEV results with the NPRM values. We have also used the FEV results, where possible, to estimate costs for turbo-downsize scenarios that were not done via actual teardown study (e.g., FEV did not conduct a teardown of a V8 DOHC to turbocharged V6 DOHC). We have also used these values to estimate costs for other camshaft configuration changes that do not involve engine downsizing.

For the OHV applications, the agencies maintained consistency with the EPA 2008 Staff Report and estimated direct manufacturing costs associated with downsizing to be $50 per cylinder, $10 per valve, and $100 per cam shaft for the 2015 model year (2006$). Therefore, these costs have not changed relative to the NPRM.

Table V-18 shows how NHTSA developed the direct cost used by the Volpe model based on NPRM values and the FEV teardown cost study for the turbocharging and downsizing technology.

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[172] U.S. Environmental Protection Agency, “Draft Report – Light-Duty Technology Cost Analysis Pilot Study,” Contract No. EP-C-07-069, Work Assignment 1-3, September 3, 2009, Docket EPA-HQ-OAR-2009-0472-0149.

[173] Burden costs include the following fixed and variable costs: rented and leased equipment; manufacturing equipment depreciation; plant office equipment depreciation; utilities expense; insurance (fire and general); municipal taxes; plant floor space (equipment and plant offices); maintenance of manufacturing equipment - non-labor; maintenance of manufacturing building - general, internal and external, parts, and labor; operating supplies; perishable and supplier-owned tooling; all other plant wages (excluding direct, indirect and MRO labor); returnable dunnage maintenance; and intra-company shipping costs (see EPA-HQ-OAR-2009-0472-0149).

[174] This “binning” approach simply bins the turbo-downsize-GDI total cost generated by FEV into separate cost bins for the turbo portion, the downsize portion, and the GDI portion.

Table V-18. Calculation of Direct Manufacturing Cost for Turbocharging and Downsizing in MY 2012 (2007 dollars)

Turbocharging and Downsizing (TRBDS)	NPRM	FEV Teardown Analysis Based Cost							Final Rule
	a	b	c	d	e	f	g	h	i
	Direct Cost TRBDS	Direct Cost Turbo-charging	Direct Cost Downsize (w/o SGDI Downsize)	Direct Cost Downsize (w/SGDI Downsize)	Cost with 1.25 ICM Turbo-charging	Cost with 1.25 ICM Downsize	Total Cost with 1.25 ICM for TRBDS	Direct Cost TRBDS	Direct Cost TRBDS
V8 SOHC 2v --> V6 DOHC TRBDS	$878	$681	($84)	($149)	$851	($112)	$740	$592	$735
V8 DOHC --> V6 DOHC TRBDS	$554	$681	($274)	($339)	$851	($254)	$597	$478	$516
V8 OHV --> V6 DOHC TRBDS	$990	$681	$315	$250	$851	$313	$1,164	$931	$961
V6 SOHC --> I4 DOHC TRBDS	$410	$404	($382)	($490)	$505	($368)	$137	$110	$260
V6 DOHC --> I4 DOHC TRBDS	$194	$404	($547)	($655)	$505	($491)	$14	$11	$102
V6 OHV --> I4 DOHC TRBDS	$720	$404	$270	$162	$505	$203	$708	$566	$643
I4 SOHC --> I4 DOHC TRBDS	$515	$404	($80)	($80)	$505	($60)	$445	$356	$356
I4 DOHC --> I4 DOHC TRBDS	$336	$404	($85)	($85)	$505	($64)	$441	$353	$353
I4 OHV --> I4 DOHC TRBDS	$515	$404	$65	$65	$505	$81	$586	$469	$469

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* Note that, where downsizing results in cost savings, the compliance cost is calculated as the IC markup less 1 which is then multiplied by the absolute value of the direct manufacturing cost. The absolute value of the direct manufacturing cost is then subtracted from that to arrive at the end result. For example, for the V8 SOHC 2v downsized to the V6 DOHC at a direct manufacturing cost of -$149, the compliance cost would be (1.25-1) x │-$149│ - │-$149│ = -$112. Note because the Volpe model combines turbocharging and downsizing, the ICM factor of 1.25 is used for the individual calculations for both turbocharging and downsizing.

Detailed descriptions of each column in Table V-18 are listed below.

Column a. NPRM cost for turbocharging and downsizing used by NHTSA including downsizing of SGDI.

Column b. FEV teardown study direct cost for turbocharging only.

Column c. FEV teardown study direct cost for downsizing, but without downsizing of SGDI components. FEV conducted major teardown cost analysis on three engine combinations. For three of the other engine downsizing combinations, FEV conducted an incremental teardown study to determine costs. For three additional combinations, cost was determined through calculation using incremental cost estimates. A summary of these combinations and downsizing costs are shown in Table V-19. More detailed explanation is provided in an EPA memo to the docket.[175]

Table V-19. Calculated Turbocharging Downsizing Technologies, but Without Downsizing of SGDI Components MY 2012 (2007 Dollars)

Technologies Torn-Down by FEV		Incremental Studied in FEV		Calculated Technologies	
Name	Value	Name	Value	Name	Value
V8 SOHC 3v-> V6 DOHC	($155)	V8 SOHC 2v -> V8 SOHC 3v	$72	V8 SOHC 2v-> V6 DOHC	($84)
V8 SOHC 3v-> V6 DOHC	($155)	V8 SOHC -> V8 DOHC	($119)	V8 DOHC -> V6 DOHC	($274)
V6 DOHC -> I4 DOHC	($547)	V6 SOHC -> V6 DOHC	$165	V6 SOHC -> I4 DOHC	($382)

Column d. FEV teardown study direct cost for downsizing including downsizing of SGDI components. Cost reduction for SGDI downsizing is based on FEV direct manufacturing costs in Table V-17. For V8 to V6 the SGDI cost reduction is $386 -$321 = $65, and for V6 to I4 the cost reduction is $321 - $213 = $108.

Column e. FEV teardown study cost for turbocharging with ICM of 1.25 applied. Because the Volpe model combines turbocharging and downsizing, the ICM factor of 1.25 is used for the individual calculations for both turbocharging and downsizing.

Column f. FEV teardown study cost for downsizing with ICM of 1.25 applied.

Column g. FEV teardown study cost for turbocharging and downsizing with ICM of 1.25 applied. Column g is the sum of column e and column f.

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[175] “Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing,” memorandum to Docket EPA-HQ-OAR-2009-0472 or NHTSA-2009-0059-0223, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

Column h. FEV teardown study direct cost for turbocharging and downsizing. Column h is equal to column g divided by the ICM factor of 1.25.

Column i. Final Rule direct cost for turbocharging and downsizing including downsizing of SGDI. For V8 to V6 TRBDS and for V6 to I4 TRBDS, column i is the average of the NPRM direct cost (column a) and the FEV teardown study direct cost for turbocharging and downsizing (column h). For I4 to I4 TRBDS, Column i is equal to the updated FEV teardown based cost (column h).

In response to the NPRM, NHTSA received comments from Honeywell that a 30 to 40 percent reduction in engine displacement is possible with the use of turbocharging. Also, if cylinder count is reduced, the cost savings in parts and assembly will offset the costs of turbocharging. For example, replacing a 6-cylinder dual overhead cam engine with a 4-cylinder turbocharged engine may be cost neutral. Honeywell commented that consideration of the potential to decrease cylinder count and offset costs should be included in calculations for fleet fuel economy and implementation costs.

In the NPRM and final rule, NHTSA uses downsizing ranging from 30 to 40 percent, which is the same as the Honeywell comment. Also, the cost analysis methodology used in the NPRM and final rule account for downsizing and the reduction in cylinder count and parts, and in assembly costs. Based on the FEV teardown study cost estimates were revised in the final rule. NHTSA estimates the direct cost to replace a 6-cylinder dual overhead cam engine with a 4-cylinder turbocharged engine is $102, compared to Honeywell’s estimate of no cost difference. NHTSA believes that teardown studies are the one of the most effective ways to estimate technology costs. In response to the NPRM, NHTSA received comments from GM related to cost. GM commented that for a full-size truck product, the downsized boosted strategy is expected to yield less fuel economy benefit at higher cost than a direct injection V8 with aggressive usage of cylinder deactivation. NHTSA analysis shows the same relationship in cost, and the Volpe model applies DEACO prior to TRBDS, recognizing the relationship. The Volpe model used for the NPRM and final rule provides one solution that manufacturers could use to meet CAFE regulations to demonstrate the feasibility of regulatory standards. It is expected that in many cases, manufacturers will identify and implement other combinations of technologies to achieve CAFE regulatory compliance, based on their unique circumstances.

In response to the NPRM, NHTSA received comments from GM that the engine oil service schedule must be more robust for turbocharged engines to avoid premature wear on oiled engine components. For this rulemaking, NHTSA analysis does not include maintenance costs. NHTSA intends to investigate maintenance costs and consider including them in future rules.

NHTSA estimates that the MY 2012 incremental compliance cost, including a medium complexity ICM mark-up of 1.25, for a turbocharged and downsized engine is $445 to downsize from an I-4 SOHC naturally-aspirated engine to a smaller displacement I-4 DOHC turbocharged engine, $325 for a downsize from a V-6 SOHC naturally-aspirated engine to an I-4 DOHC turbocharged engine, and $919 for a downsize from a V-8 SOHC naturally-aspirated engine to a V-6 DOHC turbocharged engine.

Phase-in caps have been modified from the MY 2011 final rule and are now limited to 85 percent per year with time-based learning applied. NHTSA considered the complexity of implementing this technology and determined that this technology can be applied at redesign only. There are no subclass specific limitations on its application.

(10) Cooled Exhaust Gas Recirculation/EGR Boost (EGRB)

Cooled exhaust gas recirculation (cooled EGR) or EGR Boost is a combustion concept that involves utilizing EGR as a charge dilutant 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. Cooled EGR reduces knock sensitivity which enables the use of more optimal spark advance or enables compression ratio to be increased for improved thermal efficiency, and increased fuel economy. Currently available turbo, charge air cooler, and EGR cooler technologies are sufficient to demonstrate the feasibility of this concept.

However, this remains a technology with a number of issues that still need to be addressed and for which there is no production experience. EGR system fouling characteristics could be potentially worse than diesel EGR system fouling, due to the higher HC levels found in gasoline exhaust. Turbocharger compressor contamination may also be an issue for low pressure EGR systems. Additionally, transient controls of boost pressure, EGR rate, cam phasers and intake charge temperature to exploit the cooled EGR combustion concept will require development beyond what has already been accomplished by the automotive industry. These are all “implementation readiness” issues that must be resolved prior to putting EGR Boost into high volume production.

NHTSA has concluded that these implementation issues could be resolved and this technology could be brought to production by MY 2013. Supporting this conclusion, MEMA has previously suggested a 5 to 7 percent effectiveness for cooled EGR systems, although without boosting.[176] Two public sources indicate a 10 to 20 percent fuel consumption effectiveness for a downsized DI engine with cooled EGR compared to a naturally aspirated baseline engine[i] and a 4 percent fuel consumption effectiveness for cooled EGR compared to a conventional downsized DI turbocharged engine.[ii] Based on the data from these reports, NHTSA estimates the incremental reduction in fuel consumption for EGR Boost to be 4 percent over a turbocharged and downsized DI engine. Thus, if TRBDS precedes EGRB, adding the 12 percent gain from TRBDS to the 4 percent gain from EGRB results in total fuel consumption reduction of 16 percent. This is in agreement with the range suggested in the Lotus report.

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[176] Docket No. NHTSA-2008-0089-0193.1

Regarding costs, the addition of EGR cooler and EGR valve were estimated in NHTSA's MY 2011 rule to have an incremental RPE cost impact of approximately $173 based on confidential individual component cost data from 2008 Martec describing EGR cooler costs of $75, EGR valve costs of $20 and associated piping costs of $20, totaling $115 (non-RPE). For purposes of this rulemaking, NHTSA found no information to indicate that these estimates were inaccurate. To that end, NHTSA applied an indirect cost multiplier of 1.25, for a medium complexity technology, resulting in a compliance cost of $144 for MY 2012 vehicles with time-based learning applied. EGRB can be applied to all vehicle classes starting in MY 2013. Phase-in caps are limited to 85 percent per year with time-based learning applied. NHTSA considered the complexity of implementing this technology and determined that this technology can be applied at redesign only.

(11) Diesel Engine Technologies

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. The diesel combustion cycle operates at a higher compression ratio, with a very lean air/fuel mixture, and turbocharged light-duty diesels typically achieve much higher torque levels at lower engine speeds than equivalent-displacement naturally-aspirated gasoline engines. Additionally, diesel fuel has a higher energy content per gallon.[177]

Diesel engines have emissions characteristics that present challenges to meeting federal Tier 2 NO_x emissions standards. It is a significant systems-engineering challenge to maintain the fuel consumption advantage of the diesel engine while meeting U.S. emissions regulations. Fuel consumption can be negatively impacted by emissions reduction strategies depending on the combination of strategies employed. Emission compliance strategies for diesel vehicles sold in the U.S. are expected to include a combination of combustion improvements and aftertreatment. These emission control strategies are being introduced on Tier 2 light-duty diesel vehicles today

To achieve U.S. Tier 2 emissions limits, roughly 45 to 65 percent more NO_x reduction is required compared to the Euro VI standards. Additionally, as discussed below, there may be a fuel consumption penalty associated with diesel aftertreatment since extra fuel is needed for the aftertreatment, and this extra fuel is not used in the combustion process of the engine that provides power to propel the vehicle.

Light-duty diesel emissions control systems capable of meeting Tier 2 Bin 5 emission standards are already in production. Several key advances in diesel technology have made it possible to reduce emissions coming from the engine prior to 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.

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[177] Burning one gallon of diesel fuel produces about 15 percent more carbon dioxide than gasoline due to the higher density and carbon to hydrogen ratio.

On the aftertreatment side, the traditional 3-way catalyst aftertreatment found on gasoline-powered vehicles is ineffective due to the lean-burn combustion of a diesel. All diesels will require a diesel particulate filter (DPF) or catalyzed diesel particulate filter (CDPF), a diesel oxidation catalyst (DOC), and a 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) or selective catalytic reduction (SCR), which are outlined below.

Diesel Engine with Lean NO_x Trap (LNT) Catalyst After-Treatment

A lean NO_x trap operates, in principle, by oxidizing NO to NO2 in the exhaust and storing NO2 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.

NHTSA has concluded that diesel engines on small vehicles would be LNT-based. In the NPRM, we did not include a diesel option for small vehicles because it did not appear to be a cost effective solution. Based on comments received from BorgWarner, ICCT, MEMA, and Mr. Schade we are including a diesel option for small vehicles in the final rule, and we are allowing the Volpe model to choose whether to apply the technology. It should be noted that the Volpe model analysis provides one solution that manufacturers could use to meet CAFE regulations to demonstrate feasibility for regulatory standards. It is expected that in many cases, manufacturers will identify and implement other combinations of technologies to achieve CAFE regulatory compliance, based on their unique circumstances.

Diesel Engine with Selective Catalytic Reduction (SCR) After-Treatment

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 reacts 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). 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. Manufacturers designing SCR systems intend to align urea tank refills with standard maintenance practices such as oil changes. As is the case with LNT-based diesels, EPA and NHTSA project that SCR-based diesel engines will be available within the next couple of years. Mercedes-Benz recently introduced two 2009 model year vehicles R320 and GL320, both of which are certified to Tier 2, Bin 5 emission standards. Based on public announcements from several other companies, an increased number of product offerings from multiple companies are expected over the next few years.

In response to the NPRM, NHTSA received comments from MECA that significant criteria emission reductions from diesel vehicles can be achieved through the use of several technologies, including: Diesel Particulate Filters (DPFs), and Selective Catalytic Reduction (SCR) and Lean NOx Adsorber Catalysts for Diesel Engines. MECA provided a detailed description of these technologies. MECA also commented that these emission control technologies allow all high efficiency powertrains to compete in the marketplace by enabling these powertrains to meet current and future criteria pollutant standards. In nearly all cases, these fuel-efficient powertrain designs, combined with appropriate emission controls, can be optimized to either minimize fuel consumption impacts associated with the emission control technology, or, in some cases, improve overall fuel consumption of the vehicle.

As the NPRM and final rule include descriptions of each of these technologies and cite these technologies as enablers for diesel engines to meet criteria emission regulations during the rulemaking period, and therefore enabling diesel engine technology to be included as a viable fuel economy improving technology during the rulemaking period, NHTSA views MECA's comments as supporting NHTSA's assessment of the feasibility of diesel engine technology in the final rule.

In order to maintain equivalent performance to comparable gasoline-engine vehicles, an in-line 4-cylinder diesel engine, with displacement varying around 2.0 liters was assumed to replace an I4 gasoline base engine for Subcompact, Compact, and Midsize Passenger Car, Performance Subcompact Car and Small Light Truck classes. It was assumed that diesel engines for these classes would utilize LNT aftertreatment systems.

In order to maintain equivalent performance to comparable gasoline-engine vehicles, an in-line 4-cylinder diesel engine, with displacement varying around 2.8 liters was assumed to replace a V6 gasoline base engine for Performance Compact, Performance Midsize, Large Passenger Car, Minivan, and Midsize Truck for the CAFE model. A V6 diesel engine, with displacement varying around 4.0 liters to meet vehicle performance requirements, was assumed to replace a V8 gasoline base engine for Large Truck and Performance Large Car vehicle classes for the CAFE model. It was assumed that diesel engines for these classes would utilize SCR aftertreatment systems.

Confidential manufacturer and non-confidential comment data submitted in response to NHTSA's past rulemaking for diesel engines showed a fuel consumption reduction in the range of 16.7 percent to 26.7 percent over a baseline gasoline engine. NHTSA's MY 2011 CAFE final rule, which was supported by confidential manufacturer data, estimated the fuel consumption reduction of SCR-based diesel system to be between 20 to 25 percent over a baseline gasoline engine. In response to the NPRM, NHTSA received comments from MECA that light duty diesel powertrains have higher fuel efficiency compared to gasoline engines on the order of 20 percent to 40 percent. This converts to between 16.7 and 28.6 percent on a fuel consumption effectiveness basis. MEMA commented that compared to a traditional gasoline engine, clean diesel-powered vehicles average 30 percent better fuel economy. This converts to 23.1 percent on a fuel consumption basis. Based on review of all of this information, NHTSA judged that the MY 2011 estimate of 20 to 25 percent fuel consumption reduction over a baseline gasoline engine remains the best estimate for this final rule. This equates to a 5.3 to 6.9 percent improvement for DSLT, which is incremental to a turbocharged downsized gasoline engine (TRBDS) with EGRB, and a 10.8 to 13.9 percent incremental improvement for DSLC, which is incremental to a gasoline engine with combustion restart (CBRST).

Diesel engines are more costly than port-injected spark-ignition gasoline engines. These higher costs result from:

- 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;

Due to a significant decrease in platinum group metal prices since NHTSA's MY 2011 CAFE final rule analysis, NHTSA in consultation with EPA chose to re-analyze diesel costs. In EPA's 2008 Staff Report, costs were considered for two types of diesel systems: one using a lean-NO_x trap (LNT) along with a diesel particulate filter (DPF); and one using a selective catalytic reduction (SCR) system along with a DPF. In that report, EPA estimated direct manufacturing costs to range from $1,860 for the small car (LNT plus DPF) to $2,710 for the large truck (SCR plus DPF). For comparison, the NESCCAF study showed direct manufacturing costs of $1,500 to $1,950. More recently, NHTSA's 2011 CAFE final rule showed direct manufacturing costs of $2,670 for a 4-cylinder engine using a LNT plus DPF system, $3,735 for a 6-cylinder engine using a SCR plus DPF system, and $4,668 for an 8-cylinder engine using a SCR plus DPF system. NHTSA noted that estimates in the MY 2011 CAFE final rule were higher than those shown in the proposed rule due largely to the spike in platinum group metal prices that had occurred in the months just prior to issuing the 2011 CAFE final rule.

The following diesel costs were developed by EPA, drawing on their experience with diesel engine and aftertreatment systems. A breakdown of the cost estimates is shown in Table V-. These costs are generally lower than the MY 2011 CAFE final rule assumptions and were developed by taking a look back at EPA's 2008 Staff Report, which reveals a couple of factors that resulted in somewhat misleading costs. First, the engine costs estimated there did not take into account the downsizing that would occur when moving from a gasoline engine to a diesel engine (provided equivalent performance was maintained). Second, the engine costs used in that analysis were actually stated in terms of 2002 dollars rather than 2006 dollars in which the report was meant to be stated. EPA and NHTSA engineers decided that an update to the engine-related costs would provide a much better cost estimate for converting to diesel. This was done by starting with the source for engine costs in the 2008 staff report which was an October 2005 EPA Interim Report[iii] which, in turn, sourced estimates from a 2003 study done by FEV for EPA contained within a 2004 EPA Interim Technical Report.[iv] These direct manufacturing costs are reproduced in Table V-20

Table V-20 Diesel Engine Direct Manufacturing Source Costs, Incremental to a Baseline Gasoline Engine (2002 dollars)

Component(s)	Large SUV	Midsize
Gasoline engine (baseline)	5L V8	2.4L I4
Diesel engine	4L V8	2.2L I4
Add high-pressure, common rail diesel fuel injection system	$980	$630
Delete gasoline fuel injection system	-$245	-$165
Add variable geometry turbocharger	$175	$126
Delete gasoline ignition system	-$120	-$75
Delete fuel pump and other changes to fuel system	-$94	-$75
Enhance powertrain mounting system	$87	$107
Other engine changes	$80	$70
Add air intercooler, ducts, and sensor	$80	$55
Larger battery and starter, add glow plugs	$72	$50
Delete exhaust gas oxygen sensor*	-$60	-$30
Add supplemental heater	$50	$15
Modify transmission	$25	$25
Enhance sound insulation package	$25	$10
Smaller radiator	-$13	-$4
Total	$1,042	$739

Note: Table reproduced from EPA420-R-05-012, October 2005

Building on the direct manufacturing costs shown in Table V-20, the agencies used appropriate scaling to estimate the costs for replacing a baseline gasoline engine with a diesel engine for the following five situations: a small car converted from a 2.4L I4 gasoline to a 2L I4 Diesel; a large car converted from a 4.5L V8 gasoline to a 3L V6 diesel; a medium/large MPV converted from a 3.2L V6 to a 2.8L I4 diesel; a small truck converted from a 3.2L V6 gasoline to a 2.8L I4 diesel; and a large truck converted from a 5.6L V8 gasoline to a 4L V6 diesel. The results for the five base gasoline to diesel conversions are shown in Table V-21. Values from Table V-20 have been updated to 2007 dollars using the GDP price deflator factor of 1.15 (see Appendix 3.A). Since the source costs were developed in 2003, this analysis conservatively considers the costs shown in Table V-21 as being applicable to the 2012 model year.

Table V-21 Diesel Engine Direct Manufacturing Scaled-Costs in 2012, Incremental to Baseline Gasoline Engine (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck	Notes (see text below)
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8	
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6	
Add high-pressure, common rail diesel fuel injection system	$517	$1,026	$724	$724	$1,026	1
Delete gasoline fuel injection system	-$52	-$89	-$73	-$73	-$89	2
Add variable geometry turbocharger	$145	$173	$145	$145	$201	3
Delete gasoline ignition system	-$69	-$138	-$112	-$112	-$138	4
Delete fuel pump and other changes to fuel system	-$62	-$108	-$86	-$86	-$108	5
Enhance powertrain mounting system	$123	$100	$123	$123	$100	6
Other engine changes	$57	$86	$80	$80	$86	7
Add air intercooler, ducts, and sensor	$45	$78	$63	$63	$92	8
Larger battery and starter, add glow plugs	$57	$70	$57	$57	$70	9
Delete exhaust gas oxygen sensor*	$0	$0	$0	$0	$0	10
Add supplemental heater	$17	$37	$17	$17	$57	11
Modify transmission	$29	$29	$29	$29	$29	12
Enhance sound insulation package	$11	$20	$11	$11	$29	13
Smaller radiator	-$7	-$15	-$10	-$10	-$15	14
Engine downsize credit	$0	-$185	-$390	-$390	-$185	15
Total	$813	$1,085	$580	$580	$1,156	

* Note: Oxygen sensor removals are included in aftertreatment costs.

NOTES:
The costs shown in Table V-21 were scaled in the following ways:

1. Large car and large truck calculated as 75% the cost of Table V-20's large SUV and 25% of midsize car; medium/large MPV and small truck calculated as equal to Table V-20's midsize car; small car calculated using Table V-21's Med/large MPV value of $724 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

2. The estimates generated by FEV for eliminating the gasoline fuel injection systems were considerably larger than EPA & NHTSA believed was appropriate. Therefore, for a more accurate estimate, these costs were estimated, in 2007 dollars as follows: large car and large truck were calculated using incremental costs of $8/injector, $20/fuel rail, and $5 for a pressure damper or $8x8+$20+$5=$89; medium/large MPV and small truck were calculated using incremental costs of $8/injector, $20/fuel rail, and $5 for a pressure damper or $8x6+$20+$5=$73; small car calculated using

Table V-21's Med/large MPV value of -$73 and applying the ratio of diesel engine sizes (2.0/2.8).

3. Large car calculated as the average of Table V-20's large SUV and midsize car; medium/large MPV and small truck calculated as equal to Table V-20's midsize car, and large truck calculated as equal to Table V-20's large SUV; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

4. Medium/large MPV and small truck calculated as the average of Table V-20's large SUV and midsize car; Large car and large truck calculated as equal to Table V-20's large SUV; small car calculated as equal to half of Table V-21's large truck value of -$138. Values converted to 2007 dollars using GDP factor of 1.15.

5. Medium/large MPV and small truck calculated as equal to Table V-20's midsize car; Large car and large truck calculated as equal to Table V-20's large SUV; small car calculated using Table V-21's Med/large MPV value of -$86 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

6. Medium/large MPV and small truck calculated as equal to Table V-20's large SUV; Large car and large truck calculated as equal to Table V-20's midsize car; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

7. Medium/large MPV and small truck calculated as equal to Table V-20's midsize car; Large car and large truck calculated as the average of Table V-20's large SUV and midsize car; small car calculated using Table V-21's Med/large MPV value of $80 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

8. Medium/large MPV and small truck calculated as equal to Table V-20's midsize car; Large car calculated as the average of Table V-20's large SUV and midsize car; Large truck calculated as equal to Table V-20's large SUV; small car calculated using Table V-21's Med/large MPV value of $63 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

9. Medium/large MPV and small truck calculated as equal to Table V-20's midsize car; Large car and large truck calculated as the average of Table V-20's large SUV and midsize car; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

10. Oxygen sensor costs are included in the aftertreatment costs discussed below.

11. Medium/large MPV and small truck calculated as equal to Table V-20's midsize car; Large car calculated as the average of Table V-20's large SUV and midsize car; Large truck calculated as equal to Table V-20's large SUV; small car calculated as

equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

12. Values from Table V-20 converted to 2007 dollars using GDP factor of 1.15.

13. Medium/large MPV and small truck calculated as equal to Table V-20's midsize car; Large car calculated as the average of Table V-20's large SUV and midsize car; Large truck calculated as equal to Table V-20's large SUV; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

14. Medium/large MPV and small truck calculated as the average of Table V-20's large SUV and midsize car; Large car and large truck calculated as equal to Table V-20's large SUV; small car calculated using Table V-21's Med/large MPV value of -$10 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

15. Based on the approach presented in the turbocharging/downsizing section of the TSD (section 3.5.2.1.11), the savings associated with downsizing the gasoline engine were calculated by estimating the cost in 2007 dollars of each cylinder at $51, each valve at $10, and each cam at $103.[178] Therefore, the large car and large truck, which each lose two cylinders (-$102), eight valves (-$82) and no cams realize a $185 savings. The medium/large MPV and small truck would each lose two cylinders (-$102) and eight valves (-$82) and two cams (-$205) for a savings of $390. The small car downsizing credit was left at $0 given the small displacement change and lack of cylinder or valve removals.

For the diesel aftertreatment systems, the approach taken is consistent with the approach taken in EPA's 2007/2010 Highway Diesel rule and EPA's recent locomotive and marine rule.[179] For platinum group metal costs, monthly average prices as of March 2009 as reported by Johnson-Matthey were used.[180] Those values were $1,085/troy ounce for platinum and $1,169/troy ounce for rhodium. Aftertreatment devices were sized according to the diesel engine displacement with a 1:1 ratio for both the SCR catalyst and

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[178] These are the correct costs for the 2015MY in 2007 Dollars. But, they are used here erroneously as 2012MY values. Technically, 3 years of time-based learning should have been backed out to get 2012MY values. So, the 2012MY costs are slightly underestimated by roughly $10. This was true in the proposed analysis and, because it has no meaningful impact on the analysis (1-2% of the estimated diesel costs), continues to be true in the final analysis.

[179] EPA's 2007/2010 diesel heavy-duty highway final rule at 66 FR 5002; EPA's Locomotive and Marine final rule at 73 FR 37096.

[180] http://www.platinum.matthey.com These are the PGM prices used in the NPRM. As precious metals, PGM prices swing widely year-to-year and even month-to-month. Given economic conditions during the past year and the tendency of investors during tough economic times to invest in valuable metals such as gold and PGMs, PGM prices have increased considerably since the NPRM. Were the January 2010 PGM prices used, the diesel costs presented here would increase on the order of 10-20 percent. That would serve to make diesels less cost effective options for improving fuel economy or reducing GHGs. Since diesels comprise such a small percentage of each agency's analysis from a technology penetration standpoint, even using the lower March 2009 PGM prices, the choice of what PGM prices to use is of little consequence to the analytical results for purposes of this rulemaking.

the DPF, and a 0.5:1 ratio for the DOC (i.e., the DOC is half the displacement of the engine). The end result for aftertreatment devices, including a urea dosing unit, urea tank and necessary brackets and heaters, are shown in Table V-2. Also shown in Table V-2 are the savings associated with removal of the gasoline catalyst. Note that the gasoline catalyst was sized according to the gasoline engine that served as the baseline engine.

Table V-22 Diesel Aftertreatment Direct Manufacturing Costs in 2012 (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6
DOC	$216	$277	$257	$257	$339
DPF (includes a $20 pressure sensor for OBD & sensing)	$401	$534	$503	$503	$668
SCR system (includes a $50 NOx sensor for OBD & sensing)	n/a	$904	$904	$914	$996
LNT System includes $50 NOx sensor for OBD and sensing	$442	n/a	n/a	n/a	n/a
Removal of gasoline catalysts & sensors	-$175	-$401	-$288	-$298	-$483
Total	$883	$1,314	$1,376	$1,376	$1,520

The incremental costs to convert from a gasoline to a diesel engine—Table V-21 and Table V-22 combined—are shown in Table V-23.

Table V-23 Direct Manufacturing Costs to Convert from a Gasoline to Diesel System in 2012 (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6
Engine-related costs	$813	$1,085	$580	$580	$1,156
Aftertreatment	$883	$1,314	$1,376	$1,376	$1,520
Total	$1,697	$2,399	$1,956	$1,956	$2,676

This analysis applies time-based learning to diesel systems and a medium complexity rating of 1.25. Therefore, the MY 2012 compliance costs are as shown in Table V-24.

Table V-24 Compliance Costs to Convert from a Gasoline to Diesel System in 2012 (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6
Total	$2,121	$2,999	$2,445	$2,445	$3,345

Given the above analysis, NHTSA estimated that the compliance cost of converting an I4 gasoline engine to a 2.0L diesel engine was $2,121 for MY 2012. This results in an incremental compliance cost of $759 to $907 for DSLT and $1,346 to $1,519 for DSLC, depending on decision tree path. A MY 2012 cost of $2445 was estimated for converting a V6 gasoline engine to a 2.8L I4 diesel engine. This results in an incremental compliance cost of $689 to $1,257 for DSLT and $1,226 to $1,692 for DSLC. A MY 2012 cost of $3345 was estimated for converting a V8 gasoline engine to a 4.0L V6 diesel engine. This results in an incremental compliance cost of $1,097 to $1,478 for DSLT and $1,945 to $2,667 for DSLC. These compliance costs include the medium complexity ICM markup of 1.25. In response to the NPRM, CARB commented that diesel cost estimates in the NPRM were generally consistent with their own. As costs in the final rule are unchanged from the NPRM, with the exception of the I4 gasoline to 2.0L Turbcharged Diesel that was added for the final rule, the CARB comment supports the cost estimates used in this final rule.

The diesel engine technology can be applied to all vehicle classes. Diesel engines can only be applied at redesign with time-based learning. NHTSA assumed a 3 percent phase-in cap for diesels in MY2012 and increasing 3 percent per year reaching a maximum of 15 percent in MY 2016.

b. Transmission Technologies

NHTSA has reviewed the transmission technology estimates used in the MY 2011 CAFE final rule and 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.

(12) Improved Automatic Transmission Control (IATC) (Aggressive Shift Logic and Early Torque Converter Lockup)

Calibrating the transmission shift schedule to upshift earlier and quicker, and to lock-up or partially lock-up the torque converter under a broader range of operating conditions can reduce fuel consumption. However, this operation can result in a perceptible degradation in noise, vibration, and harshness (NVH). The degree to which NVH can be degraded before it becomes noticeable to the driver is strongly influenced by characteristics of the vehicle, and although it is somewhat subjective, it always places a limit on how much fuel consumption can be improved by transmission control changes. Given that the Aggressive Shift Logic and Early Torque Converter Lockup are best optimized simultaneously due to the fact that adding both of them primarily requires only minor modifications to the transmission or calibration software, these two technologies are combined in the modeling.

(13) Aggressive Shift Logic

During operation, an automatic transmission’s controller manages the operation of the transmission by scheduling the upshift or downshift, and 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, 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.

(14) 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.[181] 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.

Regarding the effectiveness of Improved Automatic Transmission Control, the MY2011 CAFE final rule, which was supported by the 2002 NAS and NESCCAF reports as well as confidential manufacturer data, estimated an effectiveness improvement of 1 to 2 percent for aggressive shift logic and 0.5 percent for early torque converter lockup. These estimates are in agreement with the values stated in the NESCCAF report and confidential manufacturer data. For the purpose of this rule, NHTSA concluded that the combined estimated effectiveness is 1.5 to 2.5% reduction in fuel consumption.

For a cost estimate, and for a MY 2012 vehicle, NHTSA updated the MY 2011 CAFE final rule estimate of $59 with a 1.5 RPE to $60 with a low complexity ICM markups value of 1.11. This reflects a revisiting of component costs for the early torque converter lock-up technology which potentially involves hardware changes. Time based learning methods are applied so subsequent MY costs are lower. Given the relative ease of implementation, from a manufacturing perspective, the Volpe model can apply IATC at either the refresh or redesign product cycle, and there are no subclass specific limitations on its application other than that the baseline vehicle must be equipped with an automatic transmission. Phase-in caps in this rule are set at 85 percent for MYs 2012 to 2014 and 100 percent for the remaining years of the rulemaking.

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[181] Very aggressive early torque converter lock up may require an adjustment to damper stiffness and hysteresis inside the torque converter.

(15) Automatic 6-, 7- and 8-Speed Transmissions (NAUTO)

Manufacturers can also choose to replace 4- and 5-speed transmission with 6-, 7-, or 8-speed automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional planetary gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers need to develop strategies to minimize the impact of additional shifts. Some manufacturers are replacing 4- and 5-speed automatics with 6-speed automatics, and 7- and 8-speed automatics have also entered production, albeit in lower-volume applications in luxury and performance oriented cars.

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. 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.[182] 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. NHTSA reviewed these effectiveness estimates and concluded that they remain accurate. In response to the NPRM, Porsche provided estimate for fuel economy improvement for 6 to7 speed automatic transmission which is consistent with these incremental effectiveness values used in the NPRM and final rule. In the NPRM, NHTSA reviewed the cost estimates from the MY 2011 CAFE final rule which used cost estimates from 2008 Martec report and the 2008 EPA Staff Report (which assumed use of a Lepelletier gear set) and concluded that some but not all 6-speed automatic transmissions would be equipped with Lepelletier gear set. As such, the estimates were revised to establish the cost for the 6 speed transmission to be equally divided between applications using Lepelletier, and applications of a standard planetary gear set 6-speed automatic transmission as estimated in the 2008 Martec Report (and the MY 2011 CAFE final rule). The 2008 Martec report estimated a cost of $323 with RPE adjustment and $215 without RPE adjustment for converting a 4-speed to a 6-speed transmission and a cost of $638 with RPE adjustment or $425 without RPE adjustment for converting a 4-speed to an 8-speed transmission. As a result, the final incremental cost estimate in the NPRM was $170, independent of vehicle type and size and including

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[182] Page 17, “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.

a low complexity 1.11 ICM (2007 Dollars). In the CAFE model, due to the structure of the vehicle classes used, an additional $102 (2007 Dollars) was included to account for performance vehicle classes and for medium and large trucks. This is because for performance classes, additional gear ratios, such as 7 and 8 speed transmissions may be utilized, and for medium and large trucks heavier duty transmissions are required. These estimates represented MY 2012 vehicle costs

For the final analysis, as noted earlier, NHTSA has considered the teardown work done by FEV. In its teardown work, FEV determined the 6 speed automatic transmission to be $106 less costly than a 5 speed automatic transmission (direct manufacturing cost without markups). This is counterintuitive but can be attributed to the type of gear set employed in the 6 speed automatic transmission studied by FEV. That 6 speed auto transmission was equipped with a Lepelletier-like gear set and therefore does not require a 1-way clutch that is essential to other designs. The cost analysis performed in this rule requires that the cost difference between both a 4 speed and 5 speed automatic transmissions relative to 6 speed automatic transmission be established because there are a substantial number of both 4 speed and 5 speed automatic transmissions used in the baseline fleet. This was done using the NPRM analysis for a 4 speed to a 5 speed and adding the FEV results for the transition from a 5 speed to a 6 speed. The analysis resulted in a cost for a 5 speed auto transmission relative to a 4 speed auto of $91 direct manufacturing cost (2007 Dollars in 2012). As done in the NPRM, NHTSA averaged the non-Lepelletier gear set cost with the Lepelletier gear set cost (FEV tear-down value of -$106). In the 2011 FRM, NHTSA estimated the cost of a 6 speed auto transmission, without a Lepelletier gear set, relative to a 4 speed auto transmission at $215 (2007 Dollars). Therefore, the $215 value (4 speed to 6 speed) from NHTSA's 2011 FRM is used and $91 is subtracted from that (4 speed to 5 speed) to arrive at a cost of $124 as the non-Lepelletier cost for a 6 speed automatic transmission relative to a 5 speed automatic transmission. The $124 value is averaged with the FEV value of -$106 (Lepelletier cost) to get an end result of $9 (2007 Dollars in 2012). This $9 cost represents the cost for a 6 speed auto transmission relative to a 5 speed auto transmission in the final analysis. This $9 can then be added to the $91 to get a cost of $101 for a 6 speed auto transmission relative to a 4 speed auto transmission. Table V-25 shows the direct manufacturing costs used in the proposed and the final analyses. With the low complexity markup of 1.11, the compliance cost for a 6 speed automatic transmission in relative to a 4 speed automatic transmission in 2012 is $112 (2007 Dollars). With time based learning, the compliance costs in 2016 to move from a 4 speed auto to a 5 speed auto and then from a 5 speed auto to a 6 speed auto transmission would be $90 and $9, respectively (2007 Dollars).

Table V-25. Direct Manufacturing Costs for Automatic Transmissions (2007 Dollars in 2012)

Technology	Non-Lepelletier Cost Used in 2011 CAFE Analysis	NPRM	FEV tear down (Lepelletier)	Final Rule	Comments
5s auto relative to 4s auto		$91	n/a	$91	Final rule uses NPRM value
6s auto relative to 5s auto			-$106	$9	$215-$91=$124 [$124+(-$106)]/2=$9
6s auto relative to 4s auto	$215	$153	n/a	$101	$91+$9=$101 (values are rounded)

Notes: Blank cells represent values not considered in this analysis; n/a means that FEV did not conduct a tear down of the technology; refer to text for more detail on the comments.

(16) Dual Clutch Transmissions / Automated Manual Transmissions (DCTAM)

An Automated Manual Transmission (AMT) is mechanically similar to a conventional manual transmission, but shifting and launch functions are automatically controlled by the electronics. There are two basic types of AMTs, single-clutch and dual-clutch (DCT). A single-clutch AMT is essentially a manual transmission with automated clutch and shifting. Because of shift quality issues with single-clutch designs, DCTs will likely be 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 pre-selected. 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 are likely offer the greatest potential for effectiveness improvements among the various transmission options presented in this report because they offer the inherently lower losses of a manual transmission with the efficiency and shift quality advantages of electronic controls. The lower losses stem from the elimination of the conventional 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.

In response to the NPRM, NHTSA received comments from GM that included a description of technical considerations, concerns, limitations and risks that need to be considered when implementing DCT technologies. These include concerns related to the heat stress/durability of the clutch, ability of achieving a smooth control of torque during launching and shifting, NVH, creep and rollback, packaging in FWD vehicles and the application of DCT on full size trucks. GM stated that there might be an additional gear needed for DCT on full size trucks because of the lack of a torque converter. GM also expressed concerns about the US customer's acceptance of DCT due to its loss of smoothness. NHTSA judges that the expressed technical considerations, concerns, limitations and risks are recognized within the industry and it is standard industry practice to address each during the design and development phases of applying DCT technologies. Cost and effectiveness estimates used in the final rule are based on analysis that assumes each of these factors is addressed prior to production implementation of the technologies. As it is stated before, NHTSA believes that DCT offers great potential for improving fuel economy and is a valid choice for the future fuel economy improvement according to the technical sources such as the NESCCAF study and CBI information NHTSA has received.

GM also expressed concern about the added weight for the electronics for DCT, but NHTSA believes that DCT is a simpler transmission than automatic transmission and it does not need a torque converter. The overall weight for DCT should not be more than a 6 speed automatic transmission. For example, according to public information, Ford’s dry-clutch PowerShift is 30 pounds lighter than the existing four speed automatic on Ford Focus. Therefore, NHTSA judges that overall transmission system mass will not be increased with a DCT.

GM commented that some fuel economy improvement technologies, such as dry DCT, are more naturally applicable to smaller footprint vehicles and the smaller sized powertrains that accompany them. NHTSA has taken these into consideration when developing this rule and applied dry DCT only to the smallest of vehicle subclasses, Subcompact and Compact cars

For the MY 2011 CAFE final rule, NHTSA estimated a 5.5 to 9.7 percent improvement in fuel consumption over a baseline 4/5-speed automatic transmission for a wet clutch DCT, which was assumed for all but the smallest of vehicle subclasses, Subcompact and Compact cars. This results in an incremental effectiveness estimate of 2.7 to 4.1 percent over a 6-speed automatic transmission with IATC. For Subcompact, Compact Cars and Small light truck subclasses, which were assumed to use a dry clutch DCT, NHTSA estimated an 8.2 to 12.9 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. NHTSA has retained these estimates for this rule. In response to the NPRM, Porsche provided an estimate for fuel economy improvement for the DCT which is consistent with the incremental effectiveness values used in the NPRM and final rule. In reviewing the NPRM effectiveness estimates for this final rule NHTSA discovered that the DCTAM effectiveness value used in the Volpe model for Subcompact and Compact subclasses was incorrect; the (lower) wet clutch effectiveness estimate had been used instead of the intended (higher) dry clutch estimate for these vehicle classes. NHTSA has corrected the mistake in this final rule.

In the NPRM analysis, NHTSA estimated costs for 6 speed dual-clutch transmissions relative to 6 speed auto transmissions. For the dry clutch DCT, the agencies estimated a direct manufacturing cost of $59 (2007 Dollars in 2012). For the wet clutch DCT, the estimate was $126 (2007 Dollars in 2012). For the final rule, teardown study done by FEV is considered in which FEV found a wet clutch DCT to be $147 less costly than a 6 speed auto transmission. This cost savings is not unexpected when one considers that the DCT is less complex than an auto transmission. However, such a cost savings presumes that capacity exists to produce dual-clutch transmissions at volumes of 450,000 units, an assumption made by FEV. Since such capacity may not currently exist in the US, the FEV value (-$147) is not used directly but instead is averaged with the value used in the NPRM analysis ($126). Therefore, in the final rule, the wet clutch DCT is estimated to save $11 relative to a 6 speed auto transmission (2007 Dollars in 2012). To generate a dry clutch DCT cost for the final analysis, the same cost difference from the NPRM for wet clutch versus dry clutch is applied. In other words, the NPRM analysis had a cost difference of $67 which was then subtracted from the final wet-clutch DCT cost of -$11 to arrive at a result of -$78 for a dry-clutch DCT relative to a 6 speed auto transmission (2007 Dollars in 2012). Table shows the direct manufacturing costs used in the NPRM and final rule for dual clutch transmissions. Applying the medium complexity ICM of 1.25 results in costs of -$59 for the wet-clutch DCT and -$8 for the dry clutch DCT (2007 Dollars in 2012), both relative to a 6 speed auto transmission. With time based learning, these costs become -$68 and -$9, respectively, in 2016 (2007 Dollars).

Table V-26 Direct Manufacturing Costs for Dual-Clutch Transmissions (2007 Dollars in 2012)

Technology	NPRM	FEV tear down	Final Rule	Comments
6s wet DCT relative to 6s auto	$126	-$147	-$11	[$126+(-$147)]/2=-$11
6s dry DCT relative to 6s auto	$59	n/a	-$78	-$11-($126-$59) = -$78

Notes: n/a means that FEV did not conduct a tear down of the technology; refer to text for more detail on the comments.

GM commented that "Producing a DCT transmission in North America requires significant new investment to build new or retool existing transmission manufacturing plants." NHTSA has considered these in NPRM and the final rule by assigning this technology a medium complexity ICM factor of 1.25 to cover the cost. This ICM factor is carried to this final rule.

(17) Continuously Variable Transmission (CVT)

A Continuously Variable Transmission (CVT) is unique in that it does not use gears to provide ratios for operation. Instead, the most common CVT design uses two V-shaped pulleys connected by a metal belt. Each pulley is split in half and a hydraulic actuator moves the pulley halves together or apart. This causes the belt to ride on either a larger or smaller diameter section of the pulley which changes the effective ratio of the input to the output shafts. Advantages of the CVT are that the engine can operate at its most efficient speed-load point more of the time, since there are no fixed ratios. However, CVTs are limited by engine power and cannot be applied to high torque applications. Also, CVTs often have a wider range of ratios compared to conventional automatic transmissions which can provide more options for engine optimization. While CVTs by definition are fully continuous, some automakers choose to emulate conventional stepped automatic operation because some drivers are not used to the sensation of the engine speed operating independently of vehicle speed.

Considering the confidential data together with independent review, NHTSA has estimated the fuel consumption effectiveness for CVTs at 2.2 to 4.5 percent over a 4/5-speed automatic transmission, which translates into a 0.7 to 2.0 incremental effectiveness improvement over a planetary automatic transmission with the IATC technology. NHTSA continues to find these estimates to be accurate.

NHTSA adjusted the original estimates used in MY 2011 CAFE final rule to account for ICM markup of 1.25 for a medium technology. For this rule, this results in an incremental compliance cost estimate of $250 for the MY 2012 vehicles. In the Volpe model, this technology was only applied to vehicles manufactured with unibody construction methods, since ladder frame vehicles are typically unsuitable for CVTs due to their size and utility requirements. CVTs are an established and readily available technology so time based learning is applied, and as with other transmission technologies that result in new installations, CVT are only applied by the Volpe model at redesign cycle timing. The phase-in caps are now at 85 percent throughout the rulemaking period.

(18) 6-Speed Manual Transmissions (6MAN)

Manual transmissions are entirely dependent upon driver input to shift gears: the driver selects when to perform the shift and which gear to select. This is the most efficient transfer of energy of all transmission layouts, because it has the lowest internal gear losses, with a minimal hydraulic system, and the driver provides the energy to actuate the clutch. From a systems viewpoint, however, vehicles with manual transmissions have the drawback that the driver may not always select the optimum gear ratio for fuel economy. Nonetheless, increasing the number of available ratios in a manual transmission can improve fuel economy by allowing the driver to select a ratio that optimizes engine operation more often. Typically, this is achieved through adding overdrive ratios to reduce engine speed at cruising velocities (which saves fuel through reduced engine pumping losses) and pushing the torque required of the engine towards the optimum level. However, if the gear ratio steps are not properly designed, this may require the driver to change gears more often in city driving resulting in customer dissatisfaction. Additionally, if gear ratios are selected to achieve improved launch performance instead of to improve fuel economy, no fuel saving effectiveness is realized.

NHTSA's MY 2011 CAFE final rule estimated an effectiveness increase of 0.5 percent for replacing a 5-speed manual with a 6-speed manual transmission, which was derived from confidential manufacturer data. NHTSA has found no evidence to dispute this estimate and chosen to use 0.5 percent reduction in fuel consumption for replacing a 5-speed manual with a 6-speed manual transmission for this rule. NHTSA updated the 2011 final rule costs to reflect the ICM low complexity markup of 1.11 which resulted in an incremental compliance cost of $250 for MY 2012 vehicles, as compared to $338 in the final rule, with lower costs occurring in later MYs due to the application of time based learning factors. 6MAN is only applied to vehicles that use a manual transmission in the baseline product, and the Volpe model can only apply the technology at redesign cycle timing. The phase-in rate has been set to 85 percent for MY 2012 to 2014 and 100 percent for the remaining years of this rule.

c. Hybrid and Electrification/Accessory Technologies

A Hybrid is a vehicle that combines two or more sources of propulsion energy, where one uses a consumable fuel (like gasoline), and one is rechargeable (during operation, or by another energy source). Hybrid technology is established in the U.S. market and more manufacturers are adding hybrid models to their lineups. Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.
- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.
- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption. A fourth mechanism to reduce petroleum fuel consumption, available to plug-in hybrids electric vehicles (PHEV) and battery electric vehicles (EV), is by substituting the petroleum fuel energy with energy from another source, such as the electric grid. The effectiveness of fuel consumption reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, performance is vastly improved, while fuel efficiency improves significantly less than if the engine was downsized to maintain the same performance as the conventional version. While this approach has been used in cars such as the Honda Accord Hybrid (now discontinued), it is more likely to be used for vehicles like trucks where towing and/or hauling is an integral part of their performance requirements. In these cases, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed truck attribute, manufacturers are hesitant to offer a vehicle with significantly diminished towing performance with a low battery.

Although hybrid vehicles using other energy storage concepts (flywheel, hydraulic) have been developed, the systems currently in production in the U.S. for passenger cars and light trucks use battery storage and electric drive systems. Hybrid electric vehicles (HEV) are part of a continuum of vehicles using systems with differing levels of electric drive and electric energy storage. This range of vehicles includes relatively basic engine start/stop systems, HEV systems with varying degrees of electric storage and electric drive system capability, PHEV with differing degrees of all electric range and EV that rely entirely on electric drive and battery electric energy storage.

Different HEV, PHEV and EV concepts utilize these mechanisms differently, so they are treated separately for the purposes of this analysis. Below is a discussion of battery energy storage and the major hybrid concepts that were determined to be available in the near term.

i. Batteries for HEV, PHEV and EV Applications

The design of battery secondary cells can vary considerably between HEV, PHEV and EV applications.

MHEV systems will likely continue to use lead-acid batteries due to their lower voltage (12-42 VDC) and relatively low power and energy requirements. However, technology used is expected to be upgraded over conventional (non-MHEV) lead acid batteries to meet the charge cycling demands of MHEV applications, and is likely to include extended-cycle-life flooded (ELF) lead-acid batteries or absorptive glass matt, valve-regulated lead-acid (AGM/VRLA) 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-14).

EV batteries tend to be optimized for high energy density and are considerably larger than HEV batteries. PHEV battery designs are intermediate between power-optimized HEV and energy-optimized EV battery cell designs. PHEV batteries also must provide both charge depleting operation similar to an EV and charge sustaining operation similar to an HEV. Unlike HEV applications, charge sustaining operation with PHEVs occurs at a relatively low battery state of charge (SOC) which can pose a significant challenge with respect to attaining acceptable battery cycle life. In the case of the GM Volt, this limits charge depleting operation to a minimum SOC of approximately 30%.[183]

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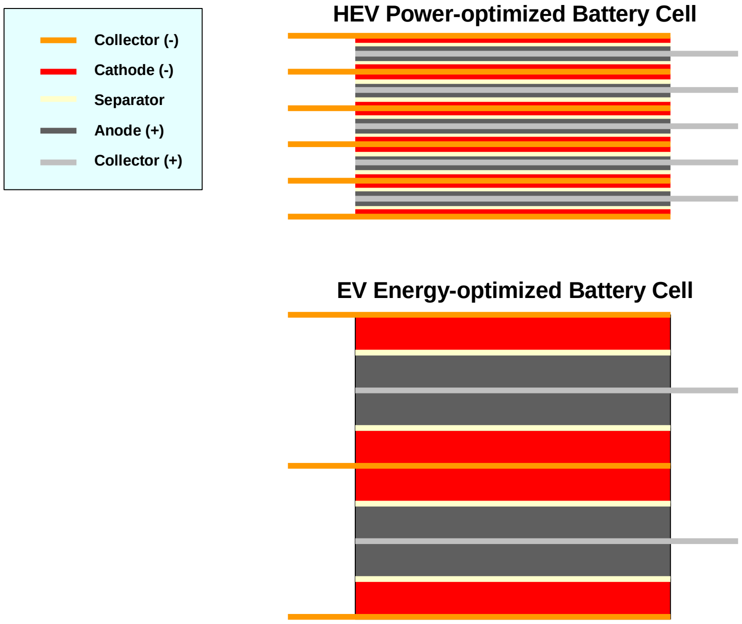
[183] "Latest Chevrolet Volt Battery Pack and Generator Details and Clarifications." Lyle Dennis interview of Rob Peterson (GM) regarding the all-electric drive range of the GM Volt, August 29, 2007. Accessed on

Figure V-14 Schematic representation of power and energy optimized prismatic-layered battery cells



Power-split hybrid vehicles from Toyota, Ford and Nissan, integrated motor assist hybrid vehicles from Honda and the GM 2-mode hybrid vehicles currently use nickel-metal hydride (NiMH) batteries. Lithium-ion (Li-ion) batteries offer the potential to approximately double both the energy and power density relative to current NiMH batteries, enabling much more 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 under development by CPI (LG-Chem) for the GM Volt PHEV and by AESC, GS-Yuasa and A123 Systems (respectively) for the upcoming Nissan, Mitsubishi and Chrysler EVs use large-format, layered-prismatic cells assembled into battery modules. The modules are then combined into battery packs.

Cathodes for large-format, automotive Li-ion batteries are becoming increasingly focused on two chemistries – $LiMn_2O_4$-spinel (CPI, GS-Yuasa, AESC) and $LiFePO_4$ (A123 Systems).

In addition to the purely hybrid technologies, which decrease the proportion of propulsion energy coming from the fuel by increasing the proportion of that energy

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the Internet on March 15, 2010 athttp://gm-volt.com/2007/08/29/latest-chevy-volt-battery-pack-and-generator-details-and-clarifications/

coming from electricity, there are other steps that can be taken to improve the efficiency of auxiliary functions (*e.g.*, power-assisted steering or air-conditioning) which also reduce fuel consumption. These steps, together with the hybrid technologies, are collectively referred to as “vehicle electrification” because they generally use electricity instead of engine power. In order to achieve consistency between the two modeling techniques, and to improve the number and range of technology offerings, the CAFE model was revised to include one additional mild hybrid technology. The high voltage or improved efficiency alternator (HVIA) technology, which was used in the 2011 rule, is no longer represented as a separate technology and has instead been incorporated into this new mild hybrid technology, as discussed further below.

ii. Hybrid System Sizing and Cost Estimating Methodology

NHTSA, in coordination with EPA reviewed estimates of cost and effectiveness for hybrid and related electrical technologies and adjusted them as appropriate. Both agencies found the hybrid technology cost estimating methodology that Ricardo and NHTSA developed during the 2011 final rule to be reasonable and used it to estimate hybrid systems costs and account for variation in component sizing across both the hybrid types and vehicle subclasses. That method utilizes four pieces of data: (1) key component sizes for a midsize car by hybrid system type; (2) normalized costs for each key component; (3) component scaling factors that are applied to each vehicle class/subclass by hybrid system type; and (4) vehicle characteristics for the subclasses which are used as the basis for the scaling factors. During development of the methodology, NHTSA and Ricardo made several assumptions:

1) Hybrid controls hardware varies with the level of functionality offered by the hybrid technology. Assumed hybrid controls complexity for a 12V micro hybrid (MHEV) and belt integrated starter generator (BISG) was 25 percent of a strong hybrid controls system and the complexity for a Crank Integrated Starter Generator (CISG) was 50 percent. These ratios were estimates based on the directional need for increased functionality as system complexity increases.
2) Li-Ion batteries for hybrid electric vehicles are currently entering production, including a 2010 MY Mercedes and Hyundai. One estimate from Anderman indicates that Li-ion market penetration will achieve 35 percent by 2015.[184] However, as was discussed above, significant development effort is underway by a number of battery producers which could impact cost and overcome other technical concerns. Therefore it was assumed that mild (MHEV, BISG and CISG) and strong hybrids (PSHEV, 2MHEV and PHEV) will use either Li-Ion or NiMH batteries, depending on cost considerations. However, plug-in hybrids will use Li-ion batteries only. Battery usage is discussed further below.
3) The plug-in hybrid battery pack was sized for a mid-sized car by assuming: the vehicle has a 20 mile all electric range and consumes an average of 300

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[184] Anderman, Advanced Automotive Battery Conference, May 2008. Proceedings available for purchase at https://www.advancedautobat.com/order/purchase_proceedings.html (last accessed March 15, 2010).

W-hr per mile; the battery pack can be discharged down to 30 percent depth of discharge;[185] and the capacity of a new battery pack is 20 percent greater than at end of life (*i.e.*, range on a new battery pack is 24 miles).

4) All hybrid systems included a DC/DC converter which was sized to accommodate vehicle electrical loads appropriate for increased vehicle electrification in the time frame considered.
5) High voltage wiring scaled with hybrid vehicle functionality and could be represented as a fraction of strong hybrid wiring. These ratios were estimates based on the directional need for increased functionality as system complexity increases.
6) All hybrid systems included a supplemental heater to provide vehicle heating when the engine is stopped; however, in this rule, it is assumed that only half of the vehicles will adapt this technology, as discussed further below. Only the strong hybrids included electric air conditioning to enable engine stop/start when vehicle air conditioning was requested by the operator.

Furthermore, NHTSA and Ricardo recognized that some strong hybrid systems replaced a conventional transmission with a hybrid-specific transmission, resulting in a cost offset (*i.e.*, a cost credit) for the removal of a portion of the clutches and gear sets within the transmission. In the MY 2011 rule, the transmission cost in Table V-27 below expressed hybrid transmission costs as a percentage of traditional automatic transmission cost, as described in the 2008 Martec Report, at $850 direct manufacturing cost (non-RPE/ICM). The method assumed that the mechanical aspect of a power-split transmission with a reduced number of gear sets and clutches resulted in a cost savings of 50 percent ($425) over a conventional transmission with torque converter. For a 2-mode hybrid, the mechanical aspects of the transmission are similar in complexity to a conventional transmission, so no cost savings was appropriate. The plug-in hybrid assumed a highly simplified transmission for electric motor drive, thus 25 percent of the base vehicle transmission cost was applied (resulting in a $638 credit).

The NHTSA MY 2011 CAFE final rule discusses in detail how the hybrid cost estimating methodology uses the information provided in the tables below to calculate costs for each of the strong hybrid systems used in this rule. It also includes a step-by-step example for the midsize vehicle mild hybrid systems used in the MY 2011 CAFE final rule.[186] As in that analysis, it is important to understand that the CISG technology replaces existing mild hybrid systems.[187]

NHTSA and EPA in reviewing the above made the following revisions.

First, NHTSA and EPA revalidated the component sizes that were estimated for a midsize car for each type of hybrid system as shown in Table V-27. However, NHTSA

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[185] The GM Volt operates between 30% DOD and 85% DOD. So there is 55% useable DOD, but charge sustaining operation starts at 30% and cycles between 30 and 35% DOD.

[186] 74 FR 14291 (Mar. 30, 2009)

[187] For the incremental CAFE model, before CISG is applied, the costs for MHEV and BISG are subtracted if they were previously applied.

and EPA added an additional component-- front engine accessory drive (FEAD), because hybridization often involves revision to the FEAD design such that certain devices (belts, pulleys, idlers, etc) as well as other engine components (alternator, A/C compressor, and starter) may no longer be needed and can thus be eliminated, or may be de-specified to lower cost alternatives. This is applicable to CISG and the strong hybrid technologies, and is intended to account for cost savings associated with items that changed or are no longer required as a result of these technology applications.

Table V-27. Component Sizes by Hybrid Type for a Midsize Car

Component	**Hybrid Type**				
	MHEV BISG	**CISG**	**PSHEV**	**2MHEV**	**PHEV**
Primary Motor power, continuous (kW)	3	11	45	45	45
Secondary Motor power, continuous (kW)	na	na	30	45	30
Primary Inverter power, continuous (kW)	3	11	45	45	45
Secondary Inverter power, continuous (kW)	na	na	30	45	30
Controls complexity (relative to strong hybrid)	25%	50%	100%	100%	100%
NiMH Battery Pack capacity (kW-hr)[1]	na	1	2	2	na
Li-Ion Battery Pack capacity (kW-hr)[1]	na	1	2	2	15
DC/DC Converter power (kW)	0.7	2	2	2	2
High Voltage Wiring (relative to strong hybrid)	na	50%	100%	100%	100%
Supplemental heating[2]	50%	50%	50%	50%	50%
Mechanical Transmission (relative to baseline vehicle)	100%	100%	50%	100%	25%
Electric AC	No	No	Yes	Yes	Yes
Blended Brakes	No	Yes	Yes	Yes	Yes
FEAD Credit	No	Yes	Yes	Yes	Yes
Charger power, continuous (kW)	na	na	na	na	3
1 - Assumes the use of either NiMH or Li-Ion, and not both.					
2 - Implemented through a reduction in component cost (50%)					

Second, the costs estimates of the key components were revised and comment to the cost as they apply to NiMH was provided by ICCT. The MY 2011 CAFE final rule was developed at a time when economic conditions were significantly different than those that currently exist, a time when many of the commodity materials used in the hybrid systems were more expensive than today. These changes in economic conditions were one of the factors leading to some of the cost revisions EPA and NHTSA jointly discussed and made. Differences in estimates provided by confidential sources to either EPA or NHTSA also played a part in the revisions. In addition, the agencies applied the new ICM mark-up factors instead of the RPE that was used previously. An appropriate ICM factor (1.45 for most mild and strong hybrid technologies) replaces the previous RPE factor (1.5). Specifically, the primary and secondary inverter cost per kilowatt were revised downward from $10 to $7, the controls cost was revised upward from $100 to $115, the DC/DC converter costs were revised from $100 to $88, the blended brake system that was revised from $400 to $310, and finally the fully learned, high volume production, cost per kilowatt hour (kW-hr) for Nickel Metal Hydride (NiMH) battery was revised from $350 to $320.

The cost for Lithium Ion (Li-Ion) batteries was also revised. As previously stated, Li-Ion batteries are being implemented in series production in model year 2010. Battery technology is changing rapidly in the marketplace today, as discussed above, and is expected to continue along this path throughout the rulemaking period. OEMs are now forming relationships with battery manufacturers in an effort to research and develop not only new and improved battery technology, but also more efficient manufacturing processes capable of supporting high volume production. Accordingly, as shown in Table V-28, the $600 per kW-hr used in the 2011 rule was revised downward to $320 per kW-hr, matching that of the NiMH technology. The revision downward from $600/kW-hr in the 2011 CAFE final rule to $320/kW-hr in this analysis was done based on a study by Deutsche Bank that estimated Li-Ion battery costs at 300-400 €/kW-hr.[v] This was converted to $500/kW-hr then learned twice using volume-based learning to arrive at the $320/kW-hr.

Comments were received from The State of New Jersey Department of Environmental Protection, MEMA, and ICCT on the subject of Lithium-ion battery and system costs. The State of New Jersey Department of Environmental Protection commented that the battery costs were too low citing an Air Resources Board report which projects $260/kW-hr. Necessary volumes and manufacturing maturity will not be accomplished during this rulemaking period to achieve this cost. MEMA commented that the cost of $320/kW-hr was too low stating that present costs far exceed $500/kW-hr. The $500/kW-hr used in this rulemaking is a 2012 figure that was adopted from the Electrification Roadmap, November 2009 and then learning, described in the previous paragraph, was applied. ICCT provided examples of charge capacity and power requirements of recently produced vehicle applications. These examples are based on an assessment of several vehicle models and are specific to those models. For this rule, NHTSA believes it is appropriate to use an average cost which is representative of all vehicle models using this technology during the 2012 to 2016 model year period. The examples cited by commenters do, however, further demonstrate the rapid pace of development and innovation in the application of these hybrid technologies. Though the agency believes the cost assumptions used in the Volpe model to be correct at the point in time of their assessment and are accurate for this rulemaking period, the agency agrees that further research will be necessary to progress from our current point in time assumptions on costs and application parameters for future rule makings.

Li-ion batteries were originally restricted to plug-in hybrids only. Recent vehicle introductions confirm either NiMH or Li-ion battery technology can be used in any mild or strong HEV application. However, manufacturers are likely to consider cost highly in their selection of battery technology. If Li-ion battery prices decrease to levels similar to NiMH, Li-ion batteries would be the default battery technology for all hybrid electric vehicles. If Li-ion battery prices remain high, NiMH would be the default battery technology for all hybrid electric vehicles. For plug-in hybrids Li-ion would continue to be required because plug-in hybrids demand higher energy density than NiMH can provide. Neither the CAFE nor OMEGA model predicts a high penetration of plug-in technology in achieving the standards.

Finally, the agencies assessed the cost savings associated with the FEAD credit discussed above. This cost was not previously represented in the hybrid cost model. As shown in Table V-28 below, a $100 credit is used which offsets directly the costs of the other components specified. This is the best approximation of the value of these items, based on NHTSA and EPA engineering assessment.

Estimates of each key component are shown in Table V-28 below along with the sources of those estimates. The cost basis estimates assume fully learned, high-volume (greater than 1.2 million units per annum) production, and the costs shown are direct manufacturing costs that are not RPE or ICM adjusted. This table does not show a cost applicable to the belt integrated starter generator system (BISG) since it is a fixed cost that, like the automatic transmission pump cost, is not scaled by subclass as described later.

Table V-28 Component Cost Basis at High Volumes and Data Sources

COMPONENT	COST BASIS	DATA SOURCE
Primary Motor ($/kW)	$15	Martec 2008
Secondary Motor ($/kW)	$15	
Primary Inverter ($/kW)	$7	Confidential Business Information
Secondary Inverter ($/kW)	$7	
Controls	$115	
NiMH Battery Pack ($/kW-hr.)	$320	2011 CAFE FRM (with revision)
Li-ion Battery Pack ($/kW-hr.)	$320	Deutsche Bank 2008
DC/DC Converter (Size: 2kW)	$88	Confidential Business Information
High Voltage Wiring	$200	Martec 2008
Supplemental Heating	$42	
Mechanical Transmission	$850	Martec 2008 (to 4-spd auto)
Electric Air Conditioning	$450	Confidential Business Information
Blended Brakes	$310	
Charger	$100	
Automatic Transmission Pump	$75	Martec 2008
FEAD Credit	$(100)	Confidential Business Information

Third, NHTSA and EPA also revised component size/scaling assumptions for some vehicles (*i.e.*, large trucks). NHTSA and EPA recognized that some manufacturers may choose not to use supplemental cabin heating opting instead to continue engine operation in the event heat demand occurs; therefore supplemental heating is specified for only half of the vehicles. Table V-28 above indicates the 50 percent application rate implemented in the hybrid cost estimating methodology reducing the component cost from $84 to $42.

NHTSA and EPA also reviewed the choice of a 3 kW DC/DC converter as a component size input for a midsize vehicle, which represented a 250 amp current capability. In retrospect this is a high specification for a midsize vehicle and we revised the estimate to a 2 kW DC/DC converter, as shown in Table V-28 above, which would represent a more reasonable 150 amp current capacity.

The scaling factor used for the primary and secondary motors and invertors on the large truck and SUV vehicles was revised. As in the MY 2011 CAFE final rule, a linear extrapolation was used from the midsize vehicle and extended it out to the largest of vehicles, the large truck class. This resulted in projected component sizes that are larger than those used on a commercially realized truck in this vehicle class, the Chevrolet Tahoe two-mode HEV. Accordingly the scaling factors have been revised for this class (and the agencies have verified scaling factors for the other classes). This more closely approximates the motor and inverter sizes specified in the Tahoe application. For future analysis, the agencies are considering whether it may be more accurate to use one set of scaling for passenger cars and another different set for light trucks.

Another revision involves the addition of a stand-alone higher voltage Start-Stop/ BISG mild hybrid system. NHTSA and EPA determined that by applying a cost increase to the MHEV technology to allow for a voltage increase (lead acid batteries) and efficiency improvements to the alternator, the system would then approximate the higher voltage Start-Stop /BISG applied by EPA. Based on confidential sources, the estimates provided were first converted to 2007 dollars and then reverse learned through two cycles, since volume learning is applicable, to arrive at a non-RPE/ICM incremental compliance cost to be $229. This cost is applicable to all classes that use higher voltage Start-Stop/BISG and is not scaled by any vehicle attribute.

Component scaling factors for each type of hybrid system as shown in Table V-29 below

Table V-29 Component Scaling Factors applied to Vehicle Class for each Hybrid System

<table>
<tr><th rowspan="2">Component</th><th colspan="5">Hybrid Type</th></tr>
<tr><th>MHEV</th><th>CISG</th><th>PSHEV</th><th>2MHEV</th><th>PHEV</th></tr>
<tr><td>Primary Motor</td><td>Engine displacement</td><td>Curb weight</td><td colspan="2">Curb weight[1]</td><td>Engine power</td></tr>
<tr><td>Secondary Motor</td><td>na</td><td>na</td><td colspan="2">Engine displacement</td><td>Curb weight[2]</td></tr>
<tr><td>Primary Inverter</td><td colspan="5">Primary motor power</td></tr>
<tr><td>Secondary Inverter</td><td>na</td><td>na</td><td colspan="3">Secondary motor power</td></tr>
<tr><td>Controls</td><td colspan="5">Complexity</td></tr>
<tr><td>NiMH Battery Pack</td><td>na</td><td colspan="3" rowspan="2">Curb weight</td><td>na</td></tr>
<tr><td>Li-Ion Battery Pack</td><td>na</td><td>Curb weight</td></tr>
<tr><td>DC/DC Converter</td><td colspan="5">Curb weight[3]</td></tr>
<tr><td>High Voltage Wiring</td><td>na</td><td colspan="4">Vehicle footprint</td></tr>
<tr><td>Supplemental heating</td><td colspan="5">Vehicle footprint</td></tr>
<tr><td>Mechanical Transmission</td><td colspan="5">Same for all vehicle classes</td></tr>
<tr><td>Electric AC</td><td>na</td><td>na</td><td colspan="3">Vehicle footprint</td></tr>
<tr><td>Blended Brakes</td><td>na</td><td colspan="4">Same for all vehicle classes</td></tr>
<tr><td>Charger</td><td>na</td><td>na</td><td>na</td><td>na</td><td>Same for all vehicle classes</td></tr>
</table>

(1) For all vehicle classes except for performance classes which use Engine Torque

(2) Curb weight used as surrogate for vehicle road load

(3) Curb weight used as surrogate for vehicle electrical load

Regarding the market data file from the MY 2011 CAFE final rule, NHTSA and EPA did not make any revisions to the average vehicle characteristics for each vehicle subclass as shown in Table V-30, which defines the average vehicle characteristics for each vehicle subclass. These characteristics were used as the basis of the scaling factors in the Volpe model.

Table V-30 Key Vehicle Characteristics For Each Vehicle Subclass for CAFE model

Vehicle Subclass	Curb Weight (lbs)	Footprint (ft2)	Engine Disp. (L)	Engine Power (hp)	Torque (ft-lb)
Subcompact Car	2795	41	1.9	134	133
Compact Car	3359	44	2.2	166	167
Midsize Car	3725	47	2.9	205	206
Large Car	4110	50	3.4	258	248
Performance Subcompact Car	3054	40	2.7	260	260
Performance Compact Car	3516	44	3.0	269	260
Performance Midsize Car	3822	47	3.9	337	318
Performance Large Car	4189	51	4.8	394	388
Minivan	4090	50	3.3	247	242
Small Truck	3413	45	2.6	178	185
Medium Truck	4260	50	3.6	250	256
Large Truck	5366	63	5.0	323	352

(19) Electrical Power Steering (EPS)

Electric power steering (EPS) provides 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. Additionally EPS is an enabler for all vehicle hybridization technologies, since it provides power steering when the engine is off, and thus NHTSA places the technology at the top of the electrification decision tree. While EPS may be implemented on most vehicles with a standard 12V system, heavier vehicles may require a higher voltage system which may add cost and complexity.

In the 2011 final rule NHTSA estimated a 1 to 2 percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer data. NHTSA reviewed these effectiveness estimates and found them to be accurate, thus they have been retained for this rule.

For costs, in the MY 2011 CAFE final rule, NHTSA estimated EPS at $105 - $120 at a 1.5 RPE markup factor. NHTSA, working in conjunction with EPA, adjusted the EPS cost for this rule based on a review of the specification of the system. Adjustments were made to the potentially higher voltage or heavier duty system operation, such as would be required on some hybrid trucks. Accordingly, higher costs were estimated for EPS due to the system's higher capability. After accounting for the differences in system capability and applying the ICM markup of low complexity technology of 1.11, the estimated costs for this rulemaking are $106 for a MY 2012 vehicle. As EPS systems are in wide spread usage today, time based learning is also deemed applicable, hence costs will be lower for later MY vehicles. The Volpe model can apply EPS at refresh or redesign cycles, since it is a reasonably non-intrusive technology. Whereas the 2011 final rule did not apply EPS to the Large Truck and SUV subclass, primarily due to concerns with the system's capability, there are no subclass specific limitations on its use in this rule for the reasons stated above. The phase-in cap has been set at 85 percent in MYs 2012 to 2014, and 100 percent thereafter,

(20) Improved Accessories (IACC)

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 (*i.e.*, "on-demand").

As the oil pump provides lubrication to the engine's sliding surfaces such as bearings, pistons, and camshafts, oil flow must be provided whenever the engine is rotating. Because mechanical oil pumps do not operate when the engine is not rotating, there is no efficiency benefit for the ability of an electric oil pump to be switched off when the engine is not rotating. The increased complexity of an electric oil pump system creates greater reliability risk compared to a conventional mechanical oil pump, and increases risk for significant engine damage should the system fail, even momentarily.

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. Further benefit may be obtained when electrification is combined with an improved, higher efficiency engine alternator. Vehicles that typically carry heavy payloads, or that are used for towing have high cooling system and cooling fan loads, and benefit less for intelligent cooling. Therefore, intelligent cooling is not applied to the Large LT subclass. In the CAFE model, IACC refers solely to improved engine cooling.

NHTSA reviewed the 1 to 2 percent IACC effectiveness estimates used in MY 2011 rule and found them to be accurate for this rule. NHTSA also confirmed the cost assumptions from the final rule and thus only adjusted the costs to reflect the new ICM markup for a low complexity technology of 1.11; this results in a cost estimate for this rulemaking of $128 at MY 2012. Since these systems are readily available and in production currently time based learning is applied. The Volpe model can apply IACC at either refresh or redesign cycle however application to the Large Truck and SUV subclass is prohibited due to the cooling system requirements of these high utility vehicles. The phase-in rate has been defined as 85 percent in MYs 2012 to 2014, and 100 percent thereafter.

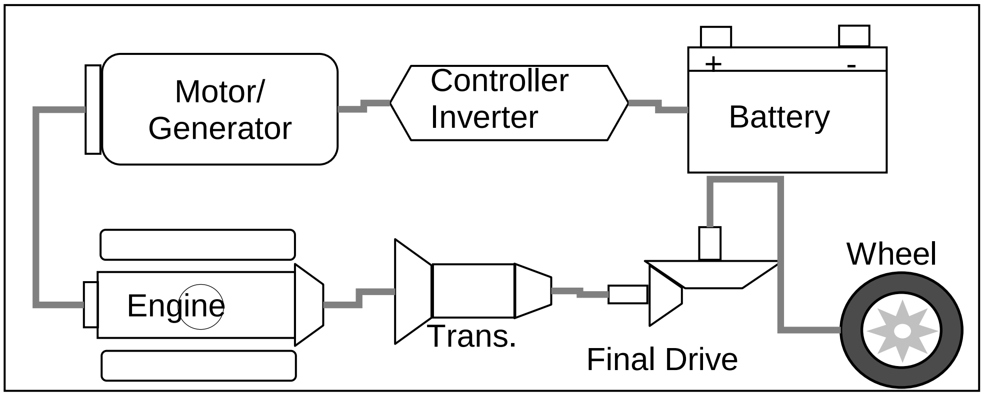
(21) 12V Micro Hybrid (MHEV)

The 12V Micro-Hybrid (MHEV) systems are the most basic of hybrid systems and offer only the ability to turn the engine off when the vehicle is stopped or potentially during deceleration (i.e. idle stop). Their low cost and adaptability to existing powertrains and platforms can make them attractive for some applications. The conventional belt-driven alternator is replaced with a belt-driven, enhanced power starter-alternator and a redesigned front-end accessory drive system. A conventional 12V gear-reduction starter is retained to ensure reliable cold-weather starting. Also, during idle-stop, some functions such as power steering and automatic transmission hydraulic pressure are lost; so electric power steering and an auxiliary transmission pump may be needed. A schematic of the MHEV system is shown in Figure V-15.

In the 2011 final rule, the effectiveness estimates for this technology ranged from 2.0 to 4.0 percent dependent on whether the vehicle is equipped with a 4, 6 or 8 cylinder engine, with the 4 cylinder engine having the lowest range and the 8 cylinder having the highest. The estimates reflect the limited capability of 12 volt systems which do not recover mechanical energy through regenerative braking or provide motive force; sources citing higher estimates typically involve higher voltage systems that have increased capability.

For this rule, the system specifications assumed in the 2011 rule[188] were applied (i.e., use of a 3 kW motor and a DC/DC converter) and the hybrid technology cost method was used to produce system costs, like was done in 2011 rule. However, the use of revised component costs and new ICM markups resulted in costs ranging from a low of $288 for Subcompact subclass to a high of $410 for the Large Performance subclass, both of which are for MY 2012 vehicles. This technology is not applied to the Large Truck and SUV subclass due to the higher utility requirements of these vehicles; however this is the only subclass limitation of the MHEV technology. Time based learning is considered applicable, and thus system costs are lower in later MYs. Application by the Volpe model is limited to the redesign cycle since the front engine accessory drive will likely require significant redesign with a phase-in cap of 85 percent for all MYs.

Figure V-15 Schematic of MHEV Type System [Husted, 2003]



Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG)

Belt Mounted Integrated Starter Generator (BISG) systems are higher voltage stop-start 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

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[188] 74 FR 14293 (Mar. 30, 2009)

enabling a limited level of regenerative braking which is generally not available to 12 volt based systems. 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. The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors[189] for energy storage. Schematically BISG is similar to the MHEV technology.

NHTSA did not have an equivalent technology to BISG in the 2011 final rule (the ISG technology used in the 2011 rule was envisioned to be more capable than BISG). Effectiveness estimates for higher voltage stop-start systems found in literature and reports typically range from 3.0 to 7.5 percent, relative to a vehicle without stop-start, and dependent on a number of vehicle characteristics such as engine displacement and vehicle size. The Volpe model, which applies BISG incrementally to the MHEV technology, uses incremental estimates of 3 to 6 percent in this rule, which makes the net effectiveness comparable to the estimates found in the 2002 NAS and 2004 NESCCAF reports for higher voltage stop-start systems. This estimate applies for all vehicle subclasses except Large Truck and SUV where, due to their high utility requirements, the BISG technology is not considered applicable. Comment received from GM support the exclusion of this technology from Large Truck applications.

For this rule, the cost estimate used by the Volpe model, which is incremental to the MHEV technology, adjusts the costs upwards by $286 to reflect the need for additional battery capacity, wiring upgrades, and a larger optimized electric machine. The cost estimates reflects volume based learning factors, since these systems are in relatively low usage at this time, and an ICM complexity markup of 1.25 for a medium complexity technology. Like MHEV, BISG can only be applied at redesign cycles times, and a flat 85 percent phase-in setting exists for all MYs.

(22) Crank Integrated Starter Generator (CISG)

Integrated motor assist (IMA) is a commercially realized system developed and marketed by Honda. This is similar to the CISG technology represented in the Volpe model. They 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 about 300 volts) and can provide torque for launch as well as generate 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 CISG systems typically do not fully launch the vehicle on electric power alone, although some can cruise on electric power; dual-clutch based CISG systems capable of all-electric drive are under

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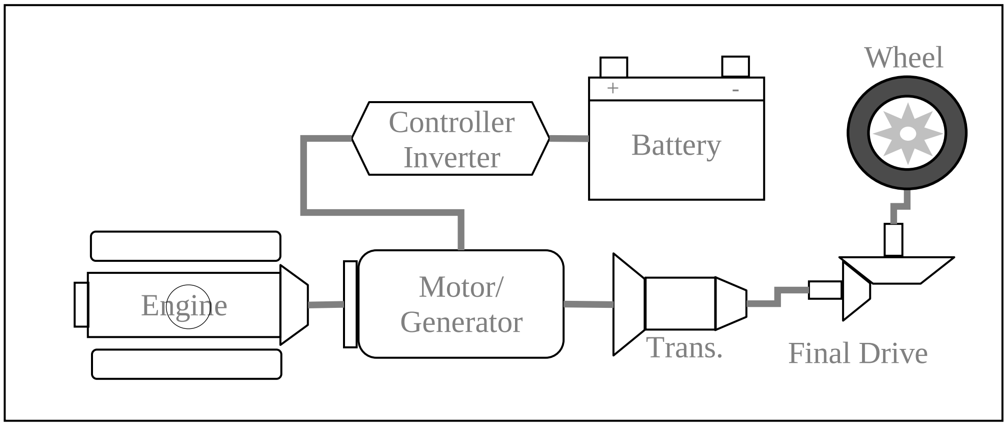
[189] A supercapacitor, also known as an electric double-layer capacitor (and, of course, not to be confused with the fictitious "flux capacitor"), is an electrochemical capacitor that is functionally similar to a conventional electrostatic or electrolytic capacitor but with a significantly higher energy density, on the order of a thousand times greater capacitance.

development. A schematic of the Honda's IMA system is shown in Figure V-1.

Figure V-16 Schematic of Honda IMA System [Husted, 2003]



NHTSA did not have an equivalent technology to CISG in the 2011 final rule (the ISG technology used in the 2011 rule was envisioned to be less capable than the CISG technology defined here). For the CISG technology NHTSA estimated a net effectiveness range of 16 to 20 percent, relative to the baseline vehicle and across all vehicle subclasses in this analysis. The Volpe model therefore applies an incremental effectiveness of approximately 8.6 to 8.9 percent relative to the BISG technology and dependent on vehicle subclass except for large truck and SUV in which case BISG does not apply. Note that the net effectiveness assumptions used in this rule do not include engine downsizing, or any other effectiveness gains from engine, transmission, or vehicle technologies added to the vehicle by the modeling process.

Using the hybrid cost estimating method, as discussed above, NHTSA has determined a compliance cost range of $2,791 for a Subcompact vehicle to $5,124 for the Large Truck and SUV vehicles, both in MY 2012. These include a high complexity ICM markup factor of 1.45 for this technology. As CISG is still in limited production use, volume based learning is applied which results in lower costs as the model applies sufficient quantities and applies two cycles of 20 percent cost reduction. CISG is applicable to all vehicle subclasses. Since significant vehicle modification is required to implement this technology the Volpe model only applies CISG during a redesign cycle. NHTSA assumed a 3 percent phase-in cap for CISG in MY2012 and increasing 3 percent per year reaching a maximum of 15 percent in MY 2016.

(23) Power Split Hybrid (PSHEV)

The Power Split hybrid has the ability to move the vehicle on electric power only. It replaces the vehicle's transmission with a single planetary gear and a motor/generator. A second, more powerful motor/generator is directly connected to the vehicle's final drive. The planetary gear splits engine power between the first motor/generator and the final drive. The first motor/generator uses power from the engine to either charge the battery or supply power to the wheels. The speed of the first motor/generator determines the relative speed of the engine to the wheels. In this way, the planetary gear allows the engine to operate independently of vehicle speed, much like a CVT. The Toyota Prius and the Ford Hybrid Escape are two examples of power split hybrid vehicles.

In addition to providing the functions of idle engine stop, subsequent restart and regenerative braking, this hybrid system allows for pure EV operation. The power split system provides good fuel consumption in city driving. During highway cycles, the hybrid functions of regenerative braking, engine start/stop and optimal engine operation cannot be applied as often as in city driving, and so the effectiveness in fuel consumption is slightly less. Additionally, it is less efficient at highway speeds due to the fact that the first motor/generator must be spinning at a relatively high speed and therefore incurs losses. Newer designs incorporate a gear-reduction motor to provide improved high speed efficiency and improved matching of motor torque to engine torque.

The Power Split hybrid also reduces the cost of the transmission, replacing a conventional multi-speed unit with a single planetary gear. The electric components are bigger than those in mild hybrid and CISG configurations so the costs are correspondingly higher.

During development of the joint rulemaking, NHTSA, in conjunction with EPA, reviewed manufacturer-supplied information that compared cars and small trucks available with and without a PSHEV hybrid system. The data was taken from EPA's fuel economy test data and indicated a combined cycle tailpipe CO2 reductions, which are equivalent to fuel consumption reductions, for the PSHEV equipped vehicles compared to the conventional vehicles that ranged from 19 to 36 percent, see Table V-31 and V-32[190]. Considering the Volpe model's incremental approach to technology application, where engine downsizing and other vehicle related effectiveness improvements are accounted for on other technology decision trees, NHTSA determined that net effectiveness estimates of 23 to 33 percent were most appropriate for the PSHEV technology in this analysis. These net effectiveness values result in incremental effectiveness estimates that range from approximately 6 to 12 percent depending on vehicle subclass and relative to a CVT.

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[190] The manufacturer data shows that, for the most part, the PSHEV equipped vehicles in the comparisons utilized engine downsizing, however the data is not intended to identify all other differences that may exist between the hybrid and non-hybrid vehicle versions, such as hybrid-specific powertrain calibrations or other vehicle modifications (tires, mass reductions, etc). Readers should exercise caution in assuming that all of the noted fuel consumption gains can be attributed solely to engine downsizing and the use of the PSHEV technology as there may be other modifications or systems that also contributed.

Table V-31 Large Car Power Split Certification Data

		Tailpipe CO_2		
		City	Hwy	55/45 comb.
Nissan Altima				
	3.5L CVT	444	306	386
	HEV 2.5L PS	317	254	286
	Net % difference			-26%
Toyota Camry				
	3.0L 5-auto	404	286	355
	HEV 2.4L PS	222	234	228
	Net % difference			-36%
Lexus GS				
	4.3L 6-auto	493	355	423
	HEV 3.5L PS	355	317	341
	Net % difference			-19%

Table V-32 Small Truck Power Split Certification Data

		Tailpipe CO_2		
		City	Hwy	55/45 comb.
Ford Escape 4X4				
	3.0L 4-auto	467	386	423
	HEV 2.3L PS	277	306	286
	Net % difference			-32%
Ford Escape 4X2				
	3.0L 4-auto	444	370	404
	HEV 2.3L PS	247	286	261
	Net % difference			-35%
Toyota Highlander 4X4				
	3.3L 5-auto	493	370	423
	HEV 3.3L PS	286	329	306
	Net % difference			-28%

Using the hybrid cost estimating method NHTSA established overall PSHEV system costs, which include the use of Electric Power Steering (EPS) and Improve Accessories (IACC) technologies, ranging from $5,509 for the Subcompact subclass to $11,534 for the Performance Large Car subclass for MY 2012 vehicles. In the Volpe model these net costs result in incremental costs ranging from $1,600 to $6,723 depending on vehicle subclass. The costs were determined using a 1.45 ICM for the high complexity PSHEV technology. Volume based learning is applicable to power split technology, so costs reduce significantly as penetration levels increase sufficiently. In the Volpe model PSHEV is not applicable to the Large Truck and SUV subclass primarily due to the high utility requirements of these vehicles. PSHEV implementation requires significant vehicle revision, therefore its application is restricted to redesign cycles only. For the strong hybrid technologies, NHTSA used phase-in caps of 3 percent per MY, so the maximum application rate occurs in MY 2016 at 15 percent.

A comment received from ICCT disagreed that volume-based learning is over for the ‘power-split hybrid electric vehicle’ and only time-based learning curve is to be applied. While power-split hybrids have been on the market long enough to achieve high production volumes, the production ramp up has been very slow and the initial costs were very high. In addition, virtually all power-split hybrid vehicles have been equipped with NiMH batteries. NHTSA expects in the future that there will be a shift toward Li-Ion battery technology, and that this change in technology will be a sufficiently significant to justify the continued use of volume based learning. Based on this, the Volpe model will continue to use volume based learning for the final rule.

(24) 2-Mode Hybrid

The 2-Mode Hybrid (2MHEV) uses an adaptation of a conventional stepped-ratio automatic transmission which replaces some of the transmission clutches with two electric motor/generators allowing the transmission to act like a CVT. The motor/generators control the ratio of engine speed to vehicle speed. The clutches allow the motors to be bypassed improving the transmission’s torque capacity and the efficiency for improved fuel economy at highway speeds and to meet the requirements needed for towing and high payload capacity. This type of system is used in the Chevrolet Tahoe Hybrid.

In addition to providing the hybrid functions of engine stop and subsequent restart and regenerative braking, the 2MHEV allows for pure EV operation. The two motor/generators allow the engine to be run in efficient operating zones. The primary motor/generator is comparable in size to that in the PSHEV system, but the secondary motor/generator is larger. The 2-mode system cost is greater than that for the power split system due to the additional transmission complexity and secondary motor sizing.

For this rule, and for similar reasons as discussed above in the PSHEV section, the CAFE model considered a net effectiveness range of 23 to 33 percent, assuming no engine downsizing so as to preserve the utility nature of medium and large trucks where the 2MHEV technology is applied (*e.g.*, maintaining full towing capability even in situations with low battery charge). These estimates lead to incremental effectiveness values ranging from approximately 3 to 9.5 percent for the truck subclasses, and relative to a CVT.

NHTSA estimated MY 2012 costs using the updated component costs and scaling factors in the hybrid cost estimating methodology discussed above and determined incremental cost estimates ranging from $3,521 to $5,779 for the three light duty truck applications. These estimates include the 1.45 ICM markup value for high complexity 2MHEV technology; volume based learning is applicable. The 2MHEV technology is only applied by the Volpe model at redesign cycle times, and it is not applicable to any of the passenger car subclasses. NHTSA used a 3 percent per MY phase-in cap, so the maximum application rate occurs in MY 2016 at 15 percent.

(25) Plug-In Hybrid

Plug-In Hybrid Electric Vehicles (PHEVs) are very similar to Hybrid Electric Vehicles, but with three significant functional differences. The first is the addition of a means to charge the battery pack from an outside source of electricity (e.g. the electric grid). Second, a PHEV would have a larger battery pack with more energy storage, and a greater capability to be discharged. Finally, a PHEV would have a control system that allows the battery pack to be significantly depleted during normal operation.

Table V-33 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 these vehicles exist on a continuum with HEVs on one end and EVs on the other.

Table V-33 Conventional, HEVs, PHEVs, and EVs Compared

	Increasing Electrification			
Attribute	Conventional	HEV	PHEV	EV
Drive Power	Engine	Blended Engine/Electric	Blended Engine/Electric	Electric
Engine Size	Full Size	Full Size or Smaller	Smaller or Much Smaller	No Engine
Electric Range	None	None to Very Short	Short to Medium	Medium to Long
Battery Charging	None	On-Board	Grid/On-Board	Grid Only

Deriving some of their propulsion energy from the electric grid provides several advantages for PHEVs. PHEVs offer a significant opportunity to replace petroleum used for transportation energy with domestically-produced electricity. The reduction in petroleum usage does, of course, depend on the amount of electric drive the vehicle is capable of under its duty cycle. PHEVs also provide electric utilities the possibility to increase electric generation during “off-peak” periods overnight when there is excess generation capacity and electricity prices are lower. Utilities like to increase this “base load” because it increases overall system efficiency and lowers average costs. Utilities are also investigating the use of PHEV and EV batteries as a source of grid storage capacity to provide ancillary services for grid stabilization purposes. 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.

PHEVs will be considerably more costly than conventional vehicles and some other advanced technologies. To take advantage of their capability, consumers would have to be willing to charge the vehicles nightly, and would need access to electric power where they park their vehicles. For many urban dwellers who may park on the street, or in private or public lots or garages, charging may not be practical. Charging may be possible at an owner’s place of work, but that would increase grid loading during peak hours which would eliminate some of the benefits to utilities of off-peak charging vs. on-peak. Oil savings will still be the same in this case assuming the vehicle can be charged fully.

The effectiveness potential of PHEVs depends on many factors, the most important being the energy storage capacity designed into the battery pack. To estimate the fuel consumption and tailpipe CO_2 reduction potential of PHEVs, EPA has developed an in-house vehicle energy model (PEREGRIN) to estimate the fuel consumption/CO_2 emissions reductions of PHEVs. This model is based on the PERE (Physical Emission Rate Estimator) physics-based model used as a fuel consumption input for EPA's MOVES mobile source emissions model.

PHEVs can have a wide variation in the All Electric Range (AER) that they offer. Some PHEVs are of the "blended" type where the engine is on during most of the vehicle operation, but the proportion of electric energy that is used to propel the vehicle is significantly higher than that used in a PSHEV or 2MHEV. In this analysis, each PHEV was modeled with enough battery capacity for a 20-mile-equivalent AER and a power requirement to provide similar performance to a hybrid vehicle. 20 miles was selected because it offers a good compromise for vehicle performance, weight, battery packaging and cost. Given expected near-term battery capability, a 20 mile range represents the likely capability that will be seen in PHEVs in the near-to-mid term.

To calculate the total energy use, the PHEV can be thought of as operating in two distinct modes, electric (EV) mode, and hybrid (HEV) mode. During EV operation the fuel consumption is zero. The EV mode fuel economy can then be combined with the HEV mode fuel economy using the Utility Factor calculation in SAE J1711 to determine a total MPG value for the vehicle. (See Table V-34)

Table V-34. Sample Calculation of PHEV Gasoline-Equivalent CO_2 Reduction

	Midsize Car
EV energy comb (0.55 city / 0.45 hwy)	0.252 kwh/mi
EV range (from PEREGRIN)	20 miles
SAE J1711 utility factor	0.30
HEV mode comb FE (0.55 city / 0.45 hwy)	49.1 mpg
Total UF-adjusted FE (UF*FCEV + (1-UF)*FCHEV)	70.1 mpg
Baseline FE	29.3 mpg
Percent FE gain	139%
Percent CO_2 reduction	-58%

Calculating a total reduction based on model outputs and the Utility Factor calculations results in a 58 percent reduction in fuel consumption for midsize and smaller passenger cars and small trucks and SUVs. This value is used as the net effectiveness estimate for these subclasses in the Volpe model, yielding incremental estimates of approximately 46 percent relative to CVT and independent of engine and other vehicle related effectiveness improvements. The CAFE model does not apply the PHEV technology to Large Cars and the Medium and Large Truck and SUV subclasses.

Using the hybrid cost estimating model and updated component costs, NHTSA determined MY 2012 incremental cost estimates for the Volpe model ranging from a low of approximately $11,500 for a subcompact car to a high of approximately $19,000 for a midsize performance car. This includes the 1.64 ICM markup value for very high complexity technology. Volume based learning lowers the costs in later model years, and a phase-in cap of 3 percent per model year is also applied.

d. Vehicle Technologies

(26) Mass Reduction

Reducing a vehicle's mass, or down-weighting a vehicle, decreases fuel consumption by reducing the energy demand needed to overcome forces resisting motion, and rolling resistance. Manufacturers employ a systematic approach to mass reduction where the net mass reduction is the addition of a direct component or system mass reduction plus the additional mass reduction taken from indirect ancillary systems and components, as a result of full vehicle optimization, effectively compounding or obtaining a secondary mass reduction from a primary mass reduction. For example, use of a smaller, lighter engine with lower torque output subsequently allows the use of a smaller, lighter-weight transmission and drive line components. Likewise the compounded mass reductions of the body, engine and drivetrain reduce stresses on the suspension components, steering components, wheels, tires and brakes, allowing further reductions in the mass of these subsystems. The reductions in unsprung masses such as brakes, control arms, wheels and tires further reduce stresses in the suspension mounting points. This produces a compound effect of mass reductions, which results in the so-called ripple effect.

Estimates of the synergistic effects of mass reduction and the compounding effect that occurs along with it can vary significantly from one report to another. For example, in discussing its estimate, an Auto-Steel Partnership report states "These secondary mass changes can be considerable—estimated at an additional 0.7 to 1.8 times the initial mass change."[191] This means for each one pound reduction in a primary component, up to 1.8 pounds can be reduced from other structures in the vehicle (i.e., a 180% factor). The report also discusses that a primary variable in the realized secondary weight reduction is whether or not the powertrain components can be included in the mass reduction effort, with the lower end estimates being applicable when powertrain elements are unavailable for down-weighting. However another report by the Aluminum Association, which primarily focuses on the use of aluminum as an alternative material for steel, estimated a factor of 64 percent for secondary mass reduction even though some powertrain elements were considered in the analysis.[192] That report also notes that typical values for this factor vary from 50 to 100 percent. Although there is a wide variation in stated estimates, synergistic mass reductions exist and the effects result in tangible mass reductions. Mass

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[191] "Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients," Malen, D.E., Reddy, K. Auto-Steel Partnership Report, May 2007. Accessed on the Internet on March 15, 2010 at: http://www.a-sp.org/database/custom/Mass%20Compounding%20-%20Final%20Report.pdf

[192] "Benefit Analysis: Use of Aluminum Structures in Conjunction with Alternative Powertrain Technologies in Automobiles," Bull, M. Chavali, R., Mascarin, A., Aluminum Association Research Report, May 2008. Accessed on the Internet on March 15, 2010 at: http://www.autoaluminum.org/downloads/IBIS-Powertrain-Study.pdf

reductions in a single vehicle component, for example a door side impact / intrusion system, may actually result in a significantly higher weight savings in the total vehicle, depending on how well the manufacturer integrates the modification into the overall vehicle design. Accordingly care must be taken when reviewing reports on weight reduction methods and practices to ascertain if compounding effects have been considered or not.

Manufacturers consider and utilize various methods and options for achieving vehicle mass reductions. Automotive companies have largely used weight savings in some vehicle subsystems to offset or mitigate weight gains in other subsystems from increase feature content such as sound insulation, entertainment system, etc. The mass reduction methods can be grouped in four major categories as follows.

- Material Substitution: One of the more common methods, and one which NHTSA has considered in prior rulemakings, is material substitution, where lower density and/or higher strength materials are utilized in a manner that preserves or improves the function of a component under consideration for redesign[193]. Aluminum Association commented on the increasing usage of aluminum while American Chemistry Council Plastics Division commented on the increasing usage of plastic composite and its strength in automotive industry. NHTSA acknowledge various approaches for material substitution and mass reduction. There are increasing numbers of advanced material applications in automotive industry, such as high strength steel body structure, aluminum engine block and transmission case, as well as composite flooring. These technologies can reduce mass for vehicles components and sub-systems significantly. For an example, aluminum hood offers 40 to 50 percent mass savings over the mild steel counterpart.

- Smart Design: Computer aided engineering (CAE) tools are another important method of improving structural strength and component designs so as to better optimize load paths and reduce stresses and bending moments applied to them. This allows better optimization of the dimensional aspects of the component (and thus its mass) while maintaining or potentially improving the function, or may integrate unique parts in a manner that reduces mass by combining functions or eliminating separate fasteners. An example of CAE in the extreme would be a traditional "body on frame" vehicle which is redesigned with a lighter "unibody" construction, where the new design optimizes exterior body size, passenger compartment space, powertrain layout and capacity, and the footprint dimension, while giving careful consideration of the utility and market position within the particular segment the vehicle competes in. Vehicle crashworthiness and safety performance must also be considered and at least preserved, if not improved.

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[193] This includes substitution of high-strength steels, aluminum, magnesium or composite materials for components currently fabricated from mild steel.

- Content Optimization: Manufacture can achieve mass reduction through content optimization. Some manufactures have replaced spare tire and tire change hardware with tire inflator kits on some of its models, such as Cadillac STS, Mazda MX-5 Miata to reduce weight and gain space.

- Vehicle Downsizing: Another way of mass reduction is reducing vehicle size. This is not common currently in US due to many factors, such as consumer choices, attribute-based CAFE standard, gasoline price, etc.

Regardless of how a vehicle's mass is actually reduced, and what level if any of secondary mass reduction is achieved, the fuel consumption reductions that result are fairly straightforward. A number of researchers and reports have examined the fuel consumption vs. weight reduction question for a variety of vehicle and engine types. For the most part, one primary variable exists which thereby bounds the two possible alternatives[194], that being whether or not the mass reductions result in: a) improved vehicle performance, such as 0 to 60 times, towing capacity; or power to weight ratio, or alternatively b) performance metrics that remain constant as a result of the weight reduction. This second alternative, with constant performance metrics, is accomplished through the application of engine resizing (*e.g.*, engines with smaller displacements which consume less fuel) that offsets the performance enhancing effects of the weight reduction, which from a fuel consumption perspective is obviously the more preferable approach. Thus two fuel consumption effectiveness estimates relating to mass reduction are generally stated in reports and literature, one which assumes improved vehicle performance (*i.e.*, the engine displacement is unchanged), and one which assumes constant performance (*i.e.*, the engine is resized). For the improved performance case, a 10 percent reduction in vehicle curb weight is generally expected to reduce fuel consumption by 3 to 4 percent. When appropriate engine resizing is applied and vehicle performance is held constant, a 10 percent curb weight reduction results in a 6 to 7 percent fuel consumption savings. Both of these estimates are documented in literature and reports on the subject of mass reduction, including the 2002 NAS report, and are also supported by simulation work conducted by Ricardo, Inc.[195], an internationally recognized consultant who, under contract, has assisted both EPA and NHTSA in technical and rulemaking related matters. Aluminum Association also presented Ricardo's study[196] in response to the NPRM which, together with response received from Porsche, MEMA and CARB, agrees with these effectiveness values.

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[194] A third alternative would be to degrade the vehicle such that mass reduction and engine downsizing results in lower performance metrics however a primary objective established by NHTSA is that the modeling process does not perceptibly change the use, function, or utility of the vehicle under consideration, therefore this is not a viable alternative.

[195] "Benefit Analysis: Use of Aluminum Structures in Conjunction with Alternative Powertrain Technologies in Automobiles," Bull, M. Chavali, R., Mascarin, A., Aluminum Association Research Report, May 2008. Accessed on the Internet on March 15, 2010 at: http://www.autoaluminum.org/downloads/IBIS-Powertrain-Study.pdf

[196] "Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicle Architectures", Research Report, conducted by Ricardo Inc. for the Aluminum Association, 2008-04, Docket number: NHTSA-2009-0059-0067.1

In preparation for this rule, in March 2009, NHTSA made a request for confidential product plan and other CAFE related technical information from manufacturers that produce light vehicles for sale in the U.S.[197] Not every manufacturer responded, and those that did in some cases either resubmitted materials previously provided to the agency or submitted truncated responses, which is understandable given the turmoil and uncertainty the industry was experiencing at that time. NHTSA also received responses for the latest request for product plans for this final rule which was sent out in September 2009. NHTSA reviewed the responses related to the subject of mass reduction and the vehicle weight trends likely to occur in the MY 2012 – 2016 fleet. These responses didn’t show a consistent approach. In some cases manufacturers are indicating weight increases (due either to more stringent FMVSS requirements or new model plans that incorporate heavier platforms or more content), in other cases no significant change is noted either way, and in some cases the submissions are outdated or incomplete (*e.g.*, impacts of the Fiat and Chrysler relationship and its effects on future product offerings). Although several OEMs have recently made public announcements indicating their intentions to decrease light vehicle average fleet weights within the upcoming years, the confidential product plans, to the extent they are a suitable source for making such a determination, do not appear to support this contention.

However one manufacturer did submit what appears to the agency to be a comprehensive response to the March request which does show significant curb weight decreases on the order of 350 to 550 pounds occurring within the timeframe. Although the stated reductions are sizeable, representing some 5 to 10 percent of the vehicle’s curb weight, some notes about the information provided are appropriate. First off, in all cases these larger reductions are being implemented at product redesign cycles only, and the earliest of these occurs in the MY 2014 period.[198] Secondly, the affected vehicles are from various vehicle segments, including cars and trucks, which represent high sales volume and a sizeable portion of the manufacturer’s overall production. And lastly the information provided does not describe, in any detail, how the specific reductions will be achieved (what techniques will be used, etc.), or what effect the changes will have on the vehicle’s physical dimensions, utility, or performance (safety and otherwise) afterwards. So while this information does support the belief that meaningful weight reductions are possible, and that at least one OEM is intending to implement them, it does not contain some of the information needed for a more robust analysis.

To gain further insight, NHTSA briefly discussed plans for weight decreases on future products with a few vehicle manufacturers. Although discussion of the methods used to achieve the reductions, and their impacts on dimensions and vehicle performance, were not within the scope of the conversations, the manufacturers did generally indicate their plans for decreasing fleet weights throughout the rulemaking period, with ranges of 5 to

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[197] This was in addition to similar requests made during the MY 2011 final rule and the 2008 NPRM that preceded it. The request also preceded the President’s May 19, 2009 announcement regarding fuel economy and green house gas standards. NHTSA notes that some manufacturers also made submissions to Congress and other governmental agencies where plans regarding future fleet planning, in terms of sales volumes and fleet configuration, were also discussed.

[198] The reductions might be best characterized as an objective for a new model platform that the company seeks to obtain.

10 percent net curb weight decreases considered potentially realizable by MY 2016. In past rulemakings, where confidential product plan information was, to the extent possible, used to establish the future fleet composition, this included the manufacturer's estimate for a future product's fuel economy rating. Therefore, in these analyses, technology changes such as weight reduction would have theoretically been accounted for in the Volpe modeling process. In the current rule, where a baseline MY 2008 fleet is projected forward into a future adjusted fleet, planned technology changes such as reductions in vehicle weights, cannot be accounted for in this way, since there was no practical way of doing so. So to the extent mass reductions do occur in this rulemakings future fleet, the Volpe modeling process will not account for their potential effect on fuel consumption without some further revision, as discussed below.

In the MY 2011 final rule NHTSA utilized three cumulative material substitution technologies that resulted in a maximum 5 percent reduction in vehicle curb weight. Material substitution was intended to be the primary means by which the weight reductions would be achieved. The three technologies were only applied to vehicles with curb weights in excess of 5,000 pounds which effectively limited their applicability to large trucks and SUVs. This was done on the basis that weight reduction from the heaviest of the vehicles in the U.S. fleet represented the most safety neutral, or potentially safety beneficial method of reducing vehicle weight. Since only large trucks were impacted, where towing and hauling capability is required, NHTSA used a 3.5 percent fuel consumption reduction per 10 percent weight decrease (i.e., no engine resizing was assumed). NHTSA has revised its approach for mass reduction in the current analysis, as is discussed in the following paragraphs.

In this rule, and in contrast to the 2011 rule, the Volpe model now applies two mass reduction technologies using a tiered approach. Mass reduction is intended to encompass a broader spectrum of methods for reducing vehicle mass, such as those discussed above, and those beyond material substitution, and is intended to be applicable to all vehicle subclasses, regardless of curb weight. Additionally in this analysis NHTSA considers that vehicle performance metrics are maintained constant as a result of the mass reductions, so appropriate levels of engine resizing are assumed.

The first of these technologies is MS1 which represents a 1.5 percent vehicle curb weight mass reduction across all vehicle subclasses. This technology is available to the Volpe model from the start of the rulemaking period, MY 2012, and may be applied during both the refresh and the redesign cycle time. For the level of mass reduction required, material substitution techniques, or other relatively easy to implement methods, are envisioned for achieving the weight savings. It is anticipated that this could occur during the early MYs of the rulemaking period and at the cycle times.

The second mass reduction technology is MS2, which occurs subsequent to, and is cumulative to, the MS1 technology. Since MS2 requires more rigorous mass reduction, additional constraints are utilized in its application. MS2 involves mass reductions of 3.5 to 8.5 percent of curb weight dependent on which vehicle subclass it is applied to. This first constraint, which varies the level of reduction by subclass, results in lower levels of mass reduction in the smaller (and lighter) vehicles, and larger levels conversely for the larger (and heavier) vehicles. This is intended to reflect, to the extent possible, the agency's past practice of reducing vehicle weights in the most safety neutral manner; smallest reductions in the smallest vehicles, largest reductions in the largest vehicles. Secondly, the MS2 technology is made unavailable to the Volpe model until MY 2014 and thus constrained on the basis that the larger levels of mass reductions required, and the types of methods and techniques needed to achieve them, cannot realistically occur without sufficient lead time for planning and implementation. In all likelihood these levels of mass reduction can only be achieved through a major redesign of the vehicle, which was what lead NHTSA to set the cycle time for the MS2 technology to redesign only, which is the final constraint used in the modeling process. Table V-35 below summarizes the mass reductions, as a percent of curb weight, for the MS1, MS2, and the combined effects by each vehicle subclass they are applied to. When both MS1 and MS2 are applied, overall mass reduction of 5 to 10 percent can occur, dependent on vehicle subclass. MEMA commented that "postponing additional mass reduction technologies until MY2014 not only hinders incorporation of already developed technologies, but also delays the overarching goal of the revised standard". NHTSA encourages any new technology application to comply with the revised standard without hindering vehicle safety. It is the manufacturer's choice to apply the most cost benefit technologies. Applying a phase-in year of 2014 does not mean manufacturers cannot apply developed technology ahead of that. It just shows that NHTSA thinks that up to 10% mass reduction needs more research, development and integration work, therefore realistically more lead time.

Table V-35. Vehicle Mass (Weight) Reduction as a Percent of Curb Weight Due to the Application of the MS1, MS2, and the Combination of Both Technologies

Vehicle Class	MS1 (%) Refresh/Redesign	MS2 (%)* Redesign only	Maximum Total Reduction (%)
Subcompact PC	1.5	3.5	5.0
Compact PC	1.5	3.5	5.0
Midsize PC	1.5	6.0	7.5
Large PC	1.5	8.5	10.0
Subcompact Performance PC	1.5	3.5	5.0
Compact Performance PC	1.5	3.5	5.0
Midsize Performance PC	1.5	6.0	7.5
Large Performance PC	1.5	8.5	10.0
Small LT	1.5	6.0	7.5
Midsize LT	1.5	6.0	7.5
Large LT and Minivan	1.5	8.5	10.0

* - MS2 is unavailable until MY2014

For effectiveness, and as discussed above, NHTSA assumes in this rule that a 10 percent reduction in mass results in a 6.5 percent reduction in fuel consumption for MS2 with appropriate engine downsizing (regardless of reduction technique used or the compounding factor achieved). This approach is intended to yield equivalent vehicle performance (*i.e.*, 0-60 mph time, towing capacity, etc). Based on the Aluminum Association's response to the NRPM, NHTSA modified the effectiveness for MS1. For MS1, because the amount of the mass reduction is small, normally no engine downsizing is considered for this amount of mass reduction and the appropriate effectiveness is 3.5

percent reduction in fuel consumption for a 10 percent reduction in mass. In developing costs for this rule NHTSA and EPA reviewed three studies of down-weighting/material substitution and the associated cost. The first study, the NAS report, estimated that vehicle weight could be reduced for approximately $1.50 per pound. (3-4% reductions in fuel consumption, without engine downsizing, from a 5% reduction in vehicle weight at a cost of $210-$350. This translates into $1.50 per pound, assuming a 3800 pound base vehicle and using the midpoint cost.) Additionally, Sierra Research estimated a 10% reduction, with compounding, could be accomplished for a cost of $1.01 per pound. Finally, MIT estimated that the weight of a vehicle could be reduced by 14%, with no compounding, for a cost of $1.36 per pound. Our final cost estimate is $1.32 per pound and is based on the average of the three referenced studies. Applying an ICM factor of 1.11 for a low complexity technology results in a compliance cost of $1.48 per pound. For the vehicle mass reduction technologies, neither volume-based nor time-based cost reductions are applied since many of the materials under consideration are commodity based and the build of materials is only loosely defined.

The Aluminum Association commented that NHTSA "significantly underestimated the potential of material substitution by only considering the direct component mass reduction". MEMA also commented that light materials can provide secondary mass savings. It is evident that manufacturers can achieve compounding through a systematical redesign approach. But as stated before, the magnitude of compounding effect varies significantly among different studies. NHTSA uses a total of up to10 percent mass reduction in the Volpe model which includes mass compounding. The effect of mass compounding is also reflected in the cost of mass reduction due to the cost saving in the downsizing of some of the components. NHTSA’s cost estimate for mass reduction also takes mass compounding into consideration by averaging the costs from the three studies mentioned above, in some of which mass compounding is considered. For future rulemaking, NHTSA intends to conduct further study of the magnitude of mass compounding.

Lastly, the phase-in cap for MS1 in this rule is 85 percent in MYs 2012 to 2015 and 100 percent in MY 2016, while for MS2 an 85 percent cap exists in MYs 2014 and 2015 followed by a 100 percent in MY 2016. Although a departure from the 2011 rulemaking, NHTSA believes that the mass reduction technologies in this rule represent a realistic approach that effectively, and when overall application rates are considered, accurately emulates the weight reductions likely to occur in the U.S. light vehicle fleet within the rulemaking timeframe.

(27) Low Drag Brakes (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. While most passenger cars have already adopted this technology with the standardization of electronic brake control, there are indications that this technology is still available for body-on-frame trucks and for some large passenger cars.

NHTSA's MY 2011 CAFE final rule estimated the effectiveness of LDB to be up to 1 percent, based on confidential manufacturer data. NHTSA has reviewed this estimate and believes it to be applicable for this final rule.

NHTSA reviewed the cost estimates from the MY 2011 CAFE final rule and determined that these estimates remain applicable for this final rule. The agency adjusted the costs to apply the ICM indirect cost multiplier of 1.11, for a low complexity technology, instead of the 1.5 RPE factor used in the 2011 final rule. The compliance cost for LDB is therefore $63 for a MY 2012 vehicle, and since no cost learning is applied, remains so throughout the rulemaking timeframe.

The phase-in cap for LDB in this rule is 85 percent in MYs 2012 to 2014, and 100 percent through the remainder of the rulemaking period. The Volpe model can apply this technology at a vehicle's refresh or redesign years, and the technology is only applicable to the Large Car, Minivan, and Medium and Large Truck and SUVs since, as mentioned above, it is already largely utilized in most other subclasses.

(28) Low Rolling Resistance Tires (ROLL)

Tire rolling resistance is the frictional loss associated mainly with the energy dissipated in the deformation of the tires under load and thus influences fuel economy and CO_2 emissions. Other tire design characteristics (*e.g.*, materials, construction, and tread design) influence durability, traction (both wet and dry grip), vehicle handling, and ride comfort in addition to rolling resistance. A typical low rolling resistance tire's attributes would include: increased tire inflation pressure, material changes, 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 suspension tuning and/or suspension design. For performance vehicle classifications, due to the increased traction requirements for braking and handling which currently cannot be fully met with low rolling resistance designs, the Volpe model does not apply this technology.

NHTSA estimates a 1 to 2 percent increase in effectiveness with a 10 percent reduction in rolling resistance, which was based on the 2002 NAS report findings and consistent with the MY 2011 final rule estimate. NHTSA still believes that this NAS effectiveness estimate is valid for this final rule.

Based on the MY 2011 CAFE final rule and the 2006 NAS/NRC report, NHTSA has estimated the cost for low rolling resistance tires to be $6 per vehicle. This is based on a cost of $1 per tire as estimated by NAS/NRC 2006 report, which is $5 per vehicle, including the spare tire. When applying the ICM low complexity markup factor of 1.11, this results in a compliance cost of $6 per vehicle for a MY 2012 vehicle.[199] Lower rolling resistance tires are widely available today however, due to the commodity based

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[199] Note that the costs developed for low rolling resistance tires for this analysis do not include the increase in lifetime costs that would be expected at each tire replacement. Instead, the analysis includes only the upfront increase in costs. The agencies intend to include the lifetime costs in the final analysis.

nature of the materials used in tire manufacturing, cost learning is not considered applicable.

The phase-in cap for the ROLL technology in this final rule is 85 percent in MYs 2012 to 2014, and 100 percent through the remainder of the rulemaking period. Due to the need to assess any potential impacts on vehicle dynamics and braking characteristics, the Volpe model can only apply this technology at a vehicle's refresh or redesign cycle, and as noted above, the model does not apply the technology to the performance subclass vehicles due to suitability concerns.

(29) 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 and CO_2 emissions. Many part-time four-wheel drive systems use some type of front axle disconnect to provide shift-on-the-fly capabilities. The front axle disconnect is normally part of the front differential assembly. As part of a shift-on-the-fly four-wheel drive system, the front axle disconnect serves two basic purposes. First, in two-wheel-drive mode, it disengages the front axle from the front driveline so the front wheels do not turn the front driveline at road speed, saving wear and tear. Second, when shifting from two- to four-wheel drive "on the fly" (while moving), the front axle disconnect couples the front axle to the front differential side gear only when the transfer case's synchronizing mechanism has spun the front driveshaft up to the same speed as the rear driveshaft. Four-wheel drive systems that have a front axle disconnect typically do not have either manual- or automatic-locking hubs. To isolate the front wheels from the rest of the front driveline, front axle disconnects use a sliding sleeve to connect or disconnect an axle shaft from the front differential side gear. NHTSA is 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 rulemaking time period.

Based on confidential manufacturer data, the MY 2011 final rule estimated an effectiveness improvement of 1 to 1.5 percent for the SAX technology and after thorough review. NHTSA finds this to be an accurate estimate for this final rule.

Regarding costs, NHTSA reviewed the incremental compliance cost from the MY 2011 final rule and concluded it remains accurate. However a new ICM factor of 1.11, for a low complexity technology, replaces the 1.5 RPE markup factor used previously. Thus, the compliance cost estimate for this rule is $87 for MY 2012 vehicles. As the SAX technology is readily available and in use today, time based learning is considered applicable, hence the costs for later MYs will be lower and are estimated to be $84 for a MY 2016 vehicle (2007 Dollars)

The phase-in cap for SAX in this final rule is 85 percent in MYs 2012 to 2014, and 100 percent throughout the remainder of the rulemaking period. Due to varying vehicle architecture designs, and thus the potential complexity associated with implementing these systems, the Volpe model can only apply this technology at a vehicle's refresh or redesign years. SAX is applicable to all vehicle subclasses however an engineering constraint programmed within the Volpe model's programming code ensures the SAX technology is only applied to vehicles that have (true) four-wheel drive systems in the baseline vehicle (i.e., SAX is not applicable to all-wheel drive equipped vehicles).

(30) Aerodynamic Drag Reduction (AERO)

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 drag and lower the vehicle's fuel consumption and CO_2 emissions. Although frontal areas tend to be relatively similar within a vehicle class (mostly due to market-competitive size requirements), 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 currently being applied. The latter list would include revised front and rear fascias, modified front air dams and rear valances, addition of rear deck lips and underbody panels, and lower aerodynamic drag exterior mirrors.

The MY 2011 final rule estimated that a fleet average of 10 to 20 percent total aerodynamic drag reduction is attainable (with a caveat for "high-performance" vehicles described below) which equates to incremental reductions in fuel consumption of 2 to 3 percent for both cars and trucks. These numbers are generally supported by confidential manufacturer data and public technical literature and therefore, NHTSA continues to use this estimate for this final rule.

The 2011 final rule also estimated a range from $60 to $116 which used a 1.5 RPE; the non-RPE costs were therefore $40 to $75. NHTSA and EPA reviewed the 2011 costs and concluded the estimate should be closer to the lower end of the 2011 rulemaking range. Thus, the cost estimate used in this rulemaking is $48 ($43 without markup), which includes a 1.11 ICM markup value for a low complexity technology. This compliance cost is for a MY 2012 vehicle and will decrease in future years due to the application of time-based learning. The AERO technology is considered to already be in use on most performance subclasses, therefore the Volpe model does not apply this technology to performance vehicles. The phase-in cap for AERO in this final rule is 85 percent in MYs 2012 to 2014, and 100 percent through the remainder of the rulemaking period. As noted above, the types of improvements envisioned in the AERO technology are suitable for application at refresh or redesign cycle.

e. Technologies considered but not included in the final rule analysis

NHTSA and EPA have identified six technologies that will not be available in the time frame considered under this rulemaking. These technologies, while considered, were not made available in the CAFE and OMEGA models. They are: electric vehicles, camless valve actuation (CVA), lean burn gasoline direct injection (LBDI), homogeneous charge compression ignition (HCCI), and electric assist turbocharging and full series hydraulic hybrids (HHV). While electric vehicles are likely to become available in small numbers in the near future, the costs for this technology (as estimated by the agencies) are non-competitive with the more conventional technologies listed above. Therefore, the Volpe model analysis would preclude their selection, when estimating the costs of the rule. Lean Burn direct injection engines are currently available in Europe, however, these vehicles cannot be designed at this time to be both efficient and meet the NOx standards in the United States with the current sulfur levels in the fuels. The other technologies listed are still in the research phase of development. NHTSA and EPA will continue to monitor the industry and system suppliers for progress on these technologies, and should they become more available, consider them for use in future rulemaking activity. More details are described below.

i. Electric Vehicles

The recent intense interest in Hybrid vehicles and the development of Hybrid vehicle battery and motor technology has helped make Electric Vehicle technology more viable than it has ever been. Electric Vehicles (EVs) require much larger batteries than either HEVs or PHEVs, but the batteries must be of a high-energy and lower-power design to deliver an appropriate amount of power over the useful charge of the battery. These high-energy batteries are generally less expensive per kilowatt-hour than high-power batteries required for hybrids, but the size of the battery pack still incurs a considerable cost.

Electric motor and power electronics designs are very similar to HEV and PHEV designs, but they must be larger, more powerful, and more robust since they provide the only motive power for the vehicle. On the other hand, the internal combustion engine, fuel system, and possibly the transmission can all be removed for significant weight, complexity and cost savings.

While a few manufactures have released public statements indicating that they are planning on producing small volumes of electric vehicles within the rulemaking time frame, the agency believes that the application of electric vehicles above and beyond these small volumes will not likely be feasible. Thus for purposes of this final rule, NHTSA has not included electric vehicles in its analysis.

ii. Camless Valve Actuation

Camless valve actuation relies on electromechanical actuators instead of camshafts to open and close the cylinder valves. When electromechanical actuators are used to replace cams and coupled with sensors and microprocessor controls, valve timing and lift can be optimized over all conditions. An engine valvetrain that operates independently of any mechanical means provides the increased flexibility for intake and exhaust timing and lift optimization. With it comes increased ability to vary valve overlap, the rapid response required to change between combustion operating modes (such as HCCI and GDI), intake valve throttling, cylinder deactivation, and elimination of the camshafts (reduced friction and rotating mass). This level of control can enable even further incremental reductions in fuel consumption.

This technology has been under research for many decades and although progress is being made, NHTSA has not found evidence to support that the technology can be successfully implemented within the 2012 through 2016 timeframe of these regulations. Thus, NHTSA has not estimated cost or effectiveness for this technology at this time.

iii. 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 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 NO_x after-treatment, lean-burn GDI engines may eventually be a possibility in North America.

NHTSA’s current assessment is that the availability of ultra-low sulfur (less than 15 ppm sulfur) gasoline is a key technical requirement for lean-burn GDI engines to meet EPA’s Tier 2 NO_x emissions standards, Since we do not believe that ULS gasoline will be available during the model years applicable to this final rule, the technology was not applied in the NHTSA analysis.

In response to the NPRM, NHTSA received comments from MECA stating that Gasoline Direct Injection offers the potential for lean operation. MECA comments also stated the current EPA fuel sulfur limits for gasoline (30 ppm average, 80 ppm cap) are too high to allow lean NOx absorber catalysts to be a viable NOx control strategy for fuel efficient, gasoline lean-burn engines that employ direct fuel injection technology. MECA’s comments are consistent with NHTSA’s assessment.

iv. Homogeneous Charge Compression Ignition

Gasoline homogeneous charge compression ignition (HCCI), also referred to as controlled auto-ignition (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 auto-ignition 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,

Combined, these effects have shown an increase in engine brake efficiency (typically 25-28%) to greater than 35% at the high end of the HCCI operating range.[200]

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 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 and CO_2 reduction potential for HCCI in the literature. Based on confidential manufacturer information, it is believed that a gasoline HCCI / GDI dual-mode engine might achieve 10-12% reduction in fuel

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[200] “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. Last accessed on March 18, 2010 at http://www.sae.org/technical/papers/2004-01-0933.

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. As noted in 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.

v. Electric Assist Turbocharging

The Alliance commented in NHTSA’s previous rulemaking that global development of electric assist turbocharging 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 believes that significant developmental work is required to demonstrate effective systems and that implementation in significant volumes will not occur in the 2012 to 2016 time frame considered in this rulemaking. Thus, this technology was not included in the final rule.

E. Cost and effectiveness tables

The tables representing the Volpe model input files for MY 2012 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-36. Technology Incremental Cost Estimates, Passenger Cars

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (2007 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		3	3	3	3
Engine Friction Reduction	EFR	50	50	50	75
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	45	45	45	90
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	142	142	142	205
Cylinder Deactivation on SOHC	DEACS	n.a.	n.a.	n.a.	0 - 56
VVT - Intake Cam Phasing (ICP)	ICP	45	45	45	90
VVT - Dual Cam Phasing (DCP)	DCP	38	38	38	83
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	142	142	142	205
Continuously Variable Valve Lift (CVVL)	CVVL	277	277	277	509
Cylinder Deactivation on DOHC	DEACD	n.a.	n.a.	n.a.	0 - 56
Cylinder Deactivation on OHV	DEACO	n.a.	n.a.	n.a.	170
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	45	45	45	45
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	142	142	142	0 - 56
Conversion to DOHC with DCP	CDOHC	276	276	276	436
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	236	236	236	341
Combustion Restart	CBRST	118	118	118	118
Turbocharging and Downsizing	TRBDS	445	445	445	325
Exhaust Gas Recirculation (EGR) Boost	EGRB	144	144	144	144
Conversion to Diesel following CBRST	DSLC	1,527.	1,527	1,527	1,556 - 1,612
Conversion to Diesel following TRBDS	DSLT	938.	938	938	1,088-1,143
6-Speed Manual/Improved Internals	6MAN	250	250	250	250
Improved Auto. Trans. Controls/Externals	IATC	60	60	60	60
Continuously Variable Transmission	CVT	250	250	250	250
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	112	112	112	112
Dual Clutch or Automated Manual Transmission	DCTAM	(59)	(59)	(8)	(8)
Electric Power Steering	EPS	106	106	106	106
Improved Accessories	IACC	128	128	128	128
12V Micro-Hybrid	MHEV	288	311	342	367
Belt mounted Integrated Starter Generator	BISG	286	286	286	286
Crank mounted Integrated Starter Generator	CISG	2,791	3,107	3,319	3,547
Power Split Hybrid	PSHEV	1,600	2,133	2,742	3,261
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	11,520	14,135	16,215	n.a.
Mass Reduction (1.5%)	MS1	1.5	1.5	1.5	1.5
Mass Reduction (3.5 to 8.5%)	MS2	1.5	1.5	1.5	1.5
Low Rolling Resistance Tires	ROLL	6	6	6	6
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	63
Secondary Axle Disconnect	SAX	87	87	87	87
Aero Drag Reduction	AERO	48	48	48	48

Table V-37. Technology Incremental Cost Estimates, Performance Passenger Cars

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (2007 Dollars) BY VEHICLE SUBCLASS - PERFORMANCE PASSENGER CARS

		Perform. Subcompact Car	Perform. Compact Car	Perform. Midsize Car	Perform. Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Low Friction Lubricants	LUB	3	3	3	3
Engine Friction Reduction	EFR	50	75	75	101
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	45	90	90	90
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	142	205	205	293
Cylinder Deactivation on SOHC	DEACS	n.a.	0 - 56	0 - 56	0 – 56
VVT - Intake Cam Phasing (ICP)	ICP	45	90	90	90
VVT - Dual Cam Phasing (DCP)	DCP	38	83	83	82
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	142	205	205	293
Continuously Variable Valve Lift (CVVL)	CVVL	277	509	509	555
Cylinder Deactivation on DOHC	DEACD	n.a.	0 - 56	0 - 56	0 – 56
Cylinder Deactivation on OHV	DEACO	n.a.	170	170	190
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	45	45	45	45
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	142	0 - 56	0 - 56	0 – 56
Conversion to DOHC with DCP	CDOHC	276	436	436	552
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	236	341	341	552
Combustion Restart	CBRST	118	118	118	118
Turbocharging and Downsizing	TRBDS	445	325	325	919
Exhaust Gas Recirculation (EGR) Boost	EGRB	144	144	144	144
Conversion to Diesel following CBRST	DSLC	1,527	1,556 – 1,612	1,556 – 1,612	2,294 – 2,349
Conversion to Diesel following TRBDS	DSLT	938	1,088 – 1,143	1,088 – 1,143	1,231 – 1,287
6-Speed Manual/Improved Internals	6MAN	250	250	250	250
Improved Auto. Trans. Controls/Externals	IATC	60	60	60	60
Continuously Variable Transmission	CVT	250	250	250	250
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	112 – 214	112 – 214	112 – 214	112 - 214
Dual Clutch or Automated Manual Transmission	DCTAM	(8)	(8)	(8)	(8)
Electric Power Steering	EPS	106	106	106	106
Improved Accessories	IACC	128	128	128	128
12V Micro-Hybrid	MHEV	314	337	372	410
Belt mounted Integrated Starter Generator	BISG	286	286	286	286
Crank mounted Integrated Starter Generator	CISG	2,839	3,149	3,335	3,571
Power Split Hybrid	PSHEV	3,661	4,018	5,287	6,723
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	14,987	16,792	19,265	n.a.
Mass Reduction (1.5%)	MS1	1.5	1.5	1.5	1.5
Mass Reduction (3.5 to 8.5%)	MS2	1.5	1.5	1.5	1.5
Low Rolling Resistance Tires	ROLL	n.a.	n.a.	n.a.	n.a.
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	63
Secondary Axle Disconnect	SAX	87	87	87	87
Aero Drag Reduction	AERO	n.a.	n.a.	n.a.	n.a.

Table V-38. Technology Incremental Cost Estimates, Light Trucks

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (2007 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	LUB	3	3	3	3
Engine Friction Reduction	EFR	75	50	75	101
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	90	45	90	90
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	205	142	205	293
Cylinder Deactivation on SOHC	DEACS	0 - 56	n.a.	0 - 56	0 – 56
VVT - Intake Cam Phasing (ICP)	ICP	90	45	90	90
VVT - Dual Cam Phasing (DCP)	DCP	83	38	83	83
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	205	142	205	293
Continuously Variable Valve Lift (CVVL)	CVVL	509	277	509	555
Cylinder Deactivation on DOHC	DEACD	0 - 56	n.a.	0 - 56	0 – 56
Cylinder Deactivation on OHV	DEACO	170	n.a.	170	190
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	45	45	45	45
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0 - 56	142	0 - 56	0 – 56
Conversion to DOHC with DCP	CDOHC	436	276	436	552
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	341	236	341	391
Combustion Restart	CBRST	118	118	118	118
Turbocharging and Downsizing	TRBDS	325	445	325	919
Exhaust Gas Recirculation (EGR) Boost	EGRB	144	144	144	144
Conversion to Diesel following CBRST	DSLC	1,556 - 1,612	1,527	1,556 -1,612	2,294 – 2,349
Conversion to Diesel following TRBDS	DSLT	1,088-1,143	938	1,088 – 1,143	1,231 – 1,287
6-Speed Manual/Improved Internals	6MAN	250	250	250	250
Improved Auto. Trans. Controls/Externals	IATC	60	60	60	60
Continuously Variable Transmission	CVT	250	250	250	n.a.
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	112	112	112 - 214	112 - 214
Dual Clutch or Automated Manual Transmission	DCTAM	(8)	(8)	(8)	(8)
Electric Power Steering	EPS	106	106	106	106
Improved Accessories	IACC	128	128	128	n.a.
12V Micro-Hybrid	MHEV	367	325	376	n.a.
Belt mounted Integrated Starter Generator	BISG	286	286	286	n.a.
Crank mounted Integrated Starter Generator	CISG	3,547	3,141	3,611	5,124
Power Split Hybrid	PSHEV	3,261	2,377	3,462	n.a.
2-Mode Hybrid	2MHEV	n.a.	3,661	4,887 - 4,989	5,902 – 6,004
Plug-in Hybrid	PHEV	n.a.	14,721	n.a.	n.a.
Mass Reduction (1.5%)	MS1	1.5	1.5	1.5	1.5
Mass Reduction (3.5 to 8.5%)	MS2	1.5	1.5	1.5	1.5
Low Rolling Resistance Tires	ROLL	6	6	6	6
Low Drag Brakes	LDB	63	n.a.	63	63
Secondary Axle Disconnect	SAX	87	87	87	87
Aero Drag Reduction	AERO	48	48	48	48

The tables representing the Volpe 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-39. Technology Incremental Effectiveness Estimates, Passenger Cars

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION(-%) BY VEHICLE SUBCLASS - PASSENGER CAR					
		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Low Friction Lubricants	LUB	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Cylinder Deactivation on SOHC	DEACS	n.a.	n.a.	n.a.	2.5 - 3.0
VVT - Intake Cam Phasing (ICP)	ICP	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Dual Cam Phasing (DCP)	DCP	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Continuously Variable Valve Lift (CVVL)	CVVL	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5
Cylinder Deactivation on DOHC	DEACD	n.a.	n.a.	n.a.	0 - 0.5
Cylinder Deactivation on OHV	DEACO	n.a.	n.a.	n.a.	3.9 - 5.5
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5
Conversion to DOHC with DCP	CDOHC	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Combustion Restart	CBRST	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5
Turbocharging and Downsizing	TRBDS	4.2 - 4.8	4.2 - 4.8	4.2 - 4.8	1.8 - 1.9
Exhaust Gas Recirculation (EGR) Boost	EGRB	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0
Conversion to Diesel following CBRST	DSLC	13.5 – 13.9	13.5 – 13.9	13.5 – 13.9	10.8 - 11.7
Conversion to Diesel following TRBDS	DSLT	5.3 – 6.9	5.3 – 6.9	5.3 – 6.9	5.3 - 6.9
6-Speed Manual/Improved Internals	6MAN	0.5	0.5	0.5	0.5
Improved Auto. Trans. Controls/Externals	IATC	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5
Continuously Variable Transmission	CVT	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4
Dual Clutch or Automated Manual Transmission	DCTAM	5.5 – 7.5	5.5 – 7.5	2.7 - 4.1	2.7 - 4.1
Electric Power Steering	EPS	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Improved Accessories	IACC	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
12V Micro-Hybrid	MHEV	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.5 - 3.5
Belt mounted Integrated Starter Generator	BISG	4.0 - 6.0	4.0 - 6.0	4.0 - 6.0	3.5 - 5.5
Crank mounted Integrated Starter Generator	CISG	8.6 - 8.9	8.6 - 8.9	8.6 - 8.9	8.7 - 8.9
Power Split Hybrid	PSHEV	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	45.2 - 47.7	45.2 - 47.7	45.2 - 47.7	n.a.
Mass Reduction (1.5%)	MS1	0.5	0.5	0.5	0.5
Mass Reduction (3.5 to 8.5%)	MS2	2.7	2.7	4.4	6.0
Low Rolling Resistance Tires	ROLL	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	0.5 - 1.0
Secondary Axle Disconnect	SAX	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Aero Drag Reduction	AERO	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0

Table V-40. Technology Incremental Effectiveness Estimates, Performance Cars

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - PERFORMANCE PASSENGER CAR					
		Perform. Subcompact Car	Perform. Compact Car	Perform. Midsize Car	Perform. Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Low Friction Lubricants	LUB	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Cylinder Deactivation on SOHC	DEACS	n.a.	2.5 - 3.0	2.5 - 3.0	2.5 - 3.0
VVT - Intake Cam Phasing (ICP)	ICP	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Dual Cam Phasing (DCP)	DCP	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Continuously Variable Valve Lift (CVVL)	CVVL	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5
Cylinder Deactivation on DOHC	DEACD	n.a.	0.0 - 0.5	0.0 - 0.5	0.0 - 0.5
Cylinder Deactivation on OHV	DEACO	n.a.	3.9 - 5.5	3.9 - 5.5	3.9 - 5.5
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5
Conversion to DOHC with DCP	CDOHC	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Combustion Restart	CBRST	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5
Turbocharging and Downsizing	TRBDS	4.2 - 4.8	1.8 - 1.9	1.8 - 1.9	1.8 - 1.9
Exhaust Gas Recirculation (EGR) Boost	EGRB	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0
Conversion to Diesel following CBRST	DSLC	13.5 – 13.9	10.8 - 11.7	10.8 - 11.7	10.8 - 11.7
Conversion to Diesel following TRBDS	DSLT	5.3 – 6.9	5.3 - 6.9	5.3 - 6.9	5.3 - 6.9
6-Speed Manual/Improved Internals	6MAN	0.5	0.5	0.5	0.5
Improved Auto. Trans. Controls/Externals	IATC	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5
Continuously Variable Transmission	CVT	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0	n.a.
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4
Dual Clutch or Automated Manual Transmission	DCTAM	2.7 - 4.1	2.7 - 4.1	2.7 - 4.1	2.7 - 4.1
Electric Power Steering	EPS	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Improved Accessories	IACC	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
12V Micro-Hybrid	MHEV	2.0 - 3.0	2.5 - 3.5	2.5 - 3.5	3.0 - 4.0
Belt mounted Integrated Starter Generator	BISG	4.0 - 6.0	3.5 - 5.5	3.5 - 5.5	3.0 - 5.0
Crank mounted Integrated Starter Generator	CISG	8.6 - 8.9	8.7 - 8.9	8.7 - 8.9	8.7 - 8.9
Power Split Hybrid	PSHEV	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	45.2 - 47.7	45.2 - 47.7	45.2 - 47.7	n.a.
Mass Reduction (1.5%)	MS1	0.5	0.5	0.5	0.5
Mass Reduction (3.5 to 8.5%)	MS2	2.7	2.7	4.4	6.0
Low Rolling Resistance Tires	ROLL	n.a.	n.a.	n.a.	n.a.
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	0.5 - 1.0
Secondary Axle Disconnect	SAX	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Aero Drag Reduction	AERO	n.a.	n.a.	n.a.	n.a.

Table V-41. 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	LUB	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Cylinder Deactivation on SOHC	DEACS	2.5 - 3.0	n.a.	2.5 - 3.0	2.5 - 3.0
VVT - Intake Cam Phasing (ICP)	ICP	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Dual Cam Phasing (DCP)	DCP	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Continuously Variable Valve Lift (CVVL)	CVVL	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5
Cylinder Deactivation on DOHC	DEACD	0 - 0.5	n.a.	0.0 - 0.5	0.0 - 0.5
Cylinder Deactivation on OHV	DEACO	3.9 - 5.5	n.a.	3.9 - 5.5	3.9 - 5.5
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5
Conversion to DOHC with DCP	CDOHC	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Combustion Restart	CBRST	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5
Turbocharging and Downsizing	TRBDS	1.8 - 1.9	4.2 - 4.8	1.8 - 1.9	1.8 - 1.9
Exhaust Gas Recirculation (EGR) Boost	EGRB	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0
Conversion to Diesel following CBRST	DSLC	10.8 - 11.7	13.5 – 13.9	10.8 - 11.7	10.8 - 11.7
Conversion to Diesel following TRBDS	DSLT	5.3 - 6.9	n.a.	5.3 - 6.9	5.3 - 6.9
6-Speed Manual/Improved Internals	6MAN	0.5	0.5	0.5	0.5
Improved Auto. Trans. Controls/Externals	IATC	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5
Continuously Variable Transmission	CVT	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0	n.a.
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4
Dual Clutch or Automated Manual Transmission	DCTAM	2.7 - 4.1	2.7 -4.1	2.7 - 4.1	2.7 - 4.1
Electric Power Steering	EPS	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Improved Accessories	IACC	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	n.a.
12V Micro-Hybrid	MHEV	2.5 - 3.5	2.0 - 3.0	2.5 - 3.5	n.a.
Belt mounted Integrated Starter Generator	BISG	3.5 - 5.5	4.0 - 6.0	3.5 - 5.5	n.a.
Crank mounted Integrated Starter Generator	CISG	8.7 - 8.9	8.6 - 8.9	8.7 - 8.9	14.1 - 16.3
Power Split Hybrid	PSHEV	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4	n.a.
2-Mode Hybrid	2MHEV	n.a.	3.0 - 7.3	3.0 - 7.3	4.1 - 9.5
Plug-in Hybrid	PHEV	n.a.	45.2 - 47.7	n.a.	n.a.
Mass Reduction (1.5%)	MS1	0.5	0.5	0.5	0.5
Mass Reduction (3.5 to 8.5%)	MS2	6.0	4.4	4.4	6.0
Low Rolling Resistance Tires	ROLL	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Low Drag Brakes	LDB	0.5 - 1.0	n.a.	0.5 - 1.0	0.5 - 1.0
Secondary Axle Disconnect	SAX	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Aero Drag Reduction	AERO	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0

The tables representing the Volpe model input files for MY 2012 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-42. Approximate Net (Accumulated) Technology Costs, Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE ($) BY VEHICLE CLASS TO KEY TECHNOLOGIES (Rounded to nearest $100)				
Final technology (As compared to baseline vehicle prior to technology application)	Subcompact Car	Compact Car	Midsize Car	Large Car
Stoichiometric Gasoline Direct Injection (SGDI)	477	477	477	716 - 771
Turbocharging and Downsizing (TRBDS)	1,039	1,039	1,039	1,158 - 1,213
Diesel Engine (DSLT/DSLC)	2,121	2,121	2,121	2,445
Dual Clutch or Automated Manual Transmission (DCTAM)	113	113	164	164
Crankshaft Integrated Starter Generator (CISG)	3,599	3,939	4,180	4,434
Power Split Hybrid (PSHEV)	5,509	6,381	7,233	8,005
2-Mode Hybrid (2MHEV)	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid (PHEV)	15,429	18,384	20,705	n.a.

Table V-43. Approximate Net (Accumulated) Technology Costs, Performance Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE ($) BY VEHICLE CLASS TO KEY TECHNOLOGIES (Rounded to nearest $100)				
Final technology (As compared to baseline vehicle prior to technology application)	Subcompact Perf Car	Compact Perf Car	Midsize Perf Car	Large Perf Car
Stoichiometric Gasoline Direct Injection (SGDI)	477	716 - 771	716 - 771	878 - 934
Turbocharging and Downsizing (TRBDS)	1,039	1,158 - 1,213	1,158 - 1,213	1,914 - 1,970
Diesel Engine (DSLT/DSLC)	2,121	2,445	2,445	3,345
Dual Clutch or Automated Manual Transmission (DCTAM)	164 - 266	164 - 266	164 - 266	164 - 266
Crankshaft Integrated Starter Generator (CISG)	3,673	4,007	4,227	4,500
Power Split Hybrid (PSHEV)	7,645	8,335	9,824	11,534
2-Mode Hybrid (2MHEV)	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid (PHEV)	18,970	21,109	23,802	n.a.

Table V-44. Approximate Net (Accumulated) Technology Costs, Light Trucks

APPROXIMATE ICM NET COSTS PER VEHICLE ($) BY VEHICLE CLASS TO KEY TECHNOLOGIES (Rounded to nearest $100)				
Final technology (As compared to baseline vehicle prior to technology application)	Minivan LT	Small LT	Midsize LT	Large LT
Stoichiometric Gasoline Direct Injection (SGDI)	716 - 771	477	716 - 771	878 - 934
Turbocharging and Downsizing (TRBDS)	1,158 - 1,213	1,039	1,158 - 1,213	1,914 - 1,970
Diesel Engine (DSLT/DSLC)	2,445	2,121	2,445	3,345
Dual Clutch or Automated Manual Transmission (DCTAM)	164	164	164 - 266	164 - 266
Crankshaft Integrated Starter Generator (CISG)	4,434	3,986	4,507	5,230
Power Split Hybrid (PSHEV)	8,005	6,673	8,279	n.a.
2-Mode Hybrid (2MHEV)	n.a.	7,810	9,660	11,398
Plug-in Hybrid (PHEV)	n.a.	18,878	n.a.	n.a.

The tables representing the Volpe 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-45. Approximate Net Technology Effectiveness, Passenger Cars

APPROXIMATE NET EFFECTIVENESS ESTIMATES (FC REDUCTION) PER VEHICLE (-%) BY VEHICLE CLASS TO KEYTECHNOLOGIES (Rounded to nearest 0.5%)				
Final technology (As compared to baseline vehicle prior to technology application)	Subcompact Car	Compact Car	Midsize Car	Large Car
Stoichiometric Gasoline Direct Injection (SGDI)	5.4 - 11.0	5.4 - 11.0	5.4 - 11.0	7.8 - 13.7
Turbocharging and Downsizing (TRBDS)	11.2 - 17.4	11.2 - 17.4	11.2 - 17.4	11.2 - 17.4
Diesel Engine (DSLT/DSLC)	20.2 - 24.9	20.2 - 24.9	20.2 - 24.9	20.2 - 24.9
Dual Clutch or Automated Manual Transmission (DCTAM)	8.2 - 12.9	8.2 - 12.9	5.5 - 9.7	5.5 - 9.7
Crankshaft Integrated Starter Generator (CISG)	16.0 - 20.0	16.0 - 20.0	16.0 - 20.0	16.0 - 20.0
Power Split Hybrid (PSHEV)	23.0 - 33.0	23.0 - 33.0	23.0 - 33.0	23.0 - 33.0
2-Mode Hybrid (2MHEV)	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid (PHEV)	55.0 - 60.0	55.0 - 60.0	55.0 - 60.0	n.a.

Table V-46. Approximate Net Technology Effectiveness,
Performance Passenger Cars

APPROXIMATE NET EFFECTIVENESS ESTIMATES (FC REDUCTION) PER VEHICLE (-%) BY VEHICLE CLASS TO KEYTECHNOLOGIES (Rounded to nearest 0.5%)				
Final technology (As compared to baseline vehicle prior to technology application)	Subcompact Perf Car	Compact Perf Car	Midsize Perf Car	Large Perf Car
Stoichiometric Gasoline Direct Injection (SGDI)	5.4 - 11.0	7.8 - 13.7	7.8 - 13.7	7.8 - 13.7
Turbocharging and Downsizing (TRBDS)	11.2 - 17.4	11.2 - 17.4	11.2 - 17.4	11.2 - 17.4
Diesel Engine (DSLT/DSLC)	20.2 - 24.9	20.2 - 24.9	20.2 - 24.9	20.2 - 24.9
Dual Clutch or Automated Manual Transmission (DCTAM)	5.5 - 9.7	5.5 - 9.7	5.5 - 9.7	5.5 - 9.7
Crankshaft Integrated Starter Generator (CISG)	16.0 - 20.0	16.0 - 20.0	16.0 - 20.0	16.0 - 20.0
Power Split Hybrid (PSHEV)	23.0 - 33.0	23.0 - 33.0	23.0 - 33.0	23.0 - 33.0
2-Mode Hybrid (2MHEV)	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid (PHEV)	55.0 - 60.0	55.0 - 60.0	55.0 - 60.0	n.a.

Table V-47. Approximate Net Technology Effectiveness, Light Trucks

APPROXIMATE NET EFFECTIVENESS ESTIMATES (FC REDUCTION) PER VEHICLE (-%) BY VEHICLE CLASS TO KEYTECHNOLOGIES (Rounded to nearest 0.5%)				
Final technology (As compared to baseline vehicle prior to technology application)	Minivan LT	Small LT	Midsize LT	Large LT
Stoichiometric Gasoline Direct Injection (SGDI)	7.8 - 13.7	5.4 - 11.0	7.8 - 13.7	7.8 - 13.7
Turbocharging and Downsizing (TRBDS)	11.2 - 17.4	11.2 - 17.4	11.2 - 17.4	11.2 - 17.4
Diesel Engine (DSLT/DSLC)	20.2 - 24.9	20.2 - 24.9	20.2 - 24.9	20.2 - 24.9
Dual Clutch or Automated Manual Transmission (DCTAM)	5.5 - 9.7	5.5 - 9.7	5.5 - 9.7	5.5 - 9.7
Crankshaft Integrated Starter Generator (CISG)	16.0 - 20.0	16.0 - 20.0	16.0 - 20.0	15.0 - 18.0
Power Split Hybrid (PSHEV)	23.0 - 33.0	23.0 - 33.0	23.0 - 33.0	n.a.
2-Mode Hybrid (2MHEV)	n.a.	23.0 - 33.0	23.0 - 33.0	23.0 - 33.0
Plug-in Hybrid (PHEV)	n.a.	55.0 - 60.0	n.a.	n.a.

C. Penetration of Technologies by Alternative

Table V-48 shows the penetration of technologies by alternative for passenger cars and Table V-46 shows the penetration of technologies for light trucks for the alternatives. 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-48. Penetration Rate of New Technologies to Passenger Cars, by Alternative

Preferred Alternative - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	76%	78%	78%	78%	77%
Engine Friction Reduction	28%	50%	55%	58%	66%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	6%	6%	8%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	8%	9%	10%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	1%
VVT - Intake Cam Phasing (ICP)	35%	33%	34%	34%	27%
VVT - Dual Cam Phasing (DCP)	41%	45%	45%	46%	53%
Discrete Variable Valve Lift (DVVL) on DOHC	17%	27%	30%	31%	37%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	3%
Cylinder Deactivation on OHV	1%	2%	2%	2%	2%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	5%	5%	5%
Discrete Variable Valve Lift (DVVL) on OHV	0%	1%	1%	3%	3%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	18%	26%	31%	35%	38%
Combustion Restart	0%	0%	2%	5%	11%
Turbocharging and Downsizing	13%	20%	21%	25%	27%
Exhaust Gas Recirculation (EGR) Boost	0%	8%	10%	14%	17%
Conversion to Diesel following TRBDS	2%	2%	2%	2%	2%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	3%	3%	3%
Improved Auto. Trans. Controls/ Externals	11%	13%	13%	10%	7%
Continuously Variable Transmission	11%	11%	11%	11%	11%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	14%	9%	7%	4%	3%
Dual Clutch or Automated Manual Transmission	24%	38%	48%	61%	69%
Electric Power Steering	40%	54%	57%	59%	72%
Improved Accessories	36%	43%	46%	50%	61%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	5%	12%	19%	25%	25%
Crank mounted Integrated Starter Generator	4%	3%	3%	3%	3%
Power Split Hybrid	5%	5%	6%	5%	5%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	19%	26%	33%	39%	47%
Mass Reduction (3.5% to 8.5%)	0%	0%	17%	31%	40%
Low Rolling Resistance Tires	50%	60%	66%	75%	78%
Low Drag Brakes	8%	9%	11%	11%	13%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	5%	5%	5%	6%
Aero Drag Reduction	39%	52%	60%	66%	71%

3% Annual Increase - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	65%	68%	66%	74%	74%
Engine Friction Reduction	26%	44%	46%	48%	57%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	5%	5%	6%	7%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	8%	9%	9%
Cylinder Deactivation on SOHC	1%	1%	1%	1%	1%
VVT - Intake Cam Phasing (ICP)	39%	40%	40%	42%	34%
VVT - Dual Cam Phasing (DCP)	38%	40%	40%	40%	47%
Discrete Variable Valve Lift (DVVL) on DOHC	16%	24%	27%	28%	32%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	1%
Cylinder Deactivation on OHV	1%	2%	2%	2%	2%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	4%	4%	4%	4%
Discrete Variable Valve Lift (DVVL) on OHV	0%	0%	0%	0%	0%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	13%	13%	15%	17%	19%
Combustion Restart	0%	0%	2%	5%	7%
Turbocharging and Downsizing	7%	8%	10%	11%	14%
Exhaust Gas Recirculation (EGR) Boost	0%	2%	4%	5%	9%
Conversion to Diesel following TRBDS	1%	1%	1%	1%	1%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/ Externals	10%	11%	8%	5%	5%
Continuously Variable Transmission	11%	11%	11%	11%	11%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	16%	11%	10%	7%	8%
Dual Clutch or Automated Manual Transmission	15%	28%	34%	42%	47%
Electric Power Steering	39%	49%	52%	55%	63%
Improved Accessories	30%	30%	31%	35%	39%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	3%	5%	7%	10%	10%
Crank mounted Integrated Starter Generator	1%	1%	1%	1%	1%
Power Split Hybrid	4%	4%	4%	4%	4%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	10%	10%	17%	22%	32%
Mass Reduction (3.5% to 8.5%)	0%	0%	14%	23%	32%
Low Rolling Resistance Tires	47%	55%	57%	59%	73%
Low Drag Brakes	8%	8%	9%	9%	9%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	4%	5%	5%	5%
Aero Drag Reduction	34%	41%	46%	54%	71%

4% Annual Increase - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	65%	67%	74%	73%	74%
Engine Friction Reduction	26%	45%	51%	56%	66%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	6%	6%	8%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	8%	9%	9%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	0%
VVT - Intake Cam Phasing (ICP)	39%	40%	40%	37%	29%
VVT - Dual Cam Phasing (DCP)	38%	39%	40%	44%	53%
Discrete Variable Valve Lift (DVVL) on DOHC	15%	24%	27%	27%	32%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	3%
Cylinder Deactivation on OHV	1%	2%	2%	2%	2%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	4%	4%	4%	4%
Discrete Variable Valve Lift (DVVL) on OHV	0%	0%	1%	2%	2%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	17%	22%	27%	31%	36%
Combustion Restart	0%	0%	3%	6%	15%
Turbocharging and Downsizing	9%	12%	15%	19%	21%
Exhaust Gas Recirculation (EGR) Boost	0%	4%	7%	11%	15%
Conversion to Diesel following TRBDS	1%	1%	1%	1%	1%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	3%	3%	3%
Improved Auto. Trans. Controls/ Externals	10%	12%	14%	11%	11%
Continuously Variable Transmission	11%	11%	11%	11%	11%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	19%	15%	16%	17%	16%
Dual Clutch or Automated Manual Transmission	15%	28%	35%	45%	52%
Electric Power Steering	39%	55%	62%	64%	79%
Improved Accessories	32%	39%	43%	50%	57%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	5%	12%	18%	24%	25%
Crank mounted Integrated Starter Generator	1%	1%	1%	1%	1%
Power Split Hybrid	4%	4%	4%	4%	4%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	18%	17%	25%	34%	40%
Mass Reduction (3.5% to 8.5%)	0%	0%	18%	32%	40%
Low Rolling Resistance Tires	48%	58%	66%	74%	88%
Low Drag Brakes	8%	9%	11%	11%	13%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	5%	5%	5%	7%
Aero Drag Reduction	35%	44%	51%	63%	79%

5% Annual Increase - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	65%	75%	74%	77%	76%
Engine Friction Reduction	26%	47%	58%	64%	68%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	6%	9%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	9%	10%	10%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	0%
VVT - Intake Cam Phasing (ICP)	39%	36%	31%	27%	24%
VVT - Dual Cam Phasing (DCP)	38%	41%	47%	51%	53%
Discrete Variable Valve Lift (DVVL) on DOHC	18%	30%	34%	35%	38%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	1%
Cylinder Deactivation on OHV	1%	2%	2%	2%	2%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	5%	5%	5%
Discrete Variable Valve Lift (DVVL) on OHV	0%	0%	1%	2%	2%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	20%	32%	39%	45%	50%
Combustion Restart	0%	0%	4%	9%	17%
Turbocharging and Downsizing	14%	24%	30%	34%	34%
Exhaust Gas Recirculation (EGR) Boost	0%	12%	18%	22%	28%
Conversion to Diesel following TRBDS	1%	1%	2%	3%	5%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	3%	4%	4%
Improved Auto. Trans. Controls/ Externals	10%	13%	14%	9%	2%
Continuously Variable Transmission	11%	11%	11%	11%	11%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	15%	10%	6%	2%	1%
Dual Clutch or Automated Manual Transmission	25%	41%	53%	66%	77%
Electric Power Steering	39%	56%	67%	70%	79%
Improved Accessories	32%	40%	45%	53%	66%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	11%	21%	28%	34%	37%
Crank mounted Integrated Starter Generator	1%	1%	1%	1%	1%
Power Split Hybrid	4%	4%	5%	5%	5%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	18%	25%	34%	45%	61%
Mass Reduction (3.5% to 8.5%)	0%	0%	19%	33%	45%
Low Rolling Resistance Tires	48%	59%	68%	77%	90%
Low Drag Brakes	8%	9%	11%	12%	13%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	5%	5%	5%	7%
Aero Drag Reduction	39%	51%	59%	66%	80%

6% Annual Increase - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	64%	72%	75%	89%	88%
Engine Friction Reduction	25%	48%	60%	69%	83%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	6%	9%	9%	9%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	9%	9%	9%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	0%
VVT - Intake Cam Phasing (ICP)	37%	33%	25%	18%	6%
VVT - Dual Cam Phasing (DCP)	37%	42%	49%	57%	69%
Discrete Variable Valve Lift (DVVL) on DOHC	26%	39%	48%	54%	64%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	1%	1%
Cylinder Deactivation on OHV	1%	2%	1%	0%	0%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	5%	4%	4%
Discrete Variable Valve Lift (DVVL) on OHV	0%	2%	2%	2%	2%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	19%	33%	44%	48%	56%
Combustion Restart	0%	0%	3%	7%	14%
Turbocharging and Downsizing	15%	27%	37%	43%	49%
Exhaust Gas Recirculation (EGR) Boost	0%	14%	25%	31%	41%
Conversion to Diesel following TRBDS	4%	4%	6%	9%	9%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	4%	4%	4%
Improved Auto. Trans. Controls/ Externals	11%	14%	14%	9%	0%
Continuously Variable Transmission	11%	11%	10%	10%	11%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	14%	9%	5%	2%	0%
Dual Clutch or Automated Manual Transmission	25%	44%	56%	67%	77%
Electric Power Steering	39%	62%	72%	78%	90%
Improved Accessories	32%	41%	46%	55%	71%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	8%	19%	27%	33%	36%
Crank mounted Integrated Starter Generator	4%	5%	6%	5%	6%
Power Split Hybrid	5%	6%	6%	8%	8%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	18%	27%	36%	47%	61%
Mass Reduction (3.5% to 8.5%)	0%	0%	19%	33%	45%
Low Rolling Resistance Tires	49%	66%	74%	80%	90%
Low Drag Brakes	8%	10%	11%	12%	14%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	5%	5%	6%	7%
Aero Drag Reduction	39%	53%	61%	66%	80%

7% Annual Increase - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	71%	74%	90%	88%	86%
Engine Friction Reduction	27%	52%	66%	73%	83%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	8%	11%	9%	9%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	9%	9%	9%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	0%
VVT - Intake Cam Phasing (ICP)	37%	31%	21%	12%	2%
VVT - Dual Cam Phasing (DCP)	37%	42%	51%	61%	68%
Discrete Variable Valve Lift (DVVL) on DOHC	26%	38%	49%	56%	62%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	1%
Cylinder Deactivation on OHV	1%	2%	1%	0%	0%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	4%	4%	4%
Discrete Variable Valve Lift (DVVL) on OHV	0%	2%	2%	4%	4%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	25%	40%	52%	61%	71%
Combustion Restart	0%	0%	2%	7%	21%
Turbocharging and Downsizing	15%	30%	41%	48%	53%
Exhaust Gas Recirculation (EGR) Boost	0%	17%	29%	36%	45%
Conversion to Diesel following TRBDS	4%	5%	7%	9%	12%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	4%	4%	4%
Improved Auto. Trans. Controls/ Externals	11%	14%	14%	9%	0%
Continuously Variable Transmission	11%	10%	9%	9%	9%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	14%	9%	5%	2%	0%
Dual Clutch or Automated Manual Transmission	25%	43%	53%	64%	74%
Electric Power Steering	40%	67%	81%	87%	90%
Improved Accessories	33%	46%	58%	71%	82%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	11%	22%	30%	37%	42%
Crank mounted Integrated Starter Generator	4%	4%	5%	5%	5%
Power Split Hybrid	5%	8%	10%	11%	12%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	18%	27%	36%	48%	85%
Mass Reduction (3.5% to 8.5%)	0%	0%	19%	33%	53%
Low Rolling Resistance Tires	50%	66%	75%	80%	90%
Low Drag Brakes	8%	10%	12%	13%	14%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	5%	6%	6%	7%
Aero Drag Reduction	39%	56%	64%	69%	80%

Max Net Benefit - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	74%	76%	91%	90%	89%
Engine Friction Reduction	27%	55%	70%	75%	85%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	8%	11%	9%	9%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	9%	9%	9%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	0%
VVT - Intake Cam Phasing (ICP)	37%	28%	19%	14%	10%
VVT - Dual Cam Phasing (DCP)	37%	45%	54%	60%	62%
Discrete Variable Valve Lift (DVVL) on DOHC	24%	36%	47%	51%	56%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	0%
Cylinder Deactivation on OHV	1%	2%	1%	1%	1%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	4%	4%	4%
Discrete Variable Valve Lift (DVVL) on OHV	0%	2%	2%	4%	4%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	22%	37%	47%	53%	59%
Combustion Restart	0%	0%	3%	8%	16%
Turbocharging and Downsizing	15%	28%	37%	42%	47%
Exhaust Gas Recirculation (EGR) Boost	0%	15%	25%	31%	39%
Conversion to Diesel following TRBDS	4%	4%	7%	8%	9%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	4%	4%	4%
Improved Auto. Trans. Controls/ Externals	11%	14%	14%	9%	2%
Continuously Variable Transmission	11%	10%	10%	10%	10%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	14%	9%	5%	2%	1%
Dual Clutch or Automated Manual Transmission	25%	43%	54%	65%	72%
Electric Power Steering	40%	66%	80%	83%	84%
Improved Accessories	33%	55%	64%	64%	67%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	11%	22%	32%	37%	41%
Crank mounted Integrated Starter Generator	4%	5%	5%	5%	5%
Power Split Hybrid	5%	8%	9%	10%	10%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	18%	32%	41%	50%	62%
Mass Reduction (3.5% to 8.5%)	0%	0%	18%	32%	47%
Low Rolling Resistance Tires	50%	66%	75%	80%	90%
Low Drag Brakes	8%	12%	14%	14%	14%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	6%	6%	7%	7%
Aero Drag Reduction	39%	56%	64%	69%	80%

Total Cost = Total Benefit - PC

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	75%	78%	90%	89%	87%
Engine Friction Reduction	27%	54%	69%	75%	84%
VVT - Coupled Cam Phasing (CCP) on SOHC	5%	8%	11%	9%	9%
Discrete Variable Valve Lift (DVVL) on SOHC	6%	7%	9%	9%	9%
Cylinder Deactivation on SOHC	1%	1%	1%	0%	0%
VVT - Intake Cam Phasing (ICP)	35%	27%	17%	12%	6%
VVT - Dual Cam Phasing (DCP)	39%	47%	55%	62%	65%
Discrete Variable Valve Lift (DVVL) on DOHC	30%	43%	54%	62%	66%
Continuously Variable Valve Lift (CVVL)	3%	2%	3%	3%	3%
Cylinder Deactivation on DOHC	1%	1%	1%	2%	1%
Cylinder Deactivation on OHV	1%	2%	1%	0%	0%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	4%	4%	4%
Discrete Variable Valve Lift (DVVL) on OHV	0%	2%	2%	4%	4%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	30%	47%	62%	68%	72%
Combustion Restart	0%	0%	5%	9%	17%
Turbocharging and Downsizing	16%	32%	43%	49%	54%
Exhaust Gas Recirculation (EGR) Boost	0%	19%	31%	37%	46%
Conversion to Diesel following TRBDS	4%	5%	7%	8%	11%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	3%	3%	4%	4%	4%
Improved Auto. Trans. Controls/ Externals	11%	14%	14%	9%	2%
Continuously Variable Transmission	11%	10%	10%	10%	10%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	14%	9%	5%	2%	0%
Dual Clutch or Automated Manual Transmission	25%	43%	54%	65%	72%
Electric Power Steering	40%	66%	81%	84%	84%
Improved Accessories	36%	58%	67%	71%	75%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	13%	23%	33%	39%	44%
Crank mounted Integrated Starter Generator	4%	4%	5%	4%	5%
Power Split Hybrid	5%	8%	9%	10%	12%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	21%	40%	51%	58%	66%
Mass Reduction (3.5% to 8.5%)	0%	0%	19%	33%	47%
Low Rolling Resistance Tires	50%	66%	75%	80%	90%
Low Drag Brakes	8%	12%	14%	14%	14%
Secondary Axle Disconnect – Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	4%	6%	6%	7%	7%
Aero Drag Reduction	39%	56%	64%	69%	80%

Table V-49. Penetration Rate of New Technologies to Light Trucks, by Alternative

Preferred Alternative - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	98%	98%	98%	98%	98%
Engine Friction Reduction	57%	78%	79%	82%	94%
VVT - Coupled Cam Phasing (CCP) on SOHC	12%	12%	12%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	5%	5%	6%	6%
Cylinder Deactivation on SOHC	9%	10%	9%	9%	9%
VVT - Intake Cam Phasing (ICP)	13%	12%	9%	6%	2%
VVT - Dual Cam Phasing (DCP)	38%	41%	49%	49%	53%
Discrete Variable Valve Lift (DVVL) on DOHC	25%	29%	35%	34%	35%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	9%	10%	9%	11%	9%
Cylinder Deactivation on OHV	17%	17%	15%	17%	22%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	6%	5%	5%	18%
Discrete Variable Valve Lift (DVVL) on OHV	0%	13%	14%	19%	19%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	22%	27%	34%	35%	42%
Combustion Restart	0%	0%	3%	7%	20%
Turbocharging and Downsizing	9%	12%	16%	17%	20%
Exhaust Gas Recirculation (EGR) Boost	0%	4%	7%	7%	11%
Conversion to Diesel following TRBDS	1%	1%	1%	1%	1%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	35%	25%	16%	5%	1%
Continuously Variable Transmission	3%	3%	3%	4%	4%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	11%	6%	2%	1%	2%
Dual Clutch or Automated Manual Transmission	32%	54%	72%	84%	90%
Electric Power Steering	72%	76%	75%	84%	91%
Improved Accessories	36%	38%	39%	43%	51%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	7%	11%	21%	22%	22%
Crank mounted Integrated Starter Generator	0%	0%	0%	0%	0%
Power Split Hybrid	3%	2%	2%	3%	3%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	15%	17%	34%	47%	61%
Mass Reduction (3.5% to 8.5%)	0%	0%	20%	34%	55%
Low Rolling Resistance Tires	92%	95%	95%	98%	99%
Low Drag Brakes	33%	52%	50%	51%	60%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	30%	33%	35%	36%	43%
Aero Drag Reduction	87%	92%	96%	97%	100%

3% Annual Increase - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	81%	80%	77%	76%	89%
Engine Friction Reduction	39%	54%	56%	59%	64%
VVT - Coupled Cam Phasing (CCP) on SOHC	11%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	4%	4%	5%	5%	5%
Cylinder Deactivation on SOHC	4%	3%	3%	3%	3%
VVT - Intake Cam Phasing (ICP)	17%	17%	17%	15%	13%
VVT - Dual Cam Phasing (DCP)	33%	35%	41%	43%	44%
Discrete Variable Valve Lift (DVVL) on DOHC	17%	20%	23%	22%	23%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	7%	8%	7%	8%	8%
Cylinder Deactivation on OHV	17%	16%	14%	15%	18%
VVT - Coupled Cam Phasing (CCP) on OHV	3%	2%	2%	3%	3%
Discrete Variable Valve Lift (DVVL) on OHV	0%	0%	0%	0%	0%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	11%	13%	14%	14%	15%
Combustion Restart	0%	0%	3%	6%	6%
Turbocharging and Downsizing	5%	8%	9%	9%	11%
Exhaust Gas Recirculation (EGR) Boost	0%	3%	5%	4%	6%
Conversion to Diesel following TRBDS	0%	0%	0%	0%	0%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	34%	23%	14%	4%	1%
Continuously Variable Transmission	3%	3%	3%	4%	4%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	14%	11%	13%	15%	17%
Dual Clutch or Automated Manual Transmission	31%	50%	60%	70%	72%
Electric Power Steering	59%	60%	61%	66%	74%
Improved Accessories	29%	29%	32%	33%	40%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	7%	9%	12%	12%	12%
Crank mounted Integrated Starter Generator	0%	0%	0%	0%	0%
Power Split Hybrid	1%	1%	1%	2%	2%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	5%	5%	25%	35%	51%
Mass Reduction (3.5% to 8.5%)	0%	0%	20%	32%	48%
Low Rolling Resistance Tires	80%	82%	81%	92%	94%
Low Drag Brakes	19%	20%	22%	26%	45%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	13%	14%	19%	22%	30%
Aero Drag Reduction	74%	79%	88%	97%	100%

4% Annual Increase - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	80%	79%	77%	82%	97%
Engine Friction Reduction	44%	60%	62%	69%	84%
VVT - Coupled Cam Phasing (CCP) on SOHC	12%	12%	12%	11%	11%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	4%	5%	9%	9%
Cylinder Deactivation on SOHC	3%	3%	2%	6%	5%
VVT - Intake Cam Phasing (ICP)	16%	16%	14%	11%	6%
VVT - Dual Cam Phasing (DCP)	34%	35%	44%	46%	51%
Discrete Variable Valve Lift (DVVL) on DOHC	24%	27%	33%	31%	36%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	7%	7%	7%	9%	9%
Cylinder Deactivation on OHV	17%	16%	14%	15%	21%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	5%	5%	18%
Discrete Variable Valve Lift (DVVL) on OHV	0%	13%	14%	18%	18%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	23%	27%	33%	33%	37%
Combustion Restart	0%	0%	3%	8%	8%
Turbocharging and Downsizing	12%	14%	17%	17%	19%
Exhaust Gas Recirculation (EGR) Boost	0%	2%	4%	4%	7%
Conversion to Diesel following TRBDS	1%	2%	2%	2%	2%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	34%	24%	18%	8%	3%
Continuously Variable Transmission	3%	3%	3%	4%	4%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	13%	7%	5%	6%	7%
Dual Clutch or Automated Manual Transmission	32%	54%	66%	78%	83%
Electric Power Steering	66%	70%	73%	81%	87%
Improved Accessories	30%	31%	33%	40%	48%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	10%	15%	24%	27%	28%
Crank mounted Integrated Starter Generator	0%	0%	0%	0%	0%
Power Split Hybrid	1%	1%	1%	2%	2%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	15%	15%	36%	45%	61%
Mass Reduction (3.5% to 8.5%)	0%	0%	21%	32%	50%
Low Rolling Resistance Tires	81%	84%	92%	99%	99%
Low Drag Brakes	20%	21%	22%	26%	48%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	16%	17%	21%	24%	33%
Aero Drag Reduction	74%	79%	89%	98%	100%

5% Annual Increase - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	77%	93%	91%	91%	91%
Engine Friction Reduction	42%	63%	73%	81%	86%
VVT - Coupled Cam Phasing (CCP) on SOHC	12%	12%	12%	11%	11%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	4%	6%	12%	13%
Cylinder Deactivation on SOHC	3%	2%	2%	5%	6%
VVT - Intake Cam Phasing (ICP)	14%	13%	11%	8%	3%
VVT - Dual Cam Phasing (DCP)	34%	36%	40%	41%	45%
Discrete Variable Valve Lift (DVVL) on DOHC	22%	29%	34%	34%	39%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	7%	8%	6%	8%	15%
Cylinder Deactivation on OHV	17%	16%	15%	16%	22%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	5%	7%	7%	18%
Discrete Variable Valve Lift (DVVL) on OHV	0%	14%	17%	22%	22%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	20%	37%	43%	52%	59%
Combustion Restart	0%	0%	3%	16%	34%
Turbocharging and Downsizing	11%	15%	22%	22%	24%
Exhaust Gas Recirculation (EGR) Boost	0%	4%	10%	11%	13%
Conversion to Diesel following TRBDS	5%	6%	8%	8%	8%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	34%	24%	15%	5%	1%
Continuously Variable Transmission	3%	3%	3%	4%	4%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	12%	6%	2%	1%	1%
Dual Clutch or Automated Manual Transmission	32%	53%	71%	84%	90%
Electric Power Steering	69%	77%	83%	88%	90%
Improved Accessories	30%	32%	40%	47%	52%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	8%	12%	22%	25%	27%
Crank mounted Integrated Starter Generator	2%	2%	4%	4%	4%
Power Split Hybrid	3%	4%	4%	4%	4%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	15%	17%	38%	50%	62%
Mass Reduction (3.5% to 8.5%)	0%	0%	21%	36%	55%
Low Rolling Resistance Tires	81%	84%	92%	99%	99%
Low Drag Brakes	25%	32%	38%	42%	65%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	16%	17%	24%	28%	39%
Aero Drag Reduction	81%	86%	90%	95%	97%

6% Annual Increase - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	76%	93%	90%	87%	85%
Engine Friction Reduction	42%	66%	76%	81%	79%
VVT - Coupled Cam Phasing (CCP) on SOHC	12%	12%	12%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	4%	6%	12%	13%
Cylinder Deactivation on SOHC	3%	3%	2%	2%	1%
VVT - Intake Cam Phasing (ICP)	14%	11%	6%	1%	1%
VVT - Dual Cam Phasing (DCP)	33%	38%	46%	47%	46%
Discrete Variable Valve Lift (DVVL) on DOHC	21%	29%	34%	34%	38%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	7%	8%	6%	7%	5%
Cylinder Deactivation on OHV	17%	13%	8%	5%	5%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	8%	9%	8%	19%
Discrete Variable Valve Lift (DVVL) on OHV	0%	14%	17%	19%	20%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	22%	43%	54%	63%	74%
Combustion Restart	0%	0%	7%	16%	38%
Turbocharging and Downsizing	15%	29%	40%	47%	57%
Exhaust Gas Recirculation (EGR) Boost	0%	14%	25%	34%	47%
Conversion to Diesel following TRBDS	5%	6%	9%	12%	14%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	35%	25%	17%	5%	1%
Continuously Variable Transmission	3%	3%	2%	2%	2%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	11%	6%	2%	1%	0%
Dual Clutch or Automated Manual Transmission	30%	51%	68%	82%	89%
Electric Power Steering	71%	79%	87%	89%	91%
Improved Accessories	31%	36%	45%	51%	53%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	12%	16%	28%	32%	38%
Crank mounted Integrated Starter Generator	1%	2%	2%	2%	2%
Power Split Hybrid	5%	6%	8%	8%	8%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	15%	18%	40%	56%	82%
Mass Reduction (3.5% to 8.5%)	0%	0%	21%	36%	55%
Low Rolling Resistance Tires	85%	88%	92%	97%	97%
Low Drag Brakes	25%	50%	53%	65%	77%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	16%	26%	33%	50%	56%
Aero Drag Reduction	87%	92%	96%	97%	100%

7% Annual Increase - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	87%	91%	87%	85%	83%
Engine Friction Reduction	42%	65%	76%	80%	78%
VVT - Coupled Cam Phasing (CCP) on SOHC	12%	12%	13%	13%	13%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	4%	6%	12%	13%
Cylinder Deactivation on SOHC	3%	3%	2%	2%	1%
VVT - Intake Cam Phasing (ICP)	14%	10%	4%	4%	4%
VVT - Dual Cam Phasing (DCP)	33%	38%	46%	47%	45%
Discrete Variable Valve Lift (DVVL) on DOHC	21%	28%	38%	39%	44%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	7%	8%	8%	9%	2%
Cylinder Deactivation on OHV	17%	9%	5%	2%	1%
VVT - Coupled Cam Phasing (CCP) on OHV	5%	19%	17%	17%	18%
Discrete Variable Valve Lift (DVVL) on OHV	0%	13%	14%	18%	19%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	22%	40%	55%	64%	76%
Combustion Restart	0%	0%	10%	22%	39%
Turbocharging and Downsizing	15%	34%	50%	57%	67%
Exhaust Gas Recirculation (EGR) Boost	0%	20%	35%	46%	60%
Conversion to Diesel following TRBDS	6%	9%	12%	15%	17%
Conversion to Diesel following CBRST	0%	0%	0%	0%	0%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	35%	25%	17%	5%	1%
Continuously Variable Transmission	3%	3%	2%	2%	2%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	11%	6%	2%	1%	0%
Dual Clutch or Automated Manual Transmission	31%	51%	67%	79%	84%
Electric Power Steering	72%	80%	88%	89%	90%
Improved Accessories	33%	38%	47%	52%	53%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	13%	16%	27%	29%	36%
Crank mounted Integrated Starter Generator	3%	4%	7%	9%	7%
Power Split Hybrid	4%	6%	9%	10%	12%
2-Mode Hybrid	0%	0%	0%	1%	1%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	15%	22%	44%	60%	87%
Mass Reduction (3.5% to 8.5%)	0%	0%	21%	36%	57%
Low Rolling Resistance Tires	92%	95%	97%	97%	97%
Low Drag Brakes	29%	56%	60%	69%	77%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	22%	35%	40%	53%	56%
Aero Drag Reduction	87%	92%	96%	97%	100%

Max Net Benefit - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	93%	91%	88%	85%	85%
Engine Friction Reduction	54%	77%	76%	77%	79%
VVT - Coupled Cam Phasing (CCP) on SOHC	13%	13%	13%	13%	13%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	5%	6%	12%	13%
Cylinder Deactivation on SOHC	9%	9%	8%	4%	4%
VVT - Intake Cam Phasing (ICP)	10%	6%	3%	3%	2%
VVT - Dual Cam Phasing (DCP)	35%	40%	44%	43%	44%
Discrete Variable Valve Lift (DVVL) on DOHC	21%	28%	33%	33%	33%
Continuously Variable Valve Lift (CVVL)	4%	4%	4%	4%	4%
Cylinder Deactivation on DOHC	7%	8%	8%	9%	6%
Cylinder Deactivation on OHV	18%	12%	9%	6%	5%
VVT - Coupled Cam Phasing (CCP) on OHV	7%	21%	21%	20%	20%
Discrete Variable Valve Lift (DVVL) on OHV	0%	13%	15%	19%	19%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	21%	40%	50%	60%	63%
Combustion Restart	0%	0%	9%	18%	28%
Turbocharging and Downsizing	16%	34%	44%	51%	54%
Exhaust Gas Recirculation (EGR) Boost	0%	18%	28%	35%	42%
Conversion to Diesel following TRBDS	7%	9%	12%	14%	15%
Conversion to Diesel following CBRST	0%	1%	1%	1%	1%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	35%	25%	17%	5%	1%
Continuously Variable Transmission	3%	3%	2%	2%	2%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	11%	6%	2%	1%	0%
Dual Clutch or Automated Manual Transmission	30%	50%	67%	80%	88%
Electric Power Steering	73%	80%	84%	89%	91%
Improved Accessories	37%	42%	47%	53%	52%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	12%	15%	27%	30%	33%
Crank mounted Integrated Starter Generator	3%	3%	5%	5%	5%
Power Split Hybrid	5%	7%	9%	9%	9%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	29%	51%	64%	71%	81%
Mass Reduction (3.5% to 8.5%)	0%	0%	21%	35%	56%
Low Rolling Resistance Tires	92%	95%	97%	97%	97%
Low Drag Brakes	33%	61%	70%	72%	74%
Secondary Axle Disconnect - Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	30%	42%	47%	54%	54%
Aero Drag Reduction	87%	92%	96%	97%	100%

Total Cost = Total Benefit - LT

Technology	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Low Friction Lubricants	93%	91%	87%	85%	84%
Engine Friction Reduction	54%	77%	82%	79%	80%
VVT - Coupled Cam Phasing (CCP) on SOHC	13%	13%	13%	13%	13%
Discrete Variable Valve Lift (DVVL) on SOHC	5%	5%	6%	12%	13%
Cylinder Deactivation on SOHC	9%	9%	8%	2%	1%
VVT - Intake Cam Phasing (ICP)	10%	6%	1%	1%	0%
VVT - Dual Cam Phasing (DCP)	35%	40%	46%	45%	45%
Discrete Variable Valve Lift (DVVL) on DOHC	21%	28%	34%	36%	41%
Continuously Variable Valve Lift (CVVL)	4%	4%	5%	5%	5%
Cylinder Deactivation on DOHC	7%	8%	8%	9%	8%
Cylinder Deactivation on OHV	18%	10%	6%	2%	1%
VVT - Coupled Cam Phasing (CCP) on OHV	7%	21%	21%	20%	20%
Discrete Variable Valve Lift (DVVL) on OHV	0%	13%	15%	18%	20%
Conversion to DOHC with DCP	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	21%	40%	52%	60%	68%
Combustion Restart	0%	0%	12%	25%	30%
Turbocharging and Downsizing	16%	36%	49%	55%	62%
Exhaust Gas Recirculation (EGR) Boost	0%	20%	32%	44%	54%
Conversion to Diesel following TRBDS	7%	9%	12%	15%	15%
Conversion to Diesel following CBRST	0%	1%	1%	1%	1%
6-Speed Manual/ Improved Internals	1%	1%	1%	1%	1%
Improved Auto. Trans. Controls/ Externals	35%	25%	17%	5%	1%
Continuously Variable Transmission	3%	3%	2%	2%	2%
6/ 7/ 8-Speed Auto. Trans with Improved Internals	11%	6%	2%	1%	0%
Dual Clutch or Automated Manual Transmission	30%	49%	67%	80%	85%
Electric Power Steering	73%	80%	88%	90%	92%
Improved Accessories	37%	42%	52%	57%	57%
12V Micro-Hybrid	0%	0%	0%	0%	0%
Belt mounted Integrated Starter Generator	12%	14%	24%	25%	29%
Crank mounted Integrated Starter Generator	3%	4%	6%	9%	7%
Power Split Hybrid	5%	7%	10%	10%	12%
2-Mode Hybrid	0%	0%	0%	0%	0%
Plug-in Hybrid	0%	0%	0%	0%	0%
Mass Reduction (1.5%)	29%	51%	69%	76%	83%
Mass Reduction (3.5% to 8.5%)	0%	0%	21%	36%	56%
Low Rolling Resistance Tires	92%	95%	97%	97%	97%
Low Drag Brakes	33%	61%	70%	72%	77%
Secondary Axle Disconnect – Unibody	0%	0%	0%	0%	0%
Secondary Axle Disconnect - Ladder Frame	30%	42%	49%	55%	57%
Aero Drag Reduction	87%	92%	96%	97%	100%

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. These mpg estimates change for some of the model years, but usually to a minimal extent, 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 makes it meet the MY 2011 fuel economy standard by adding technology. The adjusted baseline assumes for the analysis that each manufacturer, below the MY 2011 standard applicable to that manufacturer, (except BMW, Daimler, Porsche, Tata, and Volkswagen) would apply technology to achieve the MY 2011 standard. Our rationale for this adjustment of the baseline is that the costs and benefits of achieving MY 2011 mpg levels have already been analyzed and estimated in the previous analysis. The costs of these technologies are estimated, but they are not considered part of this rule. We then estimate the costs and benefits of going from the adjusted baseline to the level of the alternatives.[201]

The estimated required standard levels are shown in Table VI-3 for passenger cars for the preferred alternative. Table VI-4 provides the estimated achieved mpg levels for passenger cars for each of the alternatives. 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. We assume that BMW, Daimler, Porsche, Tata, and Volkswagen would not meet these levels because, for them, the cost of meeting these levels is more than the cost of paying penalties. These manufacturers have shown, in the past, the willingness to pay penalties rather than spend more money to improve the fuel economy of their products, so the agency believes it is reasonable to assume that they would make that choice again in the future.

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 "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 Volpe 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

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[201] 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 manufacturer's levels go slightly above the required mpg mark 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.

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 Volpe 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.[202]

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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[202] *See* Docket Nos. NHTSA-2005-22223-0003, NHTSA-2005-22223-0004 and NHTSA-2005-22223-0005.

Table VI-1

MY 2008 Fleet Extended

Estimated mpg

Passenger Cars

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	27.2	27.2	27.2	27.2	27.2
Chrysler	28.4	28.7	28.7	28.7	28.7
Daimler	25.9	25.9	25.6	25.2	25.2
Ford	28.3	28.3	28.3	28.1	28.1
General Motors	28.5	28.6	28.5	28.4	28.4
Honda	33.9	34.1	34.1	33.9	34.0
Hyundai	32.3	31.2	31.1	31.9	32.0
Kia	31.9	32.2	32.5	32.9	33.0
Mazda	30.6	30.9	31.0	30.9	30.9
Mitsubishi	29.5	29.4	29.1	28.9	28.9
Nissan	32.0	32.1	32.0	32.0	32.0
Porsche	26.2	26.2	26.2	26.2	26.2
Subaru	29.4	29.4	29.4	29.4	29.4
Suzuki	31.2	30.9	30.8	30.8	30.9
Tata	24.6	24.6	24.6	24.6	24.6
Toyota	35.4	35.5	35.4	35.3	35.3
Volkswagen	29.0	29.0	29.0	29.0	29.0
Total/Average	30.5	30.8	30.8	30.7	30.7

Table VI-2

Adjusted Baseline

Estimated mpg

Passenger Cars

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.2	30.2	30.2
Chrysler	29.7	29.9	29.9	29.8	29.9
Daimler	27.4	27.9	29.1	29.0	29.0
Ford	30.0	30.0	30.0	30.0	30.0
General Motors	30.4	30.4	30.4	30.4	30.4
Honda	33.9	34.1	34.1	33.9	34.0
Hyundai	32.3	31.2	31.1	31.9	32.0
Kia	31.9	32.2	32.5	32.9	33.0
Mazda	30.6	30.9	31.0	30.9	30.9
Mitsubishi	31.1	31.0	31.1	31.0	31.0
Nissan	32.0	32.1	32.0	32.0	32.0
Porsche	28.3	29.1	29.1	29.2	29.2
Subaru	31.0	31.0	31.0	31.1	31.1
Suzuki	31.4	31.6	31.6	31.6	31.6
Tata	26.0	27.8	28.1	28.1	28.1
Toyota	35.4	35.5	35.4	35.3	35.3
Volkswagen	30.8	30.8	30.8	30.7	30.7
Total/Average	31.6	31.8	31.8	31.8	31.9

Table VI-3

Estimated Required Fuel Economy Levels for Preferred Alternative

Estimated mpg

Passenger Cars

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	33.0	33.7	34.5	35.7	37.3
Chrysler	32.6	33.3	34.1	35.2	36.7
Daimler	32.0	32.7	33.3	34.4	35.8
Ford	32.9	33.7	34.4	35.6	37.1
General Motors	32.7	33.5	34.2	35.4	36.9
Honda	33.8	34.6	35.4	36.7	38.3
Hyundai	33.8	34.3	35.1	36.6	38.2
Kia	33.4	34.2	35.0	36.3	37.9
Mazda	33.8	34.6	35.5	36.8	38.4
Mitsubishi	34.2	35.0	35.8	37.1	38.7
Nissan	33.3	34.1	34.9	36.1	37.7
Porsche	35.9	36.8	37.8	39.2	41.1
Subaru	34.6	35.5	36.3	37.7	39.4
Suzuki	35.8	36.6	37.5	39.0	40.8
Tata	30.7	31.4	32.1	33.3	34.7
Toyota	33.9	34.7	35.5	36.8	38.4
Volkswagen	34.3	35.0	35.9	37.2	38.8
Total/Average	33.3	34.2	34.9	36.2	37.8

Table VI-4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Preferred Alternative

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.5	34.4	35.1	36.1	36.7
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	32.5	34.6	34.7	35.9	37.1
General Motors	30.8	33.5	35.0	36.2	36.9
Honda	34.0	34.9	36.0	36.7	38.3
Hyundai	34.8	34.3	36.1	37.6	38.5
Kia	33.4	34.3	35.1	36.6	37.9
Mazda	32.4	35.1	36.3	36.8	38.4
Mitsubishi	32.2	32.1	37.0	38.7	38.7
Nissan	33.3	34.7	36.6	36.7	37.7
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	37.1	39.4	39.4
Suzuki	31.4	37.0	39.1	39.5	40.9
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	36.6	36.8	37.0	38.1	38.4
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	32.8	34.4	35.3	36.3	37.2

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

3% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.1	32.6	32.9	33.6	34.5
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	31.3	33.0	33.1	33.9	34.8
General Motors	30.8	32.2	33.1	33.9	34.7
Honda	33.9	34.1	34.2	34.8	35.9
Hyundai	33.5	32.8	33.9	34.9	35.8
Kia	31.9	32.6	33.6	34.5	35.5
Mazda	32.1	33.4	34.5	34.9	36.4
Mitsubishi	32.2	32.1	35.3	36.2	36.3
Nissan	32.3	32.9	33.8	34.3	35.3
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	36.2	36.9	36.8
Suzuki	31.4	35.6	37.0	37.3	38.5
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	35.4	35.5	35.4	35.3	36.0
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	32.2	33.2	33.7	34.3	35.2

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

4% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.4	34.1	34.8	35.7	36.1
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	31.6	33.8	34.0	35.2	36.5
General Motors	30.8	32.8	34.2	35.5	36.4
Honda	34.0	34.2	35.3	36.2	37.7
Hyundai	34.1	33.4	35.2	36.7	37.7
Kia	32.1	33.6	34.8	36.5	37.3
Mazda	32.4	34.4	36.0	36.4	37.8
Mitsubishi	32.2	32.1	36.7	38.1	38.2
Nissan	32.3	33.2	35.3	36.2	37.1
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	36.5	38.7	38.7
Suzuki	31.4	36.2	38.2	38.6	40.1
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	35.5	35.7	35.6	36.3	37.8
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	32.3	33.6	34.6	35.5	36.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

5% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.5	35.0	36.0	37.3	37.8
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	31.9	34.8	35.0	36.5	38.3
General Motors	30.8	33.2	35.3	36.8	38.1
Honda	34.3	35.2	36.9	37.8	40.1
Hyundai	34.5	34.0	36.5	38.5	39.5
Kia	32.4	34.2	35.9	37.3	39.2
Mazda	32.4	34.9	37.0	38.0	39.7
Mitsubishi	32.2	32.1	38.3	40.5	40.6
Nissan	33.3	35.0	37.6	38.3	38.9
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	38.4	40.7	40.7
Suzuki	31.4	38.2	41.4	42.1	43.8
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	36.6	36.8	37.1	38.3	39.7
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	32.6	34.4	35.8	36.9	38.3

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

6% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.5	36.3	38.0	39.5	39.8
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	32.4	35.5	35.8	37.4	39.1
General Motors	30.8	33.8	36.0	38.4	39.9
Honda	34.3	36.3	38.3	39.1	41.8
Hyundai	34.8	34.4	38.4	39.8	41.4
Kia	32.8	34.9	36.8	38.8	41.1
Mazda	32.4	35.4	38.0	39.2	41.6
Mitsubishi	32.2	32.1	39.1	40.8	40.8
Nissan	33.6	35.4	39.2	40.0	40.8
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	39.9	42.8	42.8
Suzuki	31.4	38.5	42.1	42.8	44.5
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	36.9	37.1	37.5	39.3	41.7
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	32.8	34.9	36.6	38.0	39.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

7% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.5	37.0	38.7	40.3	40.4
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	32.5	35.7	36.1	37.7	39.4
General Motors	30.8	33.9	36.5	38.9	40.8
Honda	34.3	37.6	40.2	40.9	43.6
Hyundai	35.1	34.8	39.3	41.4	43.7
Kia	33.0	35.6	37.8	40.4	43.1
Mazda	32.4	36.0	38.9	39.7	43.7
Mitsubishi	32.2	32.1	38.7	40.6	40.5
Nissan	34.1	35.9	40.2	40.8	41.3
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	39.4	42.6	42.6
Suzuki	31.4	40.3	45.1	46.4	47.4
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	37.7	38.1	39.1	41.2	43.7
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	33.0	35.4	37.4	38.9	40.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Max Net Benefits

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.5	37.1	38.5	39.9	40.0
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	32.5	36.1	36.4	38.0	39.6
General Motors	30.8	33.9	36.5	38.5	39.9
Honda	34.3	37.3	39.4	40.0	41.6
Hyundai	35.0	34.7	38.6	39.9	41.5
Kia	33.1	36.4	38.3	39.6	41.1
Mazda	32.4	36.2	38.5	39.6	41.8
Mitsubishi	32.2	32.1	38.7	40.6	40.5
Nissan	34.2	36.1	40.0	40.2	40.8
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	39.7	42.2	42.2
Suzuki	31.4	38.9	42.5	43.3	44.5
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	37.6	38.0	38.9	40.3	41.7
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	33.0	35.5	37.3	38.4	39.8

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Total Cost=Total Benefit

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.9	29.9	30.3	31.0	32.4
Chrysler	31.5	37.1	38.7	39.7	39.8
Daimler	27.4	27.9	30.5	31.8	33.2
Ford	32.5	36.2	36.6	38.1	39.6
General Motors	30.8	33.9	36.5	38.9	40.8
Honda	34.3	38.3	40.8	41.5	43.2
Hyundai	35.0	34.7	39.4	41.3	43.0
Kia	33.5	36.9	39.2	40.9	42.5
Mazda	32.4	36.2	38.5	39.6	43.1
Mitsubishi	32.2	32.1	38.7	40.6	40.5
Nissan	34.4	36.4	40.4	40.6	41.3
Porsche	28.5	29.2	29.2	29.2	29.2
Subaru	32.4	32.8	39.7	42.4	42.4
Suzuki	31.4	40.2	43.9	44.6	45.3
Tata	26.3	28.1	28.7	29.2	30.8
Toyota	38.3	38.7	39.9	41.5	43.1
Volkswagen	31.6	33.6	33.9	34.0	35.5
Total/Average	33.1	35.7	37.7	39.0	40.5

Table VI-5

MY 2008 Fleet Extended

Estimated mpg

Light Trucks

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	23.0	23.1	23.1	23.0	23.0
Chrysler	21.9	22.1	22.2	22.2	22.2
Daimler	21.1	21.1	21.0	21.1	21.1
Ford	21.1	21.2	21.3	21.3	21.3
General Motors	21.3	21.4	21.5	21.4	21.4
Honda	25.1	25.1	25.1	25.0	25.0
Hyundai	24.3	24.3	24.3	24.3	24.3
Kia	23.7	23.7	23.8	23.8	23.8
Mazda	26.2	26.6	26.4	26.4	26.4
Mitsubishi	23.7	23.7	23.7	23.6	23.6
Nissan	21.9	22.0	22.1	22.1	22.1
Porsche	20.0	20.0	20.0	20.0	20.0
Subaru	26.2	26.4	26.5	26.8	26.9
Suzuki	23.3	23.3	23.3	23.3	23.3
Tata	19.7	19.8	19.8	19.7	19.7
Toyota	23.9	24.0	24.2	24.2	24.2
Volkswagen	20.2	20.2	20.2	20.2	20.2
Total/Average	22.3	22.5	22.6	22.6	22.6

Table VI-6

Adjusted Baseline

Estimated mpg

Light Trucks

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	25.7	25.8	25.8	25.7	25.7
Chrysler	24.5	24.7	24.8	24.8	24.8
Daimler	24.6	24.7	24.6	25.2	25.2
Ford	23.8	23.8	23.9	24.0	24.0
General Motors	23.3	23.4	23.5	23.5	23.5
Honda	25.8	25.9	25.9	25.8	25.8
Hyundai	25.9	25.9	25.9	25.9	25.9
Kia	25.3	25.3	25.3	25.3	25.3
Mazda	26.4	26.7	26.6	26.6	26.6
Mitsubishi	27.1	27.1	27.1	27.1	27.1
Nissan	24.5	24.5	24.6	24.7	24.7
Porsche	24.4	24.4	24.4	25.6	25.6
Subaru	26.7	26.8	27.0	27.2	27.3
Suzuki	24.7	26.4	26.4	26.4	26.4
Tata	23.8	23.9	24.1	24.3	26.3
Toyota	24.8	25.0	25.2	25.2	25.2
Volkswagen	21.1	23.8	25.0	25.1	25.1
Total/Average	24.3	24.5	24.7	24.7	24.7

Table VI-7

Estimated Required Fuel Economy Levels for Preferred Alternative

Estimated mpg

Light Trucks

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.6	27.3	27.9	28.9	30.2
Chrysler	25.7	26.2	26.8	27.8	29.0
Daimler	25.6	26.3	26.9	27.8	29.1
Ford	24.8	25.4	26.0	27.0	28.1
General Motors	24.2	24.8	25.2	26.1	27.2
Honda	26.9	27.5	28.0	29.1	30.4
Hyundai	27.0	27.6	28.2	29.3	30.7
Kia	26.2	26.7	27.3	28.3	29.5
Mazda	27.6	28.4	28.9	30.1	31.5
Mitsubishi	27.8	28.5	29.1	30.2	31.7
Nissan	25.6	26.2	26.8	27.8	29.1
Porsche	26.3	26.9	27.5	28.5	29.8
Subaru	27.9	28.6	29.2	30.4	31.9
Suzuki	27.5	28.2	28.8	29.9	31.4
Tata	27.4	28.2	28.8	29.9	31.3
Toyota	25.7	26.2	26.8	27.8	29.1
Volkswagen	25.8	26.4	27.0	28.0	29.2
Total/Average	25.4	26.0	26.6	27.5	28.8

Table VI-8

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Preferred Alternative

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.6	26.7	26.8	26.7	27.9
Chrysler	24.8	26.2	27.6	27.9	29.0
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	25.1	25.7	26.0	27.7	28.1
General Motors	23.4	25.0	25.9	26.2	27.2
Honda	27.7	27.7	28.5	29.1	30.5
Hyundai	28.1	28.0	30.6	30.7	30.7
Kia	26.1	26.7	27.5	28.4	29.7
Mazda	27.8	29.5	29.5	30.1	31.5
Mitsubishi	27.1	27.1	29.7	30.4	33.0
Nissan	25.8	26.2	27.5	27.8	29.1
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	30.3	30.7	31.1	31.8	31.9
Suzuki	24.7	31.1	31.1	31.1	31.6
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	25.7	26.3	27.6	28.3	29.2
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	25.1	26.0	27.0	27.6	28.5

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

3% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	25.6	25.7	25.8	27.2	28.4
Chrysler	24.5	25.1	26.1	26.4	27.2
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	24.0	24.5	25.0	26.6	26.6
General Motors	23.0	24.1	24.7	25.0	25.6
Honda	26.6	26.7	27.1	27.8	28.4
Hyundai	26.6	26.6	28.4	28.6	28.6
Kia	25.3	25.5	26.1	26.8	28.0
Mazda	27.0	28.3	28.3	28.5	29.4
Mitsubishi	27.1	27.1	28.3	28.6	29.5
Nissan	24.9	25.2	26.0	26.5	27.2
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	28.5	28.7	29.4	29.9	30.1
Suzuki	24.7	29.1	29.1	29.1	29.3
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	24.9	25.1	26.0	26.5	27.2
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	24.4	25.0	25.8	26.4	26.9

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

4% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	25.8	25.8	26.0	27.2	28.4
Chrysler	24.7	25.8	27.2	27.5	28.5
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	24.6	25.2	25.7	27.6	27.7
General Motors	23.3	24.7	25.5	25.8	26.8
Honda	26.8	26.9	28.1	28.9	29.9
Hyundai	27.2	27.2	29.9	30.2	30.2
Kia	25.3	26.0	27.0	27.9	29.1
Mazda	27.1	29.0	29.0	30.0	31.0
Mitsubishi	27.1	27.1	29.4	29.8	32.4
Nissan	25.5	25.9	27.0	27.5	28.6
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	29.4	29.8	30.8	31.6	31.7
Suzuki	24.7	29.6	29.6	29.6	30.8
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	24.9	25.5	26.8	27.5	28.6
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	24.7	25.5	26.5	27.2	28.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

5% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.1	26.2	26.3	27.2	28.4
Chrysler	24.8	26.1	28.0	28.5	30.0
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	25.0	25.8	26.4	28.7	29.0
General Motors	23.4	25.2	26.2	26.8	28.0
Honda	27.1	27.2	28.9	30.2	31.5
Hyundai	27.5	27.5	31.5	31.8	31.8
Kia	25.4	26.6	27.9	29.0	30.5
Mazda	27.8	30.1	30.1	30.9	32.6
Mitsubishi	27.1	27.1	30.6	31.3	32.8
Nissan	25.9	26.4	28.2	28.7	30.0
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	30.1	30.4	31.8	32.4	32.6
Suzuki	24.7	31.5	31.5	31.5	32.8
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	25.1	26.2	28.2	28.9	30.0
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	24.9	26.0	27.4	28.3	29.3

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

6% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.4	26.4	26.6	27.2	28.4
Chrysler	24.8	26.6	28.8	29.6	31.4
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	25.0	25.8	26.2	29.9	30.4
General Motors	23.4	26.2	27.5	28.4	29.3
Honda	28.0	28.0	30.5	31.6	33.3
Hyundai	28.2	28.2	32.0	32.7	32.7
Kia	25.7	27.1	28.6	30.2	32.5
Mazda	28.2	31.5	31.6	32.5	34.4
Mitsubishi	27.1	27.1	31.7	32.5	35.3
Nissan	26.1	26.6	28.6	29.0	31.5
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	30.3	30.8	32.7	33.3	33.5
Suzuki	24.7	32.4	32.4	32.4	33.5
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	25.3	26.8	29.1	29.9	31.5
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	25.0	26.5	28.1	29.4	30.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

7% Annual Increase

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.6	26.6	26.8	27.2	28.4
Chrysler	24.8	27.1	29.5	30.2	32.4
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	25.2	26.0	26.4	30.2	30.8
General Motors	23.4	26.6	28.4	29.6	30.2
Honda	28.4	28.4	31.1	31.7	33.5
Hyundai	28.5	28.5	32.7	33.4	33.4
Kia	25.9	27.1	28.8	31.3	34.5
Mazda	28.9	34.0	34.0	34.9	36.5
Mitsubishi	27.1	27.1	31.7	32.4	35.3
Nissan	26.2	26.6	28.6	29.0	31.6
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	30.3	30.8	33.1	33.8	33.9
Suzuki	24.7	32.4	32.4	32.4	33.5
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	25.6	27.4	30.5	31.3	33.0
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	25.2	26.9	28.8	30.1	31.4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Max Net Benefits

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.6	26.7	26.8	26.7	27.9
Chrysler	24.8	27.1	29.6	30.3	31.4
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	25.9	26.7	27.0	30.0	30.5
General Motors	23.4	26.6	28.0	28.8	29.3
Honda	29.0	28.9	31.6	32.1	33.1
Hyundai	29.5	29.5	33.3	33.5	33.5
Kia	26.1	27.0	28.8	31.2	33.0
Mazda	29.4	33.2	33.0	33.3	34.4
Mitsubishi	27.1	27.1	31.7	32.4	35.3
Nissan	26.6	27.1	29.1	29.2	31.4
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	30.9	31.4	33.0	33.7	33.9
Suzuki	24.7	33.3	33.3	33.3	34.2
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	26.3	28.2	30.3	31.0	31.5
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	25.5	27.3	28.8	29.9	30.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Total Cost=Total Benefit

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	26.6	26.7	26.8	26.7	27.9
Chrysler	24.8	27.1	29.6	30.3	32.1
Daimler	24.7	24.8	24.7	25.3	25.3
Ford	25.9	26.7	27.0	30.4	31.0
General Motors	23.4	26.9	28.5	29.6	29.9
Honda	29.1	29.1	31.9	32.4	34.1
Hyundai	29.7	29.7	33.6	33.8	33.8
Kia	26.1	27.0	28.8	31.2	33.0
Mazda	29.7	34.2	34.0	34.4	35.4
Mitsubishi	27.1	27.1	31.7	32.4	35.3
Nissan	26.6	27.0	29.0	29.2	31.4
Porsche	24.4	24.4	24.4	26.7	26.7
Subaru	30.9	31.4	33.2	33.9	34.0
Suzuki	24.7	34.2	34.2	34.2	35.1
Tata	23.8	23.9	24.1	24.3	27.9
Toyota	26.3	28.2	30.8	31.4	32.2
Volkswagen	21.1	23.8	26.3	26.2	26.2
Total/Average	25.5	27.4	29.1	30.2	31.1

VII. COST IMPACTS

The technology application algorithm implemented with the Volpe model was used as the basis for estimating costs for the fleet. The agency did estimate the costs or fines to bring passenger car manufacturers up to the MY 2011 standards from their MY 2008 levels, as shown in Table VII-1a and VII-1b for passenger cars and light trucks. These costs have been estimated, but they are not considered to be part of the costs of meeting the requirements. These costs, and commensurate benefits, are considered part of the costs and benefits of complying with previously issued rules. The estimates change from year to year to account for changes in the manufacturers' fleet based on changes in footprint. Otherwise the cost shown in MY 2012 would be consistent from MY 2012-2016.

Tables VII-2a to 2o show the estimated cost per vehicle and incremental total costs in millions for the various alternatives for passenger cars. Tables VII-3a to 3o 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.

In a confidential submission (NHTSA-2009-0059-0099), Chrysler presented a higher cost estimate than shown in Table VII-2a [ ].

Table VII-1a
Estimated Incremental Costs or Fines over Manufacturer's Plans
To get to Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	456	445	489	476	464
Chrysler	83	76	74	72	69
Daimler	362	413	570	570	555
Ford	92	91	88	102	97
General Motors	176	173	170	173	168
Honda	-	-	-	-	-
Hyundai	-	-	-	-	-
Kia	-	-	-	-	-
Mazda	-	-	-	-	-
Mitsubishi	197	191	177	168	166
Nissan	-	-	-	-	-
Porsche	661	861	849	834	818
Subaru	215	205	203	198	191
Suzuki	12	46	45	43	42
Tata	361	748	751	731	710
Toyota	-	-	-	-	-
Volkswagen	171	166	161	157	152
Total/Average	91	88	92	95	92

Table VII-1b
Estimated Incremental Costs or Fines over Manufacturer's Plans To get to Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	273	272	265	253	249
Chrysler	490	470	463	453	442
Daimler	729	714	708	805	785
Ford	495	460	455	449	439
General Motors	498	487	497	472	459
Honda	108	124	119	112	110
Hyundai	100	96	93	90	87
Kia	144	136	133	129	126
Mazda	12	10	10	10	9
Mitsubishi	489	469	463	464	451
Nissan	492	461	458	453	442
Porsche	1,059	1,033	1,009	1,146	1,115
Subaru	63	57	51	42	40
Suzuki	621	717	700	684	668
Tata	903	890	923	949	1,709
Toyota	91	97	91	85	82
Volkswagen	395	1,084	1,387	1,364	1,333
Total/Average	367	367	367	356	353

Table VII-2a
Estimated Incremental Costs or Fines over Adjusted Baseline Average Cost per Vehicle (2007 Dollars)
Passenger Cars

Preferred Alternative
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	157	196	255	443	855
Chrysler	794	1,043	1,129	1,270	1,358
Daimler	160	198	564	944	1,252
Ford	1,641	1,537	1,533	1,713	1,884
General Motors	552	896	1,127	1,302	1,323
Honda	33	98	205	273	456
Hyundai	559	591	768	744	838
Kia	110	144	177	235	277
Mazda	632	656	799	854	923
Mitsubishi	644	620	1,588	1,875	1,831
Nissan	119	323	707	723	832
Porsche	316	251	307	390	496
Subaru	413	472	988	1,385	1,361
Suzuki	242	625	779	794	1,005
Tata	243	258	370	532	924
Toyota	31	29	41	121	126
Volkswagen	293	505	587	668	964
Total/Average	505	573	690	799	907

Table VII-2b
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

Preferred Alternative
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	45.5	57.7	94.4	182.2	361.4
Chrysler	325.3	444.7	464.5	498.2	542.8
Daimler	33.8	40.1	137.8	249.0	339.3
Ford	2,408.9	2,283.1	2,403.0	2,642.2	2,937.0
General Motors	875.6	1,383.9	1,637.5	1,936.6	2,003.9
Honda	30.3	104.1	223.1	249.5	424.1
Hyundai	210.4	233.7	303.7	380.1	434.3
Kia	33.0	47.0	75.8	126.8	151.9
Mazda	178.8	216.3	302.2	352.8	388.0
Mitsubishi	71.0	64.8	140.0	154.3	151.4
Nissan	97.9	268.7	603.7	669.2	787.1
Porsche	13.0	10.8	10.4	12.7	16.5
Subaru	75.7	82.8	182.3	283.5	281.5
Suzuki	17.5	51.1	70.6	79.9	103.6
Tata	8.8	13.0	18.2	33.9	60.5
Toyota	50.0	56.6	85.4	263.4	279.5
Volkswagen	127.3	251.6	304.2	379.2	562.2
Total/Average	4,602.7	5,610.1	7,056.8	8,493.8	9,825.0

Table VII-2c
Estimated Incremental Costs or Fines over Adjusted Baseline Average Cost per Vehicle (2007 Dollars)
Passenger Cars

3% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	69	114	178	349	728
Chrysler	335	445	481	571	695
Daimler	77	121	492	851	1,137
Ford	292	461	467	621	754
General Motors	470	555	667	781	857
Honda	-	-	31	90	131
Hyundai	211	261	412	372	467
Kia	4	26	102	152	205
Mazda	273	308	462	516	538
Mitsubishi	550	582	1,106	1,241	1,218
Nissan	6	53	229	263	361
Porsche	217	178	213	275	342
Subaru	319	379	767	842	824
Suzuki	143	267	334	342	521
Tata	161	188	298	438	809
Toyota	-	-	-	-	24
Volkswagen	200	429	505	563	832
Total/Average	191	248	317	394	493

Table VII-2d
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

3% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	20.0	33.5	65.9	143.7	307.9
Chrysler	137.2	189.7	197.7	224.2	278.0
Daimler	16.3	24.5	120.3	224.4	308.0
Ford	429.2	685.6	732.5	957.4	1,175.1
General Motors	744.8	856.7	969.3	1,161.4	1,297.1
Honda	-	-	33.5	82.1	122.3
Hyundai	79.4	103.4	162.9	190.2	242.3
Kia	1.2	8.5	43.5	82.1	112.1
Mazda	77.3	101.8	174.7	213.1	226.4
Mitsubishi	60.7	60.9	97.5	102.1	100.7
Nissan	4.6	44.0	195.6	243.6	341.7
Porsche	8.9	7.7	7.2	8.9	11.4
Subaru	58.6	66.4	141.4	172.5	170.5
Suzuki	10.3	21.9	30.2	34.5	53.6
Tata	5.8	9.5	14.7	27.9	53.0
Toyota	-	-	-	-	53.0
Volkswagen	86.7	213.9	261.4	319.8	485.3
Total/Average	1,741.1	2,427.9	3,248.3	4,188.0	5,338.3

Table VII-2e
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

4% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	86	147	228	421	822
Chrysler	499	860	952	1,082	1,137
Daimler	94	149	542	922	1,219
Ford	425	686	710	955	1,138
General Motors	486	712	932	1,141	1,239
Honda	33	27	134	220	343
Hyundai	506	521	751	734	838
Kia	8	71	169	209	210
Mazda	560	637	860	915	922
Mitsubishi	567	612	1,511	1,706	1,670
Nissan	16	122	554	653	739
Porsche	233	196	274	363	457
Subaru	336	417	827	1,206	1,184
Suzuki	160	412	559	582	798
Tata	177	214	348	510	897
Toyota	21	20	34	122	205
Volkswagen	216	455	560	641	931
Total/Average	254	366	500	640	764

Table VII-2f
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

4% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	24.8	43.1	84.3	173.2	347.4
Chrysler	204.5	366.8	391.7	424.8	454.3
Daimler	19.8	30.1	132.5	243.2	330.4
Ford	623.3	1,018.5	1,113.0	1,472.5	1,773.7
General Motors	771.0	1,099.3	1,354.0	1,696.7	1,875.6
Honda	30.3	29.3	146.2	200.5	319.5
Hyundai	190.4	206.2	296.9	375.4	434.5
Kia	2.5	23.3	72.2	112.8	115.2
Mazda	158.6	210.1	325.4	378.3	387.5
Mitsubishi	62.5	63.9	133.2	140.4	138.1
Nissan	13.0	101.8	473.1	604.5	699.5
Porsche	9.6	8.5	9.3	11.8	15.2
Subaru	61.6	73.1	152.5	246.8	244.9
Suzuki	11.5	33.7	50.6	58.6	82.2
Tata	6.4	10.8	17.1	32.5	58.7
Toyota	34.2	39.3	71.2	265.1	456.8
Volkswagen	93.9	227.0	290.0	363.6	543.0
Total/Average	2,317.8	3,584.8	5,113.1	6,800.8	8,276.5

Table VII-2g
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

5% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	102	180	283	498	915
Chrysler	745	1,303	1,462	1,653	1,727
Daimler	110	182	591	988	1,313
Ford	743	1,245	1,261	1,583	1,923
General Motors	503	823	1,187	1,425	1,594
Honda	50	109	271	375	606
Hyundai	747	882	1,057	1,052	1,124
Kia	49	128	197	261	369
Mazda	577	718	1,166	1,407	1,427
Mitsubishi	583	650	2,534	3,213	3,141
Nissan	294	491	965	1,064	1,125
Porsche	255	234	340	456	578
Subaru	358	456	1,372	1,723	1,679
Suzuki	182	959	1,267	1,316	1,540
Tata	194	247	403	581	990
Toyota	31	29	52	129	212
Volkswagen	233	494	620	723	1,041
Total/Average	362	558	749	918	1,088

Table VII-2h
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

5% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	29.6	52.8	104.6	204.9	387.0
Chrysler	305.0	555.4	601.5	648.8	690.2
Daimler	23.3	36.8	144.6	260.7	355.7
Ford	1,091.0	1,849.2	1,977.1	2,441.5	2,998.2
General Motors	797.1	1,271.7	1,723.6	2,119.1	2,413.3
Honda	45.1	115.9	294.3	342.1	563.9
Hyundai	281.1	349.0	418.1	538.0	582.7
Kia	14.7	42.0	84.0	140.5	202.1
Mazda	163.2	236.8	441.1	581.5	599.9
Mitsubishi	64.3	68.0	223.4	264.4	259.7
Nissan	242.2	408.5	823.8	984.9	1,065.0
Porsche	10.5	10.1	11.6	14.8	19.3
Subaru	65.6	79.9	253.1	352.8	347.4
Suzuki	13.1	78.4	114.8	132.3	158.6
Tata	7.0	12.5	19.9	37.1	64.8
Toyota	50.0	56.6	107.7	279.8	472.8
Volkswagen	101.1	246.2	321.3	410.4	607.1
Total/Average	3,303.9	5,469.6	7,664.3	9,753.6	11,787.6

Table VII-2i
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

6% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	119	218	338	575	1,020
Chrysler	761	1,964	2,470	2,800	2,795
Daimler	127	215	646	1,060	1,406
Ford	1,435	1,749	1,886	2,344	2,707
General Motors	519	1,026	1,457	1,965	2,182
Honda	50	191	386	470	845
Hyundai	731	845	1,277	1,175	1,315
Kia	39	140	268	386	597
Mazda	593	756	1,534	2,110	2,279
Mitsubishi	605	642	2,688	2,934	2,933
Nissan	679	899	1,755	1,851	1,997
Porsche	277	278	406	550	699
Subaru	374	494	2,093	2,736	2,692
Suzuki	198	1,186	1,589	1,629	1,816
Tata	210	280	452	653	1,084
Toyota	97	93	119	266	404
Volkswagen	249	527	675	806	1,151
Total/Average	526	758	1,064	1,321	1,546

Table VII-2j
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

6% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	34.4	64.2	125.0	236.6	431.1
Chrysler	311.7	837.5	1,015.9	1,098.8	1,117.1
Daimler	26.8	43.4	158.0	279.5	381.0
Ford	2,106.8	2,598.6	2,956.3	3,615.3	4,220.7
General Motors	823.3	1,585.1	2,115.6	2,922.7	3,304.9
Honda	45.5	203.8	419.4	428.7	786.5
Hyundai	275.2	334.3	505.1	600.6	681.5
Kia	11.8	45.8	114.7	208.1	326.9
Mazda	167.9	249.3	580.3	872.2	958.1
Mitsubishi	66.8	67.1	236.9	241.5	242.5
Nissan	559.3	747.9	1,498.5	1,712.6	1,890.5
Porsche	11.4	12.0	13.8	17.8	23.3
Subaru	68.7	86.6	386.2	560.2	556.9
Suzuki	14.3	97.0	144.0	163.9	187.0
Tata	7.6	14.1	22.3	41.6	71.0
Toyota	155.1	181.4	247.5	579.6	899.2
Volkswagen	108.2	262.6	349.8	457.3	671.3
Total/Average	4,794.8	7,430.9	10,889.2	14,037.0	16,749.7

Table VII-2k
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

7% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	135	251	393	652	1,124
Chrysler	778	2,195	2,696	3,064	3,096
Daimler	138	248	696	1,131	1,500
Ford	1,619	1,902	2,079	2,559	2,990
General Motors	536	1,248	1,912	2,417	2,904
Honda	50	454	737	804	1,181
Hyundai	770	911	1,493	1,464	1,750
Kia	55	251	489	698	963
Mazda	610	1,013	2,097	2,299	2,704
Mitsubishi	622	675	2,758	3,098	3,182
Nissan	867	1,280	2,356	2,482	2,574
Porsche	294	317	472	643	831
Subaru	391	533	1,844	2,629	2,711
Suzuki	220	2,182	3,127	3,294	3,331
Tata	221	313	507	724	1,183
Toyota	295	276	371	574	774
Volkswagen	271	565	736	894	1,267
Total/Average	616	952	1,361	1,634	1,941

Table VII-2l
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

7% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	39.1	73.8	145.3	268.3	475.3
Chrysler	318.5	935.8	1,109.0	1,202.4	1,237.7
Daimler	29.1	50.1	170.1	298.4	406.4
Ford	2,376.6	2,825.5	3,259.6	3,946.3	4,662.1
General Motors	849.5	1,927.5	2,777.0	3,594.5	4,398.3
Honda	45.5	483.5	801.3	733.5	1,099.0
Hyundai	289.8	360.4	590.4	748.4	907.0
Kia	16.5	81.8	208.8	375.9	527.5
Mazda	172.6	334.0	793.1	950.0	1,136.8
Mitsubishi	68.6	70.5	243.1	255.0	263.1
Nissan	714.6	1,064.1	2,012.0	2,296.6	2,435.8
Porsche	12.1	13.7	16.0	20.9	27.7
Subaru	71.7	93.4	340.2	538.3	561.0
Suzuki	15.9	178.5	283.3	331.4	343.1
Tata	8.0	15.8	25.0	46.2	77.5
Toyota	470.0	536.5	770.8	1,249.3	1,722.8
Volkswagen	117.8	281.8	381.1	507.2	738.6
Total/Average	5,615.8	9,326.9	13,926.3	17,362.4	21,019.7

Table VII-2m
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

Max Net Benefits
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	141	301	426	619	1,020
Chrysler	778	2,159	2,452	2,660	2,608
Daimler	143	292	723	1,104	1,406
Ford	1,624	1,962	2,149	2,545	2,891
General Motors	536	1,292	1,939	2,235	2,400
Honda	49	365	562	609	891
Hyundai	757	945	1,304	1,196	1,321
Kia	48	264	422	503	602
Mazda	615	1,219	1,654	2,171	2,437
Mitsubishi	622	730	2,787	3,077	3,072
Nissan	882	1,229	2,080	2,086	2,104
Porsche	299	372	510	605	699
Subaru	396	582	1,961	2,589	2,580
Suzuki	226	1,248	1,649	1,721	1,876
Tata	227	357	535	697	1,084
Toyota	264	242	327	414	464
Volkswagen	271	620	769	855	1,151
Total/Average	612	954	1,282	1,460	1,628

Table VII-2n
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

Max Net Benefits
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	40.7	88.4	157.5	254.7	431.1
Chrysler	318.5	920.5	1,008.7	1,044.1	1,042.3
Daimler	30.3	59.0	176.8	291.1	381.0
Ford	2,384.6	2,914.3	3,368.6	3,924.9	4,507.0
General Motors	849.5	1,995.5	2,816.9	3,323.3	3,633.9
Honda	44.1	389.1	610.9	555.4	828.4
Hyundai	284.7	373.8	515.6	611.7	684.6
Kia	14.3	86.2	180.5	271.2	330.0
Mazda	174.1	402.0	625.5	897.2	1,024.7
Mitsubishi	68.6	76.3	245.7	253.2	254.0
Nissan	727.1	1,021.8	1,776.2	1,930.7	1,991.5
Porsche	12.3	16.1	17.4	19.6	23.3
Subaru	72.7	102.0	361.9	530.0	533.7
Suzuki	16.3	102.0	149.4	173.1	193.2
Tata	8.2	18.0	26.4	44.4	71.0
Toyota	420.2	470.7	679.9	901.0	1,033.5
Volkswagen	117.8	309.2	398.2	485.4	671.3
Total/Average	5,584.0	9,345.0	13,115.9	15,511.1	17,634.6

Table VII-2o
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Passenger Cars

Total Cost = Total Benefit
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	163	334	481	685	1,091
Chrysler	800	2,057	2,483	2,634	2,639
Daimler	165	325	773	1,164	1,472
Ford	1,646	1,966	2,198	2,612	2,947
General Motors	558	1,325	1,994	2,455	2,871
Honda	50	630	873	917	1,192
Hyundai	757	984	1,494	1,415	1,569
Kia	131	354	604	750	847
Mazda	637	1,257	1,709	2,248	2,489
Mitsubishi	649	768	2,847	3,143	3,154
Nissan	958	1,451	2,278	2,288	2,549
Porsche	327	416	576	687	793
Subaru	424	626	2,022	2,726	2,777
Suzuki	253	2,043	2,420	2,496	2,550
Tata	249	390	584	763	1,155
Toyota	496	465	622	727	772
Volkswagen	299	659	829	932	1,228
Total/Average	675	1,065	1,440	1,653	1,878

Table VII-2p
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Passenger Cars

Total Cost = Total Benefit
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	47.1	98.1	177.9	281.8	461.4
Chrysler	327.5	877.2	1,021.3	1,033.6	1,055.0
Daimler	34.9	65.7	188.9	307.1	398.9
Ford	2,416.9	2,920.9	3,445.3	4,029.2	4,595.3
General Motors	884.4	2,046.5	2,896.8	3,651.8	4,348.3
Honda	45.5	670.5	949.5	837.0	1,108.5
Hyundai	284.7	389.1	590.8	723.1	813.5
Kia	39.1	115.7	257.9	404.2	464.1
Mazda	180.3	414.7	646.3	929.0	1,046.7
Mitsubishi	71.6	80.3	251.0	258.7	260.8
Nissan	789.1	1,206.2	1,945.5	2,117.4	2,412.6
Porsche	13.4	18.0	19.6	22.3	26.4
Subaru	77.7	109.7	373.0	558.2	574.6
Suzuki	18.3	167.0	219.2	251.1	262.6
Tata	9.0	19.7	28.8	48.6	75.6
Toyota	788.5	903.3	1,292.2	1,581.4	1,718.4
Volkswagen	129.7	328.4	429.6	529.1	716.2
Total/Average	6,157.9	10,431.1	14,733.6	17,563.5	20,339.0

Table VII-3a
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

Preferred Alternative
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	252	272	338	402	827
Chrysler	409	527	876	931	1,170
Daimler	98	123	155	189	260
Ford	465	633	673	1,074	1,174
General Motors	336	513	749	807	986
Honda	233	217	370	457	806
Hyundai	693	630	1,148	1,136	1,113
Kia	406	467	582	780	1,137
Mazda	144	241	250	354	480
Mitsubishi	39	77	553	686	1,371
Nissan	398	489	970	1,026	1,362
Porsche	44	76	109	568	640
Subaru	1,036	995	1,016	1,060	1,049
Suzuki	66	1,797	1,744	1,689	1,732
Tata	66	110	137	198	690
Toyota	130	150	384	499	713
Volkswagen	44	77	552	557	606
Total/Average	322	416	621	752	961

Table VII-3b
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

Preferred Alternative
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	51.4	49.9	64.5	70.5	141.2
Chrysler	283.4	313.0	451.2	442.5	540.6
Daimler	10.6	14.0	21.2	24.6	32.8
Ford	396.3	595.1	649.5	1,006.4	1,069.1
General Motors	506.9	787.9	1,001.2	1,113.6	1,322.7
Honda	148.0	146.7	235.0	256.3	439.2
Hyundai	40.3	63.9	119.2	107.4	102.4
Kia	35.6	48.0	66.6	92.4	130.9
Mazda	8.8	15.6	17.0	26.3	34.7
Mitsubishi	1.9	3.6	29.2	39.0	75.8
Nissan	161.2	191.4	393.9	401.8	518.8
Porsche	0.6	1.1	1.8	9.7	10.7
Subaru	101.5	89.5	100.8	123.0	123.0
Suzuki	0.3	29.8	35.0	34.7	34.6
Tata	2.0	3.7	5.5	8.7	29.3
Toyota	115.6	148.6	420.4	552.2	767.5
Volkswagen	4.6	10.9	83.9	71.2	75.4
Total/Average	1,868.8	2,512.7	3,695.8	4,380.4	5,448.7

Table VII-3c

Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

3% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	96	106	179	463	867
Chrysler	-	29	242	315	477
Daimler	49	66	89	112	155
Ford	146	295	364	725	720
General Motors	(213)	(52)	94	165	292
Honda	135	121	204	263	452
Hyundai	216	227	607	620	611
Kia	-	19	195	323	675
Mazda	47	62	71	85	215
Mitsubishi	-	-	154	215	478
Nissan	67	111	356	423	632
Porsche	(28)	11	43	486	535
Subaru	385	396	377	396	397
Suzuki	(11)	782	735	708	709
Tata	(11)	33	66	110	575
Toyota	15	21	214	281	454
Volkswagen	(28)	11	514	480	507
Total/Average	1	78	234	348	484

Table VII-3d
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

3% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	19.7	19.5	34.3	81.4	148.1
Chrysler	-	17.4	124.7	149.5	220.6
Daimler	5.3	7.6	12.2	14.6	19.6
Ford	124.5	277.2	351.1	679.0	655.9
General Motors	(321.9)	(79.3)	125.5	227.3	391.4
Honda	85.4	82.0	129.7	147.5	246.5
Hyundai	12.5	23.1	63.0	58.6	56.2
Kia	-	1.9	22.3	38.2	77.7
Mazda	2.9	4.0	4.8	6.3	15.5
Mitsubishi	-	-	8.1	12.3	26.4
Nissan	27.2	43.4	144.7	165.8	240.6
Porsche	(0.4)	0.2	0.7	8.3	8.9
Subaru	37.7	35.6	37.5	45.9	46.5
Suzuki	(0.1)	12.9	14.7	14.5	14.2
Tata	(0.3)	1.1	2.7	4.8	24.4
Toyota	13.7	20.9	234.8	311.6	488.8
Volkswagen	(2.9)	1.6	78.1	61.4	63.1
Total/Average	3.4	469.1	1,388.8	2,027.0	2,744.3

Table VII-3e
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

4% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	103	140	218	524	939
Chrysler	130	287	610	678	867
Daimler	49	94	133	173	232
Ford	512	796	850	1,262	1,266
General Motors	-	196	373	432	609
Honda	226	207	407	468	695
Hyundai	554	561	1,201	1,208	1,182
Kia	-	136	331	447	798
Mazda	82	179	177	305	383
Mitsubishi	-	33	471	532	1,238
Nissan	315	381	741	839	1,153
Porsche	(17)	39	87	546	612
Subaru	946	967	981	1,028	1,017
Suzuki	-	812	764	736	993
Tata	-	60	116	176	663
Toyota	15	30	329	465	729
Volkswagen	(11)	39	530	535	579
Total/Average	166	293	506	646	830

Table VII-3f
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

4% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	21.1	25.7	41.6	92.0	160.3
Chrysler	90.1	170.8	313.9	322.4	400.8
Daimler	5.3	10.7	18.2	22.4	29.3
Ford	436.1	748.4	820.6	1,182.0	1,153.2
General Motors	-	301.3	498.2	596.4	816.6
Honda	143.3	140.2	258.2	262.5	378.7
Hyundai	32.2	57.0	124.7	114.3	108.7
Kia	-	14.0	37.9	52.9	91.8
Mazda	5.0	11.6	12.0	22.6	27.6
Mitsubishi	-	1.5	24.9	30.2	68.5
Nissan	127.6	149.2	301.0	328.6	439.0
Porsche	(0.2)	0.6	1.4	9.4	10.2
Subaru	92.7	87.0	97.4	119.2	119.2
Suzuki	-	13.4	15.3	15.1	19.8
Tata	-	2.0	4.7	7.7	28.2
Toyota	13.3	29.5	360.4	514.8	784.4
Volkswagen	(1.2)	5.4	80.6	68.4	72.0
Total/Average	965.2	1,768.4	3,011.0	3,761.0	4,708.3

Table VII-3g
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

5% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	169	209	316	591	1,028
Chrysler	365	559	1,120	1,216	1,432
Daimler	60	116	177	233	309
Ford	1,207	1,663	1,882	2,258	2,225
General Motors	297	628	866	968	1,136
Honda	258	234	611	750	1,047
Hyundai	711	685	1,923	1,909	1,862
Kia	47	293	556	782	1,157
Mazda	248	408	419	519	768
Mitsubishi	-	66	1,037	1,189	1,556
Nissan	613	723	2,142	2,148	2,315
Porsche	-	66	131	612	695
Subaru	1,225	1,220	1,365	1,374	1,357
Suzuki	16	1,998	1,895	1,837	2,096
Tata	17	94	165	242	751
Toyota	63	187	594	734	991
Volkswagen	-	66	574	596	661
Total/Average	417	633	1,036	1,186	1,361

Table VII-3h
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

5% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	34.5	38.4	60.4	103.7	175.4
Chrysler	252.9	332.0	576.5	577.9	662.0
Daimler	6.5	13.3	24.2	30.3	39.0
Ford	1,028.4	1,563.5	1,817.0	2,115.4	2,026.6
General Motors	448.7	964.5	1,158.1	1,336.1	1,523.8
Honda	163.6	158.3	387.9	420.4	570.6
Hyundai	41.4	69.5	199.7	180.6	171.3
Kia	4.1	30.1	63.6	92.5	133.2
Mazda	15.1	26.5	28.4	38.5	55.4
Mitsubishi	-	3.0	54.8	67.6	86.1
Nissan	248.4	283.0	869.7	841.4	881.9
Porsche	-	1.0	2.1	10.5	11.6
Subaru	120.0	109.8	135.5	159.4	159.2
Suzuki	0.1	33.1	38.0	37.7	41.9
Tata	0.5	3.2	6.6	10.6	31.9
Toyota	55.8	185.1	650.8	812.7	1,066.6
Volkswagen	-	9.3	87.3	76.2	82.2
Total/Average	2,420.0	3,823.5	6,160.6	6,911.7	7,718.6

Table VII-3i
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

6% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	242	301	411	657	1,115
Chrysler	382	672	1,412	1,665	2,062
Daimler	71	139	221	294	392
Ford	1,149	1,662	1,684	2,596	2,723
General Motors	308	1,268	1,655	1,976	2,163
Honda	786	675	1,368	1,531	2,032
Hyundai	1,517	1,430	2,398	2,442	2,434
Kia	123	979	1,179	1,654	1,990
Mazda	302	622	637	785	1,031
Mitsubishi	-	99	2,082	2,130	2,747
Nissan	989	1,136	2,525	2,481	3,194
Porsche	11	93	181	678	777
Subaru	1,254	1,225	1,466	1,507	1,562
Suzuki	33	3,317	2,987	2,928	3,152
Tata	33	127	215	314	844
Toyota	98	338	797	952	1,315
Volkswagen	17	99	618	662	744
Total/Average	516	943	1,394	1,706	2,007

Table VII-3j
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

6% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	49.4	55.2	78.6	115.3	190.4
Chrysler	264.3	399.2	726.9	791.5	952.8
Daimler	7.7	15.9	30.2	38.1	49.4
Ford	978.7	1,562.8	1,626.1	2,431.8	2,480.1
General Motors	465.3	1,948.3	2,212.4	2,726.4	2,901.6
Honda	498.7	456.5	867.9	858.4	1,107.9
Hyundai	88.2	145.1	249.0	231.1	223.8
Kia	10.8	100.6	134.9	195.8	229.1
Mazda	18.4	40.3	43.1	58.3	74.4
Mitsubishi	-	4.6	110.0	121.2	151.9
Nissan	400.6	444.8	1,025.0	972.0	1,216.4
Porsche	0.1	1.4	2.9	11.6	13.0
Subaru	122.8	110.1	145.5	174.9	183.2
Suzuki	0.2	54.9	59.9	60.2	63.0
Tata	1.0	4.3	8.6	13.7	35.9
Toyota	86.8	335.0	873.3	1,054.0	1,415.6
Volkswagen	1.7	14.0	94.0	84.6	92.5
Total/Average	2,994.7	5,693.1	8,288.4	9,938.9	11,381.2

Table VII-3k
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

7% Annual Increase
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	303	376	509	728	1,203
Chrysler	393	1,603	2,145	2,379	3,014
Daimler	87	167	265	354	474
Ford	1,250	1,694	1,657	2,911	3,263
General Motors	319	1,682	2,247	2,868	3,030
Honda	940	819	1,774	1,943	2,479
Hyundai	1,601	1,515	2,433	2,514	2,558
Kia	151	1,007	1,289	2,449	3,050
Mazda	985	1,984	1,940	2,027	2,382
Mitsubishi	17	132	2,078	2,262	3,101
Nissan	1,003	1,172	2,297	2,415	3,195
Porsche	27	126	225	744	871
Subaru	1,260	1,230	1,579	1,624	1,740
Suzuki	49	3,442	2,889	2,882	3,146
Tata	50	160	264	391	943
Toyota	164	572	1,221	1,359	1,703
Volkswagen	28	127	662	722	826
Total/Average	575	1,222	1,716	2,181	2,549

Table VII-3l
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

7% Annual Increase
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	61.8	69.1	97.2	127.9	205.5
Chrysler	271.9	952.1	1,104.1	1,130.6	1,392.6
Daimler	9.4	19.1	36.2	46.0	59.9
Ford	1,064.4	1,592.7	1,599.7	2,726.6	2,972.3
General Motors	482.0	2,583.3	3,003.5	3,957.2	4,064.4
Honda	596.9	554.1	1,125.9	1,089.4	1,351.8
Hyundai	93.1	153.8	252.7	237.9	235.3
Kia	13.2	103.4	147.4	290.0	351.1
Mazda	59.9	128.5	131.5	150.4	171.9
Mitsubishi	0.8	6.1	109.8	128.7	171.6
Nissan	406.4	459.0	932.5	946.1	1,217.0
Porsche	0.4	1.8	3.6	12.8	14.5
Subaru	123.4	110.7	156.7	188.5	204.1
Suzuki	0.2	57.0	58.0	59.2	62.8
Tata	1.5	5.4	10.6	17.1	40.1
Toyota	145.5	566.3	1,338.3	1,504.4	1,833.8
Volkswagen	2.9	17.9	100.7	92.3	102.7
Total/Average	3,333.6	7,380.3	10,208.4	12,705.0	14,451.3

Table VII-3m
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

Max Net Benefits
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	314	383	491	567	976
Chrysler	459	1,482	2,154	2,371	2,512
Daimler	153	216	293	343	392
Ford	1,386	1,794	1,738	2,500	2,566
General Motors	380	1,356	1,703	2,021	2,095
Honda	1,043	908	1,883	2,013	2,159
Hyundai	1,183	1,118	2,177	2,183	2,131
Kia	461	964	1,309	2,437	2,692
Mazda	855	1,399	1,321	1,407	1,505
Mitsubishi	94	187	2,100	2,251	2,802
Nissan	1,117	1,229	2,391	2,443	2,925
Porsche	94	175	252	728	783
Subaru	1,366	1,311	1,556	1,594	1,621
Suzuki	127	2,328	2,212	2,151	2,265
Tata	121	214	297	374	850
Toyota	936	1,208	1,498	1,613	1,711
Volkswagen	94	176	690	711	744
Total/Average	761	1,249	1,665	1,948	2,082

Table VII-3n
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

Max Net Benefits
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	64.2	70.3	93.8	99.5	166.6
Chrysler	317.6	880.7	1,109.0	1,126.8	1,160.9
Daimler	16.6	24.7	40.0	44.6	49.4
Ford	1,180.8	1,686.7	1,678.3	2,341.5	2,336.6
General Motors	573.4	2,082.6	2,276.5	2,789.0	2,810.9
Honda	662.1	614.2	1,194.7	1,128.8	1,177.0
Hyundai	68.8	113.5	226.1	206.5	196.0
Kia	40.4	99.0	149.7	288.5	309.8
Mazda	51.9	90.6	89.5	104.4	108.6
Mitsubishi	4.5	8.6	111.0	128.1	155.0
Nissan	452.4	481.1	970.6	957.1	1,114.0
Porsche	1.2	2.6	4.0	12.5	13.0
Subaru	133.8	117.9	154.5	185.0	190.2
Suzuki	0.6	38.5	44.4	44.2	45.2
Tata	3.6	7.2	12.0	16.3	36.1
Toyota	829.9	1,196.7	1,641.8	1,785.8	1,842.4
Volkswagen	9.8	24.9	104.8	90.9	92.5
Total/Average	4,411.6	7,539.9	9,900.7	11,349.5	11,804.4

Table VII-3o
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2007 Dollars)
Light Trucks

Total Cost = Total Benefit
Average Cost per Vehicle

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	320	399	530	600	1,020
Chrysler	464	1,504	2,184	2,405	2,713
Daimler	153	233	326	371	430
Ford	1,386	1,811	1,766	2,645	2,942
General Motors	380	1,583	2,035	2,558	2,597
Honda	1,052	927	1,939	2,073	2,390
Hyundai	1,825	1,620	2,670	2,682	2,649
Kia	466	980	1,342	2,464	2,692
Mazda	2,121	3,292	2,849	2,964	3,035
Mitsubishi	99	209	2,139	2,279	3,052
Nissan	1,062	1,197	2,389	2,436	2,929
Porsche	99	197	291	755	821
Subaru	1,366	1,311	1,638	1,697	1,741
Suzuki	127	3,242	2,947	2,885	2,995
Tata	127	237	336	407	894
Toyota	942	1,208	1,605	1,689	1,855
Volkswagen	99	193	723	739	782
Total/Average	780	1,344	1,806	2,157	2,366

Table VII-3p
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2007 Dollars)
Light Trucks

Total Cost = Total Benefit
Total Incremental Costs

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	65.3	73.3	101.1	105.3	174.1
Chrysler	321.4	893.7	1,124.2	1,143.2	1,253.5
Daimler	16.6	26.6	44.5	48.1	54.3
Ford	1,180.8	1,702.2	1,704.8	2,478.0	2,679.8
General Motors	573.4	2,431.0	2,720.6	3,528.8	3,484.3
Honda	667.7	627.1	1,230.7	1,162.4	1,303.1
Hyundai	106.1	164.5	277.3	253.7	243.7
Kia	40.9	100.7	153.5	291.7	309.8
Mazda	128.9	213.2	193.1	220.0	219.0
Mitsubishi	4.8	9.7	113.0	129.6	168.8
Nissan	430.2	468.8	970.2	954.2	1,115.4
Porsche	1.3	2.9	4.7	12.9	13.7
Subaru	133.8	117.9	162.6	197.0	204.2
Suzuki	0.6	53.7	59.1	59.3	59.8
Tata	3.8	8.0	13.5	17.8	38.0
Toyota	834.7	1,196.7	1,759.3	1,869.6	1,996.7
Volkswagen	10.4	27.2	109.9	94.5	97.3
Total/Average	4,520.5	8,117.4	10,742.1	12,566.3	13,415.5

Technology Costs

Table V-5 above provides the technology cost estimates used in this analysis. The technology cost estimates are intended to represent manufacturers' direct costs for high-volume production of vehicles with these technologies and sufficient experience with their application so that all cost reductions due to "learning curve" effects have been fully realized. Costs are then modified by applying indirect cost multipliers ranging from 1.11 to 1.64 to the estimates of vehicle manufacturers' direct costs for producing or acquiring each technology to improve fuel economy, depending on the complexity of the technology and the time frame over which costs are estimated. Chapter V also discusses technology cost issues in much more detail.

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.[203] The NAS study estimated "constant performance 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. A fuller discussion of this issue is presented in Chapter VIII.

Financial Impacts of Raising CAFE Standards

The automobile industry is currently experiencing substantial economic hardship, even in the absence of new fuel economy standards. Many major firms have announced a steady stream of

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[203] National Academy of Sciences, ***Costs and Effectiveness of Increasing Corporate Average Fuel Economy Standards***, 2002.

plant closings, layoffs, and employment of new employees at reduced wages. NHTSA believes these hardships have much to do with the condition of the national economy and perhaps the price of gasoline, and little, if anything, to do with the stringency of CAFE standards for the current or recent model years. We believe that given the scale of the recent decline in industry sales, and the restrictiveness of private credit markets, that near-term developments will be compelled by the industry's immediate financial situation, rather than by the long-term financial consequences of this rulemaking.

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 improvements in fleet fuel economy required by this rule are consistent with the pressure induced by changing consumer preferences.

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.

On May 19, 2009, President Obama announced a National Fuel Efficiency Policy.[204] This policy reflected a consensus among stakeholders (including 14 automobile companies) on desirable and achievable fuel economy standards. We believe that this consensus reflects the view of the industry that given current economic conditions, and in the light of Federal assistance proffered via various means, that the standards finalized here are economically practicable.

On the other hand, the agency is mindful that CAFE standards do affect the relative competitiveness of different vehicle manufacturers, and recognizes that standards more stringent than those promulgated here could have a more detrimental effect.

NHTSA's central problem is to determine what new standards might be economically practicable within the MY 2012-2016 time frame, given the state of both the domestic and the international auto industries. The complexity of an economic practicability determination has been materially increased by the substantial financial assistance provided to the automobile industry by the U.S. Government. In addition to the large sums provided to Chrysler and GM, Congress has appropriated $7.5 billion (to support a maximum of $25 billion in loans under Section 136 of EISA to support the development of advanced technology vehicles and components in the United States.[205] On June 23, 2009, the Department of Energy announced the first three loans under this program: $5.9 billion for Ford for advanced vehicle manufacturing,

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[204] The White House, "President Obama Announces National Fuel Efficiency Policy," May 19, 2009. *Available at* http://www.whitehouse.gov/the_press_office/President-Obama-Announces-National-Fuel-Efficiency-Policy/. (last accessed March 4, 2010).

[205205] The authorizing language for this provision is in Section 136 of EISA. This language is amended and funds are appropriated in the Emergency Economic Stabilization Act of 2008 (H.R. 1424, Pub.L. 110-343). *See also* the DOE Advanced Technology Vehicle Manufacturing Loan Program website: http://www.atvmloan.energy.gov/ (last accessed March 15, 2010).

$1.3 billion for Nissan for vehicle and battery manufacturing, and $0.5 billion for electric vehicle start-up Tesla Motors.[206]

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 final MY 2012-2016 standards are "within the financial capability of the industry, but not so stringent as to threaten substantial economic hardship for the industry," no matter who contributes the funds. We have set the MY 2012-2016 CAFE standards so that they are both technologically and economically feasible. In principle, most vehicles meeting the standard will provide social benefits to the public at large and private benefits to automobile owners greater than their extra cost.

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 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.

NHTSA further considers the sales and employment impacts of the final standards on individual manufacturers as part of its efforts to determine whether the standards are economically practicable. The sales analysis looks at a purchasing decision from the eyes of a knowledgeable and rational consumer, comparing the estimated cost increase versus the payback in fuel savings over 5 years (the average new vehicle loan) for each manufacturer. This relationship depends on the cost-effectiveness of technologies available to each manufacturer based on a 3 percent discount rate for future fuel savings.

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.

The Impact of Higher Prices on Sales and Employment

The effect of this rule on sales of new vehicles depends partly 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, which by itself would discourage sales. At the same time, the rule will require manufacturers to improve the fuel economy of at least some of their models, which will lower their operating costs.

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[206] US Department of Energy, "Obama Administration Awards First Three Auto Loans for Advanced Technologies to Ford Motor Company, Nissan Motors and Tesla Motors," June 23, 2009. Available at: http://www.atvmloan.energy.gov/ (last accessed March 15, 2010).

However, this rule will *not* change the way that potential buyers evaluate improved fuel economy. If some consumers find it difficult to estimate the value of future fuel savings and correctly compare it with the increased cost of purchasing higher fuel economy (possibilities discussed below in Chapter VIII) – or if they simply have low values of saving fuel – this rule will not change that situation, and they are unlikely to purchase the more fuel-efficient models that manufacturers offer. To the extent that other consumers more completely or correctly account for the value of fuel savings and the costs of acquiring higher fuel economy in their purchasing decisions, they will also continue to do so, and they are likely to view models with improved fuel economy as more attractive purchases than currently available models. The effect of the rule on sales of new vehicles will depend on which form of behavior is more widespread.

In general we would expect that the net effect of this rule would be to reduce sales of new vehicles or leave them unchanged. If consumers are satisfied with the combinations of fuel economy levels and prices that current models offer, we would expect some to decide that the higher prices of those models no longer justify purchasing them, even though they offer higher fuel economy. Other potential buyers may decide to purchase the same vehicle they would have before the rule took effect, or to adjust their purchases in favor of models offering other attributes. Thus sales of new models would decline, regardless of whether “consumer-side” failures in the market for fuel economy currently lead buyers to under-invest in fuel economy. However, if there is some market failure on the producer or supply side that currently inhibits manufacturers from offering increases in fuel economy that would increase their profits – for example, if producers have underestimated the demand for fuel economy, or do not compete vigorously to provide as much as buyers would prefer – then the new standards would make vehicles more attractive to many buyers, and their sales should increase (potential explanations for such producer market failures are discussed in Chapter VIII, below).

NHTSA examined the potential impact of higher vehicle prices on sales on an industry-wide basis for passenger cars and light trucks separately. We note that the analysis conducted for this rule does not have the precision to examine effects on individual manufacturers or different vehicle classes. The methodology NHTSA used for estimating the impact on vehicle sales in effect assumes that the latter situation will prevail; although it is relatively straightforward, it relies on a number of simplifying assumptions.

There is a broad consensus in the economic literature that the price elasticity for demand for automobiles is approximately –1.0.[207, 208, 209] 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 technologies that improve fuel economy. 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

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[207] Kleit, A.N. (1990). “The Effect of Annual Changes in Automobile Fuel Economy Standards,” *Journal of Regulatory Economics*, vol. 2, pp 151-172. Docket EPA-HQ-OAR-2009-0472-0015

[208] Bordley, R. (1994). “An Overlapping Choice Set Model of Automotive Price Elasticities,” *Transportation Research B*, vol 28B, no 6, pp 401-408. Docket NHTSA-2009-0059-0153

[209] 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. Docket NHTSA-2009-0059-0039

impact on sales from price elasticity could be applied directly. However, we believe that consumers do value improved fuel economy, because they reduce the operating cost of the vehicles. How much consumers value fuel economy is an ongoing debate. We know that different consumers value different aspects of their vehicle purchase, and we are trying to get an estimate of how average consumers value fuel economy, but we do not have a reliable consumer survey on this issue. We also believe that consumers consider other factors that affect their costs and have included these in the analysis. Thus, this analysis makes one set of assumption, but many different assumptions and estimates of the sales impact could be made.

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? The estimates reported below assume that manufacturers will be able to pass all of their costs to improve fuel economy on to consumers. However, the ability of manufacturers to pass the compliance costs on to consumers will depend upon how consumers value the fuel economy improvements.[4] Consumer valuation of fuel economy improvements often depends upon the price of gasoline, which has recently been very volatile. To the extent that we have accurately predicted the price of gasoline and consumers reactions, and manufacturers can pass on all of the costs to consumers, then the sales and employment impact analyses are reasonable. If manufacturers only increase retail prices to the extent that consumers value these fuel economy improvements, then there would be no impact on sales.

Sales losses are predicted to 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.

To estimate the average value consumers place on fuel savings at the time of purchase, we assume as a starting point that the average purchaser considers the fuel savings they would receive over a 5 year timeframe. We chose 5 years because this is the average length of time of a financing agreement.[5] The present values of these savings were calculated using a 3 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 National Automobile Dealers Association (NADA) agreed with several of the agency’s assumptions, saying the National Program proposal reasonably assumes buyers will value any fuel savings associated with the purchase of a new motor vehicle over a 5-yr period, rather than over a vehicle's full useful life. Even at high fuel prices, consumers who view fuel economy as an important purchase criteria will be hard-pressed to make the case for buying a more fuel efficient new vehicle if the up-front capital costs associated with doing so cannot be recouped in short order. Of course, for purposes of calculation payback, real-world

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[4] Gron, Ann and Swenson, Deborah, 2000, “Cost Pass-Through in the U.S. Automobile Market”, *The Review of Economics and Statistics*, 82: 316-324. Docket EPA-HQ-OAR-2009-0472-0007

[5] 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 March 4, 2010).

purchaser finance costs, opportunity costs, and additional maintenance costs all should be accounted for.

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 2007 by state and weighted them by population by state to determine a national weighted-average sales tax of 5.5 percent.

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 of insurance costs that depend on vehicle value. The Insurance Information Institute[6] provides the average value of collision plus comprehensive insurance in 2006 as $448. The average value of a new passenger car in 2006, according to the U.S. Department of Energy, was $22,651.[7] Using sales volumes from Ward's Automotive Yearbook 2008 for MY 2007 sales and the MY 2008 base vehicle average prices, we determined an average passenger car and an average light truck price. The average base price for all passenger cars using this method was $26,201 and for all light trucks was $29,678 ($2007 dollars). While this method does not give an exact price, the ratio of light truck prices to passenger car prices was applied and on-road registrations for passenger cars and light trucks for 2006 were applied to get an overall new light vehicle price.[8] The result is an average price for light vehicles of $24,033[9] for 2006. 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 1.86% of the price of a vehicle. If we assume that this premium is proportional to the new vehicle price, it represents about 1.86 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 8.5 percent of the vehicle's price at a 3 percent discount rate.

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[6] 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).

[7] U.S. Department of Energy, 2008, "Average Price of a New Car, 1970-2006," *available at* http://www1.eere.energy.gov/vehiclesandfuels/facts/2008_fotw520.html (last accessed March 4, 2010).

[8] The base price does not include the more expensive lines of a model or purchased optional equipment; nor does it count discounts given. Thus, it is not an average light truck purchase transaction price, but a price that we can track.

[9] $29,678/$26,201 = 1.1327 * $22,651 = $25,657 average price for light trucks. In 2006, passenger cars were 54% of the on road fleet and light trucks were 46% of the on road fleet, resulting in an average light vehicle price for 2006 of $24,033.

Third, we considered that 70 percent of new vehicle purchasers take out loans to finance their purchase. The average new vehicle loan is for 5 years at a 6 percent rate.[10] At these terms the average person taking a loan will pay 16 percent more for their vehicle over the 5 years than a consumer paying cash for the vehicle at the time of purchase.[11] Discounting the additional 3.2 percent (16 percent / 5 years) per year over the 5 years using a 3 percent mid-year discount rate[12] results in a discounted present value of 14.87 percent higher for those taking a loan. Multiplying that by the 70 percent that take a loan, means that the average consumer would pay 10.2 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. In other words, 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%[13] 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 at new of 30.6 percent.

We add these four factors together. At a 3 percent discount rate, the consumer considers she could get 30.6 percent back upon resale in 5 years, but will pay 5.5 percent more for taxes, 8.5 percent more in insurance, and 10.2 percent more for loans, results in a 6.48 percent return on the increase in price for fuel economy technology (30.6 percent – 5.5 percent - 8.5 percent – 10.2 percent). Thus, the increase in price per vehicle is multiplied by 0.9352 (1 – 0.0648) before subtracting the fuel savings to determine the overall net consumer valuation of the increase of costs on his purchase decision.

A sample calculation for passenger cars under the Preferred Alternative at a 3 percent discount rate in MY 2012 is an estimated retail price increase of $505 which is multiplied by 0.9352 to get a residual price increase of $472. The estimated fuel savings over the 5 years of $310 at a 3 percent discount rate results in a net cost to consumers of $162. Comparing that to the $22,651 average price of a passenger car is a 0.71 percent price increase. Passenger car sales were estimated to be about 9,123,000 passenger cars for MY 2012. With a price elasticity of –1.0, a 0.71 percent increase in net cost to consumers could result in an estimated loss in sales of 65,202 passenger cars.

Tables VII-4 a, b, and c show the estimated impact on sales for passenger cars, light trucks, and combined, respectively. The Preferred Alternative has the highest combined passenger car and light truck sales increases predicted using this methodology.

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[10] New car loan rates in 2007 average about 7.8 percent at commercial banks and 4.5 percent at auto finance companies, so their average is close to 7 percent.

[11] Based on www.bankrate.com auto loan calculator for a 5 year loan at 6 percent.

[12] For a 3 percent discount rate, the summation of 3.2 percent x 0.9853 in year one, 3.2 x 0.9566 in year two, 3.2 x 0.9288 in year three, 3.2 x 0.9017 in year 4, and 3.2 x 0.8755 in year five.

[13] [13] 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).

Note that there is no feedback loop between this sales analysis and the Volpe model. These sales estimates are not used to determine additional or less mileage traveled or fuel consumed. The Volpe model does not attempt to estimate the extent to which the sales volumes of different vehicle models might change in response to fuel economy increases, financial outlays for additional technology, and increases in civil penalties that could all result from increased CAFE standards.

There are studies that estimate that people may hold onto their vehicles longer as a result of an increase in price, everything else being held equal. This analysis estimates that consumers will purchase more vehicles because of their improved fuel economy. In general, changes in prices or other characteristics of the new vehicles market will also have consequences for the used vehicle market. Specifically, any action that raises prices for new vehicles will also tend to increase prices of used vehicles, and in turn cause owners of existing vehicles to keep them in service for slightly longer. However, the agency estimates that the value of fuel savings over the lifetimes of the new vehicles will exceed the increase in their prices, prompting an increase in sales of new vehicles during most model years that the rule affects. As a consequence, prices for used vehicles are also likely to decline, leading to slight increases in the rate at which used vehicles are retired from service ("scrapped") and replaced with new models. In turn, this will accentuate the effects of the standards on fuel consumption and GHG emissions; at the same time, total criteria pollutant emissions from the entire vehicle fleet may also decrease, as newer, lower-polluting vehicles replace used vehicles.

General Motors (OAR-472-6953.1) commented that the NHTSA usually does a manufacturer by manufacturer analysis of sales, but so far agencies have only done an industry-wide analysis. GM stated that the agencies must complete their analysis of sales and employment impacts of standards on individual manufacturers before setting final standards. In response, NHTSA does not believe that estimating sales impacts by manufacturer is required, even if the agency may have done it in the past. With all the uncertainty regarding consumer valuation of fuel economy improvements and consumer surplus, estimating sales impacts is an inexact science, and the agency has even less confidence at this time in estimating sales by manufacturer.

Two commenters agreed with the agency analysis that sales would go up. The Investor Network on Climate Risk (OAR-0472-7243.1) and the New Jersey Department (NHTSA-2009-0059-0073) agreed with the findings that project a positive impact on vehicle sales due to reduced fuel costs outweighing the costs of meeting the new emissions and fuel economy standards.

Walter McManus (OAR-472-3651.1) commented on the results of two reports that estimated an increase in sales. The first, "CAFE and the U.S. Auto Industry Revisited," Citi Investment Research and Planning, analyzed two regulatory scenarios, specifically, "CAFE 2020," equivalent to reaching a combined 35 mpg in 2020, and National Pavley, equivalent to reaching a combined 35 mpg in 2015. The analysis estimated the impacts on sales, costs, and profits relative to a baseline forecast, and concluded that the National Program will help "Detroit 3" profits, which will go up by $3 billion per year based on the relative value consumers put on fuel costs compared to vehicle price, the future price of fuel, and the combined direct and indirect costs incurred to improve fuel economy. McManus further stated that the report also found that the new standards will save two manufacturing plants' worth of jobs, and that consumers will save money too despite pump prices of $2.50/gallon, because fuel savings will more than offset vehicle price increases. The second report, "Fixing Detroit: How Far, How Fast, How Fuel Efficient" was described as analyzing three different fuel economy increases--30% (to 35 mpg), 40% (to 37.7 mpg), and 50% (to 40.4 mpg). The model used in the report estimated the impact of improving fuel economy on vehicle costs, vehicle prices, and consumer demand. McManus stated that the report found that the Detroit 3 would always be better off increasing fuel economy, and that the more they improved, the better off they would be, because consumers value fuel economy more than it costs manufacturers to add technology. McManus stated that a 30% increase in fuel economy, as with the National Program, is estimated to increase vehicle costs by $1,715, while the fuel savings value to consumers will be $2,578.

In response, the agency notes that these analyses appear to come to similar conclusions as NHTSA's conclusion for purposes of this analysis, that fuel savings should be valued by consumers at levels higher than price increases, and that if that occurs, vehicle sales would increase.

Table VII-4a
Potential Impact on Sales
Passenger Cars

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Preferred	-65,202	46,801	103,422	168,334	227,039
3%	-9,302	54,369	91,838	131,092	196,193
4%	-18,694	54,899	105,781	162,650	239,959
5%	-23,655	57,280	123,764	181,100	253,045
6%	-66,461	28,276	69,191	109,779	177,630
7%	-82,835	-2,203	19,695	53,158	90,246
Max Net	-81,930	946	42,573	89,321	147,282
TC = TB	-93,933	-16,361	16,698	57,137	100,283

Table VII-4b
Potential Impact on Sales
Light Trucks

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Preferred	48,561	106,658	139,893	171,920	213,868
3%	11,021	44,784	72,918	111,536	137,306
4%	7,287	52,946	93,466	136,400	175,282
5%	-21,608	28,302	62,836	121,314	169,990
6%	-27,282	16,460	55,058	102,421	139,073
7%	-27,556	-7,222	40,806	59,225	81,159
Max Net	-36,600	18,512	57,310	90,736	124,057
TC = TB	-38,972	7,428	48,414	74,060	102,287

Table VII-4c
Potential Impact on Sales
Passenger Cars and Light Trucks Combined

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Preferred	-16,641	153,459	243,315	340,255	440,907
3%	1,719	99,153	164,757	242,628	333,499
4%	-11,407	107,845	199,247	299,050	415,241
5%	-45,262	85,582	186,601	302,414	423,036
6%	-93,743	44,735	124,249	212,200	316,703
7%	-110,391	-9,425	60,501	112,383	171,405
Max Net	-118,530	19,458	99,883	180,056	271,339
TC = TB	-132,905	-8,933	65,112	131,196	202,570

The estimates provided in the tables above are meant to be illustrative rather than a definitive prediction. When viewed at the industry-wide level, they give a general indication of the potential impact on vehicle sales. As shown below, the overall impact is positive and growing over time for both cars and trucks. Because the fuel savings associated with this rule are expected to exceed the technology costs, the effective prices of vehicles (the adjusted increase in technology cost less the fuel savings over five years) to consumers will fall, and consumers will buy more new vehicles. As a result, the lower net cost of the vehicles is projected to lead to an increase in sales for both cars and trucks.

As discussed above, this result depends on the assumption that more fuel efficient vehicles yielding net consumer benefits over their first five years would not otherwise be offered, due to market failures on the part of vehicle manufacturers. However, vehicle models that achieve the fuel economy targets prescribed by today's rulemaking are already available, and consumers do not currently purchase a combination of them that meets the fuel economy levels this rule requires. This suggests that the rule may not result in an increase in vehicle sales, because it does not alter how consumers currently make decisions about which models to purchase. In addition, this analysis has not accounted for a number of factors that might affect consumer vehicle purchases, such as changing market conditions, changes in vehicle characteristics that might accompany improvements in fuel economy, or consumers considering a different "payback period" for their fuel economy purchases. If consumers use a shorter payback period, sales will increase by less than estimated here, and might even decline, while if consumers use longer payback periods, the increase in sales is likely to be larger than reported. In addition, because this is an aggregate analysis some individual consumers (including those who drive less than estimated here) will receive lower net benefits from the increase n fuel economy this rule requires, while others (who drive more than estimated here) will realize even greater savings. These complications – which have not been taken into account in our analysis – add considerable uncertainty to our estimates of changes in vehicle sales resulting from this rule.

Potential Impact on Employment

There are three potential areas of employment that fuel economy standards could impact. 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 does not anticipate a huge number of incremental jobs in the engineering field. Often people would be diverted from one area to another and the incremental number of jobs might be a few thousand.

The second area is the impact that new technologies would have on the production line. Again, we do not anticipate a large number of incremental workers, as for the most part you are replacing one engine with another or one transmission with another. In some instances the technology is more complex, requiring more parts and there would be a small increase in the number of production employees, but we do not anticipate a large change.

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. In order to get 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 1,313,600 workers. Since then there has been a steady decline to 1,096,900 in 2006 and more rapid decreases in 2007, 2008, and 2009. Employment in 2008 was about two-thirds of the 2000 level and in the first six months of 2009 employment has been around 680,000, averaging about one-half of the peak in the year 2000. Table VII-5 shows how many vehicles are produced by the average worker in the industry. Averaging the information shown for 2000-2008, the average U.S. domestic employee produces 11.3 vehicles (the same number as in 2008). Thus, one could assume that projected sales loss divided by 11.3 would give an estimate of the potential employment loss.

Table VII-5
U.S. Light Duty Vehicle Production and Employment

	U.S. Light Vehicle Production	Motor Vehicle Vehicle and Parts U.S. Employment[210]	Production per Employee
2000	12,773,714	1,313,600	9.7
2002	13,568,385	1,151,300	11.8
2004	13,527,309	1,112,700	12.2
2006	12,855,845	1,096,900	11.7
2008	9,870,473	876,300	11.3
Total/Average	62,595,726	5,550,800	

Combining MY 2012-2016, we estimate that the Preferred Alternative will result in a small net increase in sales (65,480), and thus in employment (5,795). At this time, the agency considers these effects to occur in the short to medium term (meaning up to 5 years). Over the next few years, consumers can elect to defer vehicle purchases by continuing to operate existing vehicles. Eventually, however, the rising maintenance costs for aging vehicles may make replacements look more attractive.

However, vehicle owners may also react to persistently higher vehicle costs by permanently owning fewer vehicles, and keeping existing vehicles in service for somewhat longer. In this case, the possibility exists that there may be permanent sales losses, compared with a situation in which vehicle prices are lower.

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[210] 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).

Table VII-6
Impact on Auto Industry Employment by Alternative
Passenger Cars and Light Trucks Combined
(Jobs)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Preferred	-1,473	13,580	21,532	30,111	39,018
3%	152	8,775	14,580	21,471	29,513
4%	-1,009	9,544	17,632	26,465	36,747
5%	-4,006	7,574	16,513	26,762	37,437
6%	-8,296	3,959	10,996	18,779	28,027
7%	-9,769	-834	5,354	9,945	15,169
Max Net	-10,489	1,722	8,839	15,934	24,012
TC = TB	-11,762	-791	5,762	11,610	17,927

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

Improving new vehicles' fuel efficiency provides direct benefits to their buyers and users by reducing fuel consumption and fuel costs throughout those vehicles' lifetimes, stimulating increased vehicle use through the fuel economy rebound effect, and increasing vehicles' driving range so that they require less frequent refueling. At the same time, the reduction in fuel use that results from requiring 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 federal outlays to secure imported oil supplies and cushion the U.S. economy against their potential interruption. Reducing fuel consumption also lowers the economic costs of environmental externalities resulting from fuel production and use, including reducing the impacts on human health from emissions of criteria air pollutants, and reducing future economic damages from potential changes in the global climate caused by greenhouse gas emissions.

These benefits are partly offset by the increase in fuel use that results from added vehicle use due to the fuel economy rebound effect, as well as by added costs from the increased congestion, crashes, and noise caused by increased vehicle use. They would also be partially offset by any losses in the utility that new vehicles provide to their buyers (and subsequent owners) if manufacturers change other vehicle attributes as part of their strategies to comply with higher fuel economy requirements. Nevertheless, the total economic benefits from requiring higher fuel economy are likely to be substantial, and the agency has attempted to quantify each of these components carefully.

NHTSA's analysis of alternative increases in the CAFE standards that would apply to MY 2012-2016 passenger cars and light trucks estimates the economic benefits from adopting more stringent CAFE standards separately for each model year over its lifespan in the U.S. vehicle fleet, extending from the initial year when a model year is offered for sale through the year when nearly all vehicles from that model year have been retired from service. Each category of benefits resulting from increased fuel economy is measured by comparing the future values of fuel consumption and its associated economic impacts under alternative increases in CAFE standards – and the corresponding improvements in fuel economy – to their value under the baseline alternative, which would extend current CAFE standards to apply to future model years, thus resulting in only minimal improvement in fuel economy.

Because these benefits occur throughout the lifetimes of vehicles whose fuel economy increases in response to higher CAFE standards, their projected values during each future year of their respective lifetimes must be discounted to their present values as of the time each model year is produced and sold in order to facilitate comparison to the costs incurred by vehicle manufacturers for improving fuel economy.[211] Thus the selection of an appropriate discount rate

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[211] Discounting to the year when each model year was produced allows future economic benefits from improving each model year's fuel economy to be compared to added production costs for making those vehicles more fuel-efficient, which are assumed to be incurred at the time those vehicles are manufactured.

is also an important issue in the agency's analysis of benefits from requiring cars and light trucks to achieve higher fuel economy.

This chapter first discusses the forecasts, assumptions, and parameter values that NHTSA uses to analyze benefits from improved fuel economy. Because it plays a critical role in determining the magnitude of these benefits, this section also includes a detailed discussion of the fuel economy rebound effect and the agency's assumption about its magnitude. Next, the chapter discusses the methods the agency employs to estimate the direct benefits to vehicle buyers resulting from higher fuel economy, as well as the nature of potential welfare losses to buyers from changes in other vehicle characteristics that might accompany improvements in fuel economy. The chapter then details the procedures that are used to estimate broader benefits to the U.S. economy – and in the case of reductions in greenhouse gas emissions, the global economy – that result from lower fuel production and consumption. It also describes how the increases in external costs resulting from added vehicle use are calculated.

Finally, the chapter presents empirical estimates of the value of each of these benefits that the agency estimates would result from establishing alternative CAFE standards for MY 2012-2016 passenger cars and light trucks. These estimates are presented in physical units, as total undiscounted economic values of future benefits, and discounted to their present values using alternative discount rates.

A. Basic Inputs for Analysis of Economic Impacts

The magnitudes and economic values of these benefits and costs from increased fuel economy are influenced by a number of forecast variables, parameter values, and assumptions. These include the level of vehicle sales during each model year affected by higher CAFE standards, the relationship between increases in these vehicles' EPA-measured fuel efficiency and their actual on-road fuel efficiency, assumptions about the lifetimes and usage of future model-year vehicles, the magnitude of the fuel economy rebound effect, future fuel prices and taxes, the values of economic externalities resulting from petroleum consumption and imports, the economic values of environmental externalities resulting from fuel production, distribution, and use, the value of increased refueling range, and the discount rate applied to future benefits and costs. The following sections discuss the specific forecasts, parameter values, and assumptions NHTSA has employed to estimate benefits and costs from alternative CAFE standards that would require increases in the fuel economy of passenger cars and light trucks produced during model years 2012 through 2016.

Projected Sales of MY 2012-2016 Passenger Cars and Light Trucks

A critical variable affecting the total economic benefits from requiring improvements in passenger car and light truck fuel economy is the number of vehicles likely to be produced under stricter CAFE standards. Projections of total passenger car and light truck sales for future years (see Table VIII-1a and VIII-1b) were obtained from the Energy Information Administration's (EIA) Annual Energy Outlook 2010 Early Release (AEO 2010), a standard government reference for projections of energy production and consumption in different sectors of the U.S.

economy.[212] In using these forecasts, NHTSA made the simplifying assumption that projected sales of cars and light trucks during each calendar year from 2012 through 2016 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.

NHTSA estimated production volumes of passenger cars and light trucks for individual manufacturers by first calculating their respective shares of total production for each model year. These shares were calculated by dividing each manufacturer's planned car or light truck production volumes by the sum of planned production volumes reported by all manufacturers.[213] Next, the resulting estimates of individual manufacturer's shares of total car and light truck production during a model year were applied to forecast total car and light truck sales for the corresponding calendar year from AEO 2010. This produces estimates of passenger car and light truck production by each manufacturer during each model year from 2012 through 2016. NHTSA employs this process in order to develop production forecasts that are consistent with both the production plans that individual manufacturers reported to the agency, and the forecasts of total sales of new cars and light trucks reported by the Energy Information Administration in AEO 2010.[214]

Changes in Vehicle Classification

Passenger automobiles were defined in the Energy Policy and Conservation Act of 2007 (EPCA) as "any automobile (other than an automobile capable of off-highway operation) which the Secretary [*i.e.*, NHTSA] decides by rule is manufactured primarily for use in the transportation of not more than 10 individuals." Thus there are two general groups of automobiles that qualify under EPCA as non-passenger automobiles or light trucks: (1) those defined by NHTSA in its regulations as other than passenger automobiles because they were not manufactured "primarily" for transporting up to ten individuals; and (2) those expressly excluded from the passenger category by statute due to their capability for off-highway operation, regardless of whether they were manufactured primarily for passenger transportation. NHTSA's classification rule directly tracks those two groups of non-passenger automobiles in subsections (a) and (b), respectively, of 49 CFR Part 523.5.

In the final rule for model year 2011, NHTSA tightened the coverage of its regulatory definition of "light truck" to ensure that 2 wheel drive (2WD) versions of an SUV are not classified as light trucks under Part 523.5(b) simply because that same SUV model is also available in a 4WD

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[212] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2009*, Updated Reference Case (April 2009), Supplemental Table 57, http://www.eia.doe.gov/oiaf/aeo/supplement/stimulus/arra/excel/suptab_57.xls (last accessed March 15, 2010).

[213] These product plans are submitted to NHTSA in response to the agency's request for information from vehicle manufacturers, and include responses to very detailed questions about vehicle model characteristics that influence fuel economy. The baseline market forecast mix of products (make/model, engines, transmissions, etc.) that NHTSA has used in its analysis is based on the confidential product plan information manufacturers submit to the agency.

[214] For manufacturers that did not submit plans, planned production volumes for model years 2012-2016 were assumed to be the same as their model year 2008 production volumes as recorded in NHTSA's CAFE compliance database.

version.[215] In addition, 2WD SUVs may not be properly classified as light trucks simply because a manufacturer asserts that their base form has no back seat and thus would "provide greater cargo-carrying than passenger-carrying volume" according to Part 523.5(a)(4). No change in the regulatory definition of a light truck is necessary to implement this clarification. It results in the re-classification of an average of 1,400,000 2WD SUVs from light trucks to passenger cars in each of the five model years that would be covered by the alternative standards considered in this rulemaking.

Adjusted Sales Forecasts

Tables VIII-1a and VIII-1b report forecast production volumes of passenger cars and light trucks for each manufacturer during model years 2012 through 2016. The figures reported in these tables reflect the AEO 2009 Reference Case forecasts of passenger car and light truck sales for 2012-2016, the planned production volumes for model years 2012-2106 reported to NHTSA by individual manufacturers, and the reclassification of certain light truck models as passenger cars. The tables also reflect the reasonable assumption that while sales of cars or light trucks produced during a *model* year will be distributed over more than one *calendar* year, production and sales for each model year will ultimately be equal.

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[215] In order to be properly classifiable as a light truck under Part 523, a 2WD SUV must either be over 6,000 lbs GVWR and meet 4 out of 5 ground clearance characteristics to make it off-highway capable under Part 523.5(b), or meet one of the functional characteristics under Part 523.5(a) (*e.g.*, greater cargo carrying capacity than passenger carrying capacity). In other words, a 2WD vehicle of 6,000 lbs GVWR or less, even if it has a sufficient number of clearance characteristics, cannot be considered off-highway capable.

Table VIII-1a
Sales Projections – Passenger Cars
(Thousands of vehicles)

Manufacturer	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	231.0	289.6	293.9	370.0	411.6	422.8
Chrysler	326.3	409.4	426.4	411.3	392.5	399.7
Daimler	213.8	211.6	202.5	244.5	263.7	270.9
Ford	1,344.4	1,468.1	1,485.7	1,567.7	1,542.4	1,559.2
General Motors	1,248.9	1,586.0	1,544.9	1,452.5	1,487.2	1,514.4
Honda	850.8	906.0	1,064.8	1,087.0	912.4	930.3
Hyundai	382.2	376.3	395.5	395.5	511.2	518.4
Kia	305.7	299.6	326.6	427.2	538.7	548.0
Mazda	292.6	283.1	329.9	378.3	413.3	420.5
Mitsubishi	104.2	110.3	104.5	88.1	82.3	82.7
Nissan	611.6	824.0	831.6	854.1	925.4	946.5
Porsche	25.1	41.1	43.3	34.0	32.4	33.3
Subaru	169.7	183.5	175.2	184.5	204.7	206.9
Suzuki	49.5	72.3	81.8	90.6	100.6	103.0
Tata	23.2	36.4	50.5	49.3	63.7	65.5
Toyota	1,355.6	1,591.0	1,941.4	2,078.9	2,176.5	2,226.4
Volkswagen	388.1	434.4	498.6	517.9	567.7	583.2
Total	7,922.7	9,122.7	9,797.1	10,231.3	10,626.4	10,831.7

Table VIII-1b
Sales Projections – Light Trucks
(Thousands of vehicles)

Manufacturer	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	203	204	184	191	176	171
Chrysler	737	692	594	515	475	462
Daimler	97	108	115	136	130	126
Ford	792	852	940	966	937	911
General Motors	1,347	1,511	1,536	1,337	1,380	1,342
Honda	585	635	677	635	561	545
Hyundai	46	58	102	104	95	92
Kia	88	88	103	114	118	115
Mazda	58	61	65	68	74	72
Mitsubishi	45	48	46	53	57	55
Nissan	331	405	392	406	392	381
Porsche	13	13	15	16	17	17
Subaru	105	98	90	99	116	117
Suzuki	7	5	17	20	21	20
Tata	31	30	34	40	44	42
Toyota	888	887	990	1,096	1,107	1,077
Volkswagen	83	105	141	152	128	124
Total	5,458	5,798	6,038	5,947	5,826	5,669

Accounting for the Fuel Economy Rebound Effect

The fuel economy rebound effect refers to the fraction of fuel savings expected to result from an increase in vehicle fuel economy – particularly an increase required by the adoption of higher CAFE standards – that is offset by additional vehicle use. The increase in vehicle use occurs because higher fuel economy reduces the fuel cost of driving, typically the largest single component of the monetary cost of operating a vehicle, and vehicle owners respond to this reduction in operating costs by driving slightly more. By lowering the marginal cost of vehicle use, improved fuel economy leads to an increase in the number of miles vehicles are driven each year and over their lifetimes. Even with their higher fuel economy, this additional driving consumes some fuel, so the rebound effect reduces the net fuel savings that result when new CAFE standards require manufacturers to improve fuel economy.

The rebound effect – originally termed the "take back" effect – expresses the fraction of fuel savings expected to result from an increase in vehicle fuel economy that is offset by additional vehicle use. This measure also equals the percentage by which annual vehicle use increases when the fuel cost of driving each mile declines in response to higher fuel economy. Researchers typically measure the rebound effect by the elasticity of total or average vehicle use with respect to either fuel economy itself or fuel cost per mile driven, expressed as a positive percentage (rather than a decimal number, the usual convention for expressing elasticity). Because the fuel cost of driving each mile is equal to fuel price per gallon divided by fuel economy in miles per gallon, it is easy to understand why this measure declines and vehicle use increases in response to increased fuel economy.

The magnitude of the rebound effect is an important determinant of the actual fuel savings that are likely to result from adopting stricter CAFE standards, and thus an important parameter affecting NHTSA's evaluation of alternative standards for future model years. Research on the magnitude of the rebound effect in light-duty vehicle use dates to the early 1980s, and almost unanimously concludes that a statistically significant rebound effect occurs when vehicle fuel efficiency improves.[216]

The most common approach to estimating its magnitude has been to analyze household survey data on vehicle use, fuel consumption, fuel prices, and other determinants of household travel demand to isolate the response of vehicle use to higher fuel economy. Several other studies have relied on econometric analysis of annual U.S. data on vehicle use, fuel economy, fuel prices, and other variables to identify the response of average vehicle use to changes in fleet-wide average fuel economy. Two recent studies analyzed yearly variation in vehicle ownership and use, fuel prices, and fuel economy among individual states over an extended time period in order to measure the response of vehicle use to changing fuel economy and other factors.[217]

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[216] 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 is most appropriate for evaluating the fuel savings and emissions reductions resulting from stricter standards that would apply to future model years.

[217] 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.

An important distinction among studies of the rebound effect is whether they assume that the effect is constant, or is likely to vary 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 varies in response to changes in retail fuel prices or average fuel economy. Many studies using household survey data estimate significantly different rebound effects for households owning varying numbers of vehicles and thus imply that its average value will change over time as vehicle ownership patterns evolve.

However, these studies arrive at differing conclusions about whether the rebound effect is larger among households that own more vehicles, and thus provide conflicting estimates of changes in its magnitude as the distribution of households by vehicle ownership levels changes. 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 in response to fuel costs.

In order to arrive at an estimate of the rebound effect for use in assessing the fuel savings, emissions reductions, and other impacts of alternative standards, NHTSA reviewed 22 studies of the rebound effect conducted from 1983 through 2005. The agency then conducted a detailed analysis of the 66 separate estimates of the long-run rebound effect reported in these studies, which is summarized in Table VIII-2 below.[218] 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. Estimates of the rebound effect reported in the 17 published studies show the same range, but a slightly higher mean value (24 percent). Although this result is not shown in the table, approximately two-thirds of all the estimates reviewed and of all published estimates fall in the range of 10-30 percent.

We are aware of two potential issues involved in these estimates. One, the estimates of total annual car and truck VMT are developed by the states and submitted to FHWA. Each state uses its own definition of a car and a truck. For example, some states classify minivans as cars and some as trucks. Thus, there are known inconsistencies with these estimates when evaluated separately for cars and trucks. Also, total gasoline consumption can be reasonably estimated from excise tax receipts, but separate estimates for cars and trucks are not available. We are not aware of the precise methodology used to develop the distinct on-road fuel economy estimates for cars and trucks developed by FHWA. We do not believe that they are based on direct measurements from substantial numbers of vehicles, as no such test programs were found by EPA during its fuel economy labeling rule in 2006. Also, the year-to-year consistency for both car and truck fuel economy implies some methodology other than direct measurement. For this reason, NHTSA and EPA are not using distinct on-road fuel economy gaps for cars and trucks, but one common value of 20 percent for both vehicle classes for purposes of estimating the fuel savings of the standards.

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[218] 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, we computed a weighted average of the reported values using the reported distribution of households among vehicle ownership categories.

Table VIII-2
Summary of Previous Rebound Effect Estimates

Category of Estimates	Number of Studies	Number of Estimates	Range		Distribution		
			Low	High	Median	Mean	Std. Dev.
All Estimates	22	66	7%	75%	22%	23%	14%
Published Estimates	17	50	7%	75%	22%	24%	14%
U.S. Time-Series Data	7	34	7%	45%	14%	18%	9%
Household Survey Data	13	23	9%	75%	31%	31%	16%
Pooled U.S. State Data	2	9	8%	58%	22%	25%	14%
Constant Rebound Effect (1)	15	37	7%	75%	20%	23%	16%
Variable Rebound Effect (1)	10	29	10%	45%	23%	23%	10%

(1) Three studies estimated both constant and variable rebound effects.

As Table VIII-2 illustrates, 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 have a mean of 18 percent, while the mean of 23 estimates based on household survey data is 31 percent, and the mean of 9 estimates based on pooled state data (25 percent) is slightly above that of the entire sample. The average mean is 23 percent for both the 37 estimates that assume a constant rebound effect and the 29 estimates reported in studies that allow the rebound effect to vary in response to fuel prices, vehicle ownership, or household income.

Recent studies provide some evidence that the rebound effect has been declining over time, and it may decline further over the immediate future if income rises faster than gasoline prices. This result seems plausible, because the responsiveness of vehicle use to variation in fuel costs would be expected to decline as they account for a smaller proportion of the total monetary cost of driving, which has been the case until very recently. At the same time, rising personal incomes would be expected to reduce the sensitivity of vehicle use to fuel costs as the time component of driving costs – which is likely to be related to income levels – accounts for a larger fraction of the total cost of automobile travel. The widely-cited study by Small and Van Dender estimated that the long-run rebound effect averaged 22 percent over the period from 1966-2001, but declined to 11 percent over the last five years of that period (1997-2001).[219] These authors subsequently reported that the long-run rebound effect appears to have dropped further to 6 percent over the period from 2000-2004.[220]

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

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[219] Small, K. and K. Van Dender, 2007a. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect", The Energy Journal, vol. 28, no. 1, pp. 25-51. Docket EPA-HQ-OAR-0472-0018

[220] Small, K. and K. Van Dender, 2007b. "Long Run Trends in Transport Demand, Fuel Price Elasticities and Implications of the Oil Outlook for Transport Policy," OECD/ITF Joint Transport Research Centre Discussion Papers 2007/16, OECD, International Transport Forum. Docket EPA-HQ-OAR-0472-0020

efficiency, road supply, the number of vehicles in use, vehicle prices, and other factors. As the studies by Small and Van Dender emphasize, it is important to account for the effect of fuel prices on vehicle buyers' demand for fuel efficiency when attempting to estimate the rebound effect. Failing to incorporate the response of fuel efficiency to fuel prices is likely to cause the rebound effect to be overestimated, because the changes in fuel economy resulting from variation in fuel prices partly offset the latter's effect on fuel cost per mile.

NHTSA's analysis used national aggregate data on light-duty vehicle travel covering the period from 1950 through 2006. Several different approaches were used to estimate the effect of fuel efficiency on car and light truck use, and various econometric procedures were employed to account for its relationship to fuel prices and control for the effect of this relationship on the estimated value of the rebound effect. The results from NHTSA's analysis are presented in Table VIII-3. For each model that was estimated, the table reports the average value of the rebound effect over the period from 1950-2006, as well as its value during the final year of that period. In addition, the table reports the average projected values of rebound effect between 2010 and 2030, which were developed using forecasts of personal income, fuel prices, and fuel efficiency from EIA's *Annual Energy Outlook 2009* 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%, and comparing these estimates to its calculated values for 2006 (which range from 8-14%) supports the finding from recent research that it is declining in magnitude. The forecast values of the rebound effect shown in the table, which range from 4-16%, also suggest that this decline is likely to continue through 2030.

Table VIII-3 Summary of NHTSA Estimates of the Long-Run Rebound Effect Using U.S. Annual Data for 1950-2006

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 rationing, time trend	OLS	34.0%	20.8%	13.6%
Single-equation VMT model	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per road mile, % of fleet manufactured under CAFE standards, new vehicle prices	IV (for fuel cost per mile)	16.3%	9.2%	7.0%
Three-equation system for VMT, fuel efficiency, and vehicle stock	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population licensed to drive, new vehicle prices, % of fleet manufactured under CAFE standards	2SLS	29.5%	13.4%	15.9%
Three-equation system for VMT, fuel efficiency, and vehicle stock	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population licensed to drive, new vehicle prices, % of fleet manufactured under CAFE standards	3SLS	29.8%	13.7%	16.2%
Three-equation system for VMT, fuel efficiency, and vehicle stock	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population licensed to drive, new vehicle prices, % of fleet manufactured under CAFE standards	Vector auto-regression	19.9%	10.8%	--
Three-equation system for VMT, fuel efficiency, and vehicle stock	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population licensed to drive, new vehicle prices, % of fleet manufactured under CAFE standards	Vector error-correction	20.7%	11.2%	--

*Using AEO2009 Reference Case forecasts of fuel prices, fuel economy, and personal income.

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. For the final rulemaking, the agencies chose to use 10 percent as their primary estimate of the rebound effect, with a range of 5-15 percent for use in sensitivity testing.

The 10 percent figure is well below those reported in almost all previous research, and 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 Small and Van Dender and by 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 here also suggest that this is likely to be the case. As a consequence, the agencies concluded that a value below the historical estimates is likely to provide a more reliable estimate of its magnitude during the future period spanned by NHTSA's analyses of the impacts of this rule. The 10 percent estimate meets this condition, since it lies below the 15-30 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 Van Dender and by Greene. 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 the historical estimates and the projected future estimates. NHTSA will continue to review this estimate of the rebound effect in future rulemakings.

One possible alternative to attempting to estimate the rebound effect *per se* would be to use the price elasticity of demand for gasoline, which measures the sensitivity of gasoline consumption to a change in its price, in order to establish a lower bound on its magnitude. The elasticity of gasoline demand with respect to its price per gallon is likely to provide a reasonable proxy for the rebound effect, since a decline in the price of gasoline has exactly the same effect on the per-mile cost of driving as an equivalent increase in fuel economy. In the very short run, the only way that people can respond to changes in the price of gasoline is to alter the number of miles they drive.[221] Over the relatively short time span of several months, most estimates indicate that the price elasticity of demand for gasoline is approximately -0.1, which corresponds to the short-run rebound effect of 10 percent used in this FRIA. Over the period of a year, however, the price elasticity of demand is likely to increase somewhat in magnitude, up to a range of -0.3 to -0.4.[222] It seems reasonable to assume that the majority of the change in gasoline consumption over such a period results from changes in vehicle use, as distinguished from changes in the fuel economy of new vehicles, since only about 5-10 percent of the fleet would be replaced within one year.

Additionally, NHTSA recognizes that as the world price of oil falls in response to lower U.S. demand for oil, there is the potential for an increase in oil use and, in turn, greenhouse gas emissions outside the U.S. This so called international oil "take back" effect is difficult to estimate. Given that oil consumption patterns vary across countries, there will be different demand responses to a change in the world price of crude oil. In addition, many countries

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[221] Over the long run, consumers can alter their choice of vehicle (and thus the fuel economy they achieve), in addition to altering their number of miles driven.

[222] The long-run price elasticity of demand for gasoline is in the 0.6 to 0.8 range.

around the world subsidize their oil consumption. It is not clear how oil consumption would change due to changes in the market price of oil given the current pattern of demand and subsidies. Further, many countries, especially in the developed countries/regions (*i.e.*, the European Union), already have or anticipate implementing policies to limit GHG emissions. Further out in the future, it is anticipated that developing countries would take actions to reduce their GHG emissions as well. Any increases in petroleum consumption and GHG emissions in other nations that occur in response to a decline in world petroleum prices would be attributed to those nations, and recorded in their respective GHG emissions inventories. Thus, including the same increase in emissions as part of the impact of adopting CAFE standards in the U.S. would risk double-counting of global emissions totals.

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.[223]

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.[224] 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 2011-2016 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.

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[223] 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).

[224] 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).

Table VIII-4 compares the agency's estimates of fleet-wide average fuel economy under test conditions for 2000 through 2006 to the Federal Highway Administration's (FHWA) published estimates of the estimates of actual on-road fuel economy achieved by passenger cars and light trucks during each of those years. As it shows, FHWA's estimates of actual fuel economy for passenger cars ranged from 21 percent to 23 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions over this period. Similarly, FHWA's estimates of actual fuel economy for light trucks ranged from 16 percent to 18 percent lower than NHTSA's estimates of average light truck fuel economy under test conditions. These results appear to confirm that the 20% on-road fuel economy discount or gap represents a reasonable estimate for use in evaluating the fuel savings likely to result from alternative CAFE standards for MY 2012-2016 vehicles.

Table VIII-4
Estimated Fleet-Wide Fuel Economy of Passenger Cars and Light Trucks Compared to Reported Fuel Economy

Calendar Year	**Passenger Cars**			**Light-Dutry Trucks**		
	NHTSA Estimated Test MPG	**FHWA Reported Actual MPG**	**Percent Difference**	**NHTSA Estimated Test MPG**	**FHWA Reported Actual MPG**	**Percent Difference**
2000	28.2	21.9	-22.2%	20.8	17.4	-16.3%
2001	28.2	22.1	-21.7%	20.8	17.6	-15.5%
2002	28.3	22.0	-22.3%	20.9	17.5	-16.2%
2003	28.4	22.2	-21.9%	21.0	17.2	-18.0%
2004	28.5	22.5	-21.1%	21.0	17.2	-18.3%
2005	28.6	22.1	-22.8%	21.1	17.7	-16.3%
2006	28.8	22.5	-21.8%	21.2	17.8	-16.2%
Average, 2000-2006	28.4	22.2	-22.0%	21.0	17.5	-16.7%

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 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 Tables VIII-5a and VIII-5b.[225] 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.[226]

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.[227] Table VIII-5a and VIII-5b also report 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.

As Tables VIII-5a and VIII-5b also show, the resulting 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 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 Tables VIII-5a and VIII-5b, 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 2012 vehicles will be considered to be of age 1 during calendar year 2012. This convention is used in order to account

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[225] 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.

[226] 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 Tables VIII-5a and VIII-5b. 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.

[227] 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.

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.[228]

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[228] As an illustration, virtually the entire production of model year 2012 cars and light trucks will have been sold by the end of calendar year 2012, so those vehicles are defined to be of age 1 during calendar year 2012. Model year 2012 vehicles are subsequently defined to be of age 2 during calendar year 2013, age 3 during calendar year 2014, 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-5a
Survival Rates and Unadjusted Annual Vehicle-Miles Traveled (VMT) by Age for Passenger Cars

Vehicle Age	**Estimated Survival Fraction**	**Estimated Annual VMT**	**Survival-Weighted Annual VMT**
1	0.9950	14,231	14,160
2	0.9900	13,961	13,821
3	0.9831	13,669	13,438
4	0.9731	13,357	12,998
5	0.9593	13,028	12,497
6	0.9413	12,683	11,938
7	0.9188	12,325	11,324
8	0.8918	11,956	10,662
9	0.8604	11,578	9,961
10	0.8252	11,193	9,237
11	0.7866	10,804	8,499
12	0.7170	10,413	7,466
13	0.6125	10,022	6,138
14	0.5094	9,633	4,907
15	0.4142	9,249	3,831
16	0.3308	8,871	2,934
17	0.2604	8,502	2,214
18	0.2028	8,144	1,652
19	0.1565	7,799	1,220
20	0.1200	7,469	896
21	0.0916	7,157	656
22	0.0696	6,866	478
23	0.0527	6,596	348
24	0.0399	6,350	253
25	0.0301	6,131	185
26	0.0227	5,940	135
Estimated Passenger Car Lifetime VMT			161,847

Table VIII-5b
Survival Rates and Unadjusted Annual Vehicle-Miles Traveled (VMT)
by Age for Light Trucks

Vehicle Age	Estimated Survival Fraction	Estimated Annual VMT	Survival-Weighted Annual VMT
1	0.9950	16,085	16,004
2	0.9741	15,782	15,374
3	0.9603	15,442	14,829
4	0.9420	15,069	14,195
5	0.9190	14,667	13,479
6	0.8913	14,239	12,691
7	0.8590	13,790	11,845
8	0.8226	13,323	10,960
9	0.7827	12,844	10,053
10	0.7401	12,356	9,145
11	0.6956	11,863	8,252
12	0.6501	11,369	7,391
13	0.6042	10,879	6,573
14	0.5517	10,396	5,735
15	0.5009	9,924	4,971
16	0.4522	9,468	4,281
17	0.4062	9,032	3,669
18	0.3633	8,619	3,131
19	0.3236	8,234	2,665
20	0.2873	7,881	2,264
21	0.2542	7,565	1,923
22	0.2244	7,288	1,635
23	0.1975	7,055	1,393
24	0.1735	6,871	1,192
25	0.1522	6,739	1,026
26	0.1332	6,663	887
27	0.1165	6,648	774
28	0.1017	6,648	676
29	0.0887	6,648	590
30	0.0773	6,648	514
31	0.0673	6,648	447
32	0.0586	6,648	390
33	0.0509	6,648	338
34	0.0443	6,648	294
35	0.0385	6,648	256
36	0.0334	6,648	222
		Estimated Lifetime Light Truck VMT	190,066

Adjusting Vehicle Use

The estimates of average annual miles driven by passenger cars and light trucks reported in Tables VIII-5a and VIII-5b reflect the historically low gasoline prices that prevailed 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 2010*** Early Release Reference Case. 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 2012-2016 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 reported previously in Tables VIII-5a and VIII-5b to adjust annual mileage by age during each calendar year of the expected lifetimes of MY 2012-2016 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.[229] During that time, however, the total number of passenger cars registered for in the U.S. grew by only about 0.3 percent annually.[230] 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.[231] Further, the AEO 2010 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.

In order to develop reasonable estimates of future growth in average car and light truck use, NHTSA calculated the rate of growth in the mileage schedules shown in Tables VIII-5a and VIII-5b that would be necessary for total car and light truck travel to increase at the rate forecast in the AEO 2010 Reference Case. This rate was calculated in a manner that is also consistent with future changes in the overall size and age distributions of the U.S. passenger car and light truck fleets that are implied by the agency's adjusted forecasts of total car and light truck sales reported previously in Tables VIII-1a and VIII-1b, together with the survival rates reported in Tables VIII-5a and VIII-5b. The growth rate in average annual car and light truck use produced

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[229] 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).

[230] 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.

[231] *See supra* note [2 above here]

by this calculation is approximately 1.15% per year.[232] This rate was applied to the mileage figures reported in Tables VIII-5a and VIII-5b to estimate annual mileage by age during each year of the expected lifetimes of MY 2012-2016 cars and light trucks.

Tables VIII-5c and VIII-5d report the results of applying the adjustments for both future fuel prices and annual growth in car and light truck use to the figures reported previously in Tables VIII-5a and VIII-5b. Separate adjustments for projected fuel prices and growth in car and light truck use were made for each calendar year from 2012 through 2030. Because the effects of both fuel prices and cumulative growth in average vehicle use vary by year, these adjustments result in differing VMT schedules for each future year. The adjusted annual VMT estimates reported in Tables VIII-5c and VIII-5d, as well as their lifetime totals, represent *averages* of the adjusted values of annual car and light truck use by age for calendar years 2012-2030. However, the estimates of fuel savings and other impacts of improved fuel efficiency for *individual* calendar years over the lifetimes of model year 2012-16 cars and light trucks employ the adjusted values of car and light truck use by age during those specific calendar years.

While the adjustment for future fuel prices reduces average mileage at each age from the values shown previously, the adjustment for expected future growth in average vehicle use increases it. Comparing the mileage estimates in Tables VIII-5c and VIII-5d to those shown previously in Tables VIII-5a and VIII-5b shows that the net effect of these two adjustments is to increase expected lifetime mileage significantly. As an illustration, expected lifetime mileage for passenger cars rises to 195,264 miles in Table VIII-5c from the 161,847 miles reported previously in Table VIII-5a (or by 21%), while Table VIII-5d shows that expected lifetime mileage for light trucks increases from the 190,066 miles reported previously in Table VIII-5b to 225,865 miles (or by 19%). As previously, however, the estimates of survival-weighted mileage decline to less than 1,000 miles per year after age 20 for cars and after age 27 for light trucks. Thus they have relatively little impact on lifetime fuel savings or other benefits from higher fuel economy, particularly after discounting the benefits that occur in those distant future years to their present values.

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[232] It was not possible to estimate separate growth rates in average annual use for cars and light trucks, because of the significant reclassification of light truck models as passenger cars discussed previously.

Table VIII-5c
Survival Rates and Adjusted Annual Vehicle-Miles Traveled (VMT)
by Age for Passenger Cars

Vehicle Age	**Estimated Survival Fraction**	**Estimated Annual VMT**	**Survival-Weighted Annual VMT**
1	0.9950	17,270	17,183
2	0.9900	16,943	16,774
3	0.9831	16,599	16,319
4	0.9731	16,163	15,728
5	0.9593	15,761	15,119
6	0.9413	15,337	14,437
7	0.9188	14,881	13,672
8	0.8918	14,429	12,868
9	0.8604	13,940	11,994
10	0.8252	13,495	11,136
11	0.7866	12,964	10,198
12	0.7170	12,510	8,970
13	0.6125	11,990	7,344
14	0.5094	11,470	5,843
15	0.4142	10,997	4,555
16	0.3308	10,543	3,488
17	0.2604	10,125	2,637
18	0.2028	9,714	1,970
19	0.1565	9,307	1,456
20	0.1200	8,891	1,067
21	0.0916	8,546	783
22	0.0696	8,285	577
23	0.0527	8,136	429
24	0.0399	7,896	315
25	0.0301	7,699	232
26	0.0227	7,530	171
		Adjusted Lifetime Passenger Car VMT	195,264

Table VIII-5d
Survival Rates and Adjusted Annual Vehicle-Miles Traveled (VMT)
by Age for Light Trucks

Vehicle Age	**Estimated Survival Fraction**	**Estimated Annual VMT**	**Survival-Weighted Annual VMT**
1	0.9950	19,219	19,123
2	0.9741	18,782	18,296
3	0.9603	18,419	17,688
4	0.9420	17,946	16,905
5	0.9190	17,502	16,085
6	0.8913	16,952	15,109
7	0.8590	16,439	14,121
8	0.8226	15,829	13,021
9	0.7827	15,218	11,911
10	0.7401	14,648	10,841
11	0.6956	13,992	9,733
12	0.6501	13,450	8,744
13	0.6042	12,832	7,753
14	0.5517	12,212	6,737
15	0.5009	11,600	5,811
16	0.4522	11,069	5,005
17	0.4062	10,617	4,313
18	0.3633	10,125	3,679
19	0.3236	9,650	3,123
20	0.2873	9,238	2,654
21	0.2542	8,882	2,258
22	0.2244	8,667	1,945
23	0.1975	8,400	1,659
24	0.1735	8,395	1,456
25	0.1522	8,197	1,248
26	0.1332	8,188	1,091
27	0.1165	8,218	957
28	0.1017	8,216	836
29	0.0887	8,213	728
30	0.0773	8,211	635
31	0.0673	8,210	553
32	0.0586	8,208	481
33	0.0509	8,203	418
34	0.0443	8,196	363
35	0.0385	8,182	315
36	0.0334	8,167	273
Adjusted Lifetime Light Truck VMT			225,865

Estimating Annual Fuel Consumption

NHTSA estimated annual fuel consumption during each year of the expected lifetimes of model year 2012-2016 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.[233] 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 2012-2016 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 Adjusted Baseline alternative, 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 2012-2016 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 2010 Early Release to each future year's estimated fuel savings. The AEO 2010 Reference Case forecast of future fuel prices, which is reported in Table VIII-6, 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 State and 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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[233] 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-6 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 2010 extend through 2035, the agency's analysis of the value of fuel savings over the lifetimes of MY 2012-2016 cars and light trucks requires forecasts extending through calendar year 2050, approximately the last year during which a significant number of MY 2016 vehicles will remain in service.[234] To obtain fuel price forecasts for the years 2036 through 2050,the agency assumes that retail fuel prices will continue to increase after 2035 at the average rates reported in the AEO 2010 Reference Case forecast over the period from 2025 through 2035 (in constant-dollar terms).[235] As Table VIII-6 shows, the projected retail price of gasoline expressed in 2007 dollars rises steadily over the forecast period, from $2.47 in 2011 to $4.49 in 2050.

The agency has updated its estimates of gasoline taxes, using updated state tax rates reported for January 1, 2006[236] Expressed in 2007 dollars, federal gasoline taxes are currently $0.178 while state and local gasoline taxes together average $0.231 per gallon, for a total tax burden of $0.401 per gallon. Following the assumptions used by EIA in AEO 2010, state and local gasoline taxes are assumed to keep pace with inflation in nominal terms, and thus to remain constant when expressed in constant 2007dollars. In contrast, EIA assumes that federal gasoline taxes will remain unchanged in *nominal* terms, and thus decline throughout the forecast period when expressed in constant 2007 dollars. 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 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.

EIA's AEO 2010 Early Release Reference Case reflects the effects of the American Reinvestment and Recovery Act of 2009, as well as of recent revisions to the U.S. and global

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[234] 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.

[235] This projection uses the rate of increase in fuel prices for 2020-2030 rather than that over the complete forecast period (2009-2030) because there is extreme volatility in the forecasts for the years 2009 through approximately 2020. Using the average rate of change over the complete 2009-2030 forecast period would result in projections of declining fuel prices after 2030.

[236] FHWA, Highway Statistics 2006, Section I: Motor Fuel -- Rates and Revenues, Table MF-121T, available at http://www.fhwa.dot.gov/policy/ohim/hs06/pdf/mf121t.pdf. (last accessed March 15, 2010).

economic outlook. In addition, it also reflects the provisions of the Energy Independence and Security Act of 2007 (EISA), including the requirement that the combined mpg level of U.S. cars and light trucks reach 35 miles per gallon by model year 2020. Because this provision would be expected to reduce future U.S. demand for gasoline, and thus lead to a decline in its future price, there is some concern about whether the AEO 2010 forecast of fuel prices partly reflects the increases in CAFE standards considered in this rule, and whether it is thus suitable for valuing the projected reductions in fuel use.

In response to this concern, the agencies note that EIA issued a revised version of AEO 2008 in June 2008, which modified its previous December 2007 Early Release of AEO 2008 to reflect the effects of then recently-passed EISA legislation.[237] The fuel price forecasts reported in EIA's Revised Release of AEO 2008 differed by less than one cent per gallon throughout the entire forecast period (2008-230) from those previously issued as part of its initial release of AEO 2008. Thus, the agencies are reasonably confident that the fuel price forecasts presented in AEO 2010 and used to analyze the value of fuel savings projected to result from this rule are not unduly affected by the CAFE provisions of EISA.

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[237] Energy Information Administration, Annual Energy Outlook 2008, Revised Early Release (June 2008), Table 12. Available at http://www.eia.doe.gov/oiaf/archive/aeo08/excel/aeotab_12.xls (last accessed March 15, 2010).

Table VIII-6 Adjustment of Forecast Retail Gasoline Prices to Reflect the Economic Value of Fuel Savings

Year	AE0 2010 Forecast of Retail Gasoline Price	Estimated Federal and State Taxes	Forecast Gasoline Price Excluding Taxes	Forecast Gasoline Price Including Energy Security Externalities
	(2007 $/ gallon)	(2007 $/ gallon)	(2007 $/ gallon)	(2007 $/ gallon)
2011	$2.47	$0.40	$2.08	$2.24
2012	$2.61	$0.40	$2.21	$2.38
2013	$2.84	$0.40	$2.45	$2.62
2014	$2.95	$0.39	$2.56	$2.73
2015	$3.00	$0.39	$2.61	$2.78
2016	$3.07	$0.39	$2.68	$2.85
2017	$3.13	$0.39	$2.75	$2.92
2018	$3.19	$0.39	$2.80	$2.97
2019	$3.22	$0.38	$2.84	$3.01
2020	$3.27	$0.38	$2.89	$3.06
2021	$3.29	$0.38	$2.92	$3.09
2022	$3.34	$0.37	$2.96	$3.13
2023	$3.37	$0.37	$2.99	$3.16
2024	$3.38	$0.37	$3.01	$3.18
2025	$3.42	$0.37	$3.05	$3.22
2026	$3.46	$0.36	$3.09	$3.26
2027	$3.49	$0.36	$3.13	$3.30
2028	$3.54	$0.36	$3.18	$3.35
2029	$3.59	$0.36	$3.23	$3.40
2030	$3.60	$0.35	$3.25	$3.42
2031	$3.64	$0.35	$3.29	$3.46
2032	$3.69	$0.35	$3.34	$3.51
2033	$3.72	$0.35	$3.37	$3.54
2034	$3.77	$0.35	$3.42	$3.59
2035	$3.83	$0.34	$3.48	$3.65
2036	$3.87	$0.34	$3.53	$3.69
2037	$3.91	$0.34	$3.57	$3.74
2038	$3.95	$0.34	$3.61	$3.78
2039	$3.99	$0.34	$3.66	$3.82
2040	$4.04	$0.33	$3.70	$3.87
2041	$4.08	$0.33	$3.75	$3.91
2042	$4.12	$0.33	$3.79	$3.96
2043	$4.17	$0.33	$3.84	$4.01
2044	$4.21	$0.33	$3.89	$4.05
2045	$4.26	$0.32	$3.93	$4.10
2046	$4.30	$0.32	$3.98	$4.15
2047	$4.35	$0.32	$4.03	$4.19
2048	$4.39	$0.32	$4.08	$4.24
2049	$4.44	$0.31	$4.12	$4.29
2050	$4.49	$0.31	$4.17	$4.34

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).[238] 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.

The Value of Increased Driving Range

Improving the fuel economy of passenger cars and light-duty trucks may also increase their driving range before they require refueling. By reducing the frequency with which drivers typically refuel their vehicles and extending the upper limit of the range they can travel before requiring refueling, improving fuel economy thus provides some additional benefits to their owners. Alternatively, if manufacturers respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting cost saving will presumably be reflected in lower vehicle sales prices. If manufacturers respond by doing so, this presumably reflects their judgment that the value to economic benefits to vehicle buyers from lower purchase prices exceeds that from extended refueling range.

No direct estimates of the value of extended vehicle range are readily available, so the agencies' analyses calculate the reduction in the annual number of required refueling cycles that results from improved fuel economy, and applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value.[239] As a coarse illustration of how the value of extended refueling range is estimated, a typical small light truck model has an average fuel tank size of approximately 20 gallons.[240] Based on a California Air Resources Board Study,

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[238] These benefits are included in the value of fuel savings reported in Tables VIII-5 through VIII-9.

[239] Department of Transportation, Guidance Memorandum, "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations," Apr. 9, 1997. http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf (last accessed March 15, 2010); update *available at* http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf (last accessed March 15, 2010).

[240] Based on the Volpe Model Market Data file for Model Year 2011, average tank volumes for cars and trucks are 16.6 gallons and 23.0 gallons, respectively. This produces a production weighted average of 19.3 gallons.

the average fuel purchase is approximately 55% of tank volume.[241] Therefore, increasing this model's actual on-road fuel economy from 24 to 25 mpg would extend its driving range from 216 miles (= 9 gallons x 24 mpg) to 225 miles (= 9 gallons x 25 mpg). Assuming that this vehicle is driven 12,000 miles/year, this reduces the number of times it needs to be refueled each year from 55.5 (= 12,000 miles per year / 216 miles per refueling) to 53.3 (= 12,000 miles per year / 225 miles per refueling), or by 2.2 refuelings per year.

Weighted by the nationwide mix of urban (about 2/3) and rural (about 1/3) driving and average vehicle occupancy for all driving trips (1.6 persons), the DOT-recommended value of travel time per vehicle-hour is $24.00 (in 2006 dollars).[242] Assuming that locating a station and filling up requires five minutes, the annual value of time saved as a result of less frequent refueling amounts to $4.40 (calculated as 5/60 x 2.2 x $24.00). This calculation is repeated for each future calendar year that light trucks of each model year affected by the alternative fuel economy standards considered in this rule would remain in service. Like fuel savings and other benefits, however, the value of this benefit declines over a model year's lifetime, because a smaller number of vehicles originally produced during that model year remain in service each year, and those remaining in service are driven fewer miles.

The agencies' estimate of benefits from less frequent refueling is subject to several sources of uncertainty.

First, this analysis assumes that manufacturers will not adjust fuel tank capacities downward (from the current average of 19.3 gallons) when they improve the fuel economy of their vehicle models, so that the entire increase in fuel economy will be reflected in increased driving range. Should manufacturers choose to downsize fuel tanks, and all other factors have been estimated with no error, the current estimates of refueling benefits would be overstated. Should manufacturers downsize tanks to fully offset any increase in vehicle range, there would be no extension in driving range and no resultant benefit to consumers. However, should fuel tank sizes be reduced, vehicle space, utility and value would increase and vehicle weight and production costs would decrease, improving fuel economy and CO_2 emissions.

A larger fuel tank size requires additional manufacturing costs (if for nothing more than increased materials or increased molding costs to squeeze more tank volume in unusually shaped spaces underbody), adds weight (thus, reduces fuel economy and increases CO_2 emissions) and takes up potentially usable vehicle space. It also increases vehicle range (a widely advertised vehicle attribute), which reduces the frequency of vehicle refueling for at least some owners and (less frequently) increases peace of mind when operating a vehicle in areas with limited refueling

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[241] California Environmental Protection Agency, Air Resources Board. Draft Assessment of the Real-World Impacts of Commingling California Phase 3 Reformulated Gasoline. August 2003 (Docket EPA-HQ-OAR-2009-0472-0087.1)

[242] The hourly wage rate during 2006 is estimated to be $24.00. Personal travel (94.4% of urban travel) is valued at 50 percent of the hourly wage rate. Business travel (5.6% or urban travel) is valued at 100 percent of the hourly wage rate. For intercity travel, personal travel (87%) is valued at 70 percent of the wage rate, while business travel (13%) is valued at 100 percent of the wage rate. The resulting values of travel time are $12.67 for urban travel and $17.66 for intercity travel, and must be multiplied by vehicle occupancy (1.6) to obtain the estimated value of time per vehicle hour.

options. Given this clear trade-off, manufacturers must use some type of optimization schema to determine the appropriate tank size for each vehicle. If manufacturers choose to retain the current fuel tank size, then the impact on manufacturing costs is obvious: zero. At least some portion of the driving public will save a considerable amount of time with some value. Given range is a widely publicized vehicle attribute, manufacturers will only reduce tank size if it lowers production costs sufficiently to overcome the loss in vehicle desirability. Thus, either consumers save time or production costs go down. Much as the agencies assume that cost increases are passed through to consumers, the agencies assume that cost savings from reducing fuel tank size (by reducing engineering complexity and materials required) would be passed through to consumers.

Further, the agencies assume that manufacturers operate in a manner that maintains or increases the desirability of a vehicle. Consequently, should a manufacturer choose to reduce fuel tank size, this option should provide welfare gains equivalent to or greater than the loss in welfare from reducing driving range. In the context of the rule, the improvement in CO_2 or fuel economy from downsizing a fuel tank will additionally decrease a manufacturers cost of compliance with the standards. The weight reduction estimates modeled in OMEGA and the Volpe model do not include any reduction in the size and weight of fuel tanks, excluding potential light weight materials substitution which would not affect fuel volume, thus this benefit has not been counted elsewhere.

Second, the agencies' analysis assumes that fuel purchases average 55 percent of fuel tank capacity. However, as shown in the California Air Resource Board (CARB) report, refueling patterns vary. Moreover, the 55 percent estimate implies that drivers, *on average*, are either refueling when nearly a half tank of gas remains in their vehicles, or that they are habitually not filling their tanks. Since many drivers only refuel when their tanks are very low, and since many drivers habitually refuel, this in turn implies that many drivers in the CARB study are refueling when their tanks are still well above 50 percent full. While based on field data, this estimate may thus overestimate the impact of refueling benefits.

For the primary analysis in both the proposal and this final rulemaking, the agencies assume that 100 percent of all refueling is demand-based; *i.e.*, that every gallon of fuel which is saved would reduce the need to return to the refueling station. Based on anecdotal evidence, this value is potentially an overestimate. As an example, some people may refuel every Sunday morning at the same time as they buy their newspaper and chewing gum. Barring unusually long trips, these people would not benefit from an increased driving range.

In order to understand how sensitive the overall estimate of the refueling benefit is to this specific input, we provide the following example. If 25 percent of gallons are refueled on a habitual rather than demand-based schedule, and the rest of the assumptions remain constant, the value of increased driving range decreases by 25 percent. There would be no value of increased driving range derived from these gallons. Returning to the example light truck discussed above, which generated a value of increased driving range worth $4.40 in the first year, if this owner refilled ¼ of his annual fuel on a habitual rather than demand based schedule, the value of increased driving range would decrease to $3.30. Unfortunately, the agencies do not have a basis for this 25 percent value, thus this example is for illustrative purposes only. However, as noted below, DOT is undertaking a new survey which may provide a data-based basis for revising our 100 percent assumption for future analysis.

Third, the agencies' estimate of refueling benefits assumes that refueling stops involve the same number of vehicle occupants as the overall average for all vehicle trips (1.6 persons). To the extent that drivers refuel while doing other errands or in advance of picking up passengers, this figure may overestimate the typical vehicle occupancy during refueling, and thus the total savings in refueling time. Similarly, the hourly value used to estimate the economic value of savings in refueling time reflects the typical mix of personal and business travel purposes, and drivers are likely to assign different values to their time when traveling for these different purposes. To the extent that drivers seek to refuel when traveling for purposes that typically use less valuable time, the hourly value used in the agencies' analysis may overstate the benefits from saving refueling time.

Finally, the agencies assume that both finding and using a refueling station takes, on average, five minutes. There are few, if any, data sources on average refueling time, and this estimate is subject to significant uncertainty.

For these reasons, the agencies' estimate of savings in refueling time is uncertain. To reduce the uncertainty, a new project is being planned by DOT which will include a detailed study of refueling events, using a random sample of refueling stations across the U.S. It is projected to include ~7,000 observations (time to refuel, # gallons refueled, etc.) and ~5,000 surveys of refueling participants. The agencies anticipate that this will provide a robust data set on which to revise many of the key inputs to the refueling benefit calculation. Some of the specific data categories which will be surveyed are listed below:

- Miles driven and time out of way to get to gas station
- Fuel gage level before and after refueling
- # gallons purchased
- # people in vehicle, above and below 16 years old
- Reasons for travel
- Reason for stopping at gas station (*e.g.*, fuel level too low, or other)

While the study results are not available in time for this final rulemaking, it is anticipated that the data will improve future estimations of the value of increased driving range.

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.[243]

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, which imposes economic costs on all other purchasers in the global petroleum market in excess of the higher prices paid by U.S. consumers.[244] 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."

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[243] *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.

[244] 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.

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.[245] 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.[246]

In analyzing benefits from its recent 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.[247] 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. [248] 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 recently-issued Renewable Fuel Standard Rule of 2007 (RFS)[249].

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 recommendations. [250] 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.

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[245] 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).

[246] *Id.*, at 18-19.

[247] 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).

[248] 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).

[249] Federal Register Vol.72, #83, May 1, 2007 pp.23,900-24,014

[250] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*, ICF, Inc., September 2007. Docket NHTSA-2009-0059-0160

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 \$4.52 to 22.65 per barrel, with a most likely estimate of \$12.50 per barrel of petroleum imported into the U.S. (expressed in 2007 Dollars). 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 \$0.108 to \$0.539 per gallon, with the actual value most likely to be \$0.298 per gallon saved (again in 2007 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.[251] 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 2012-2016 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.

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

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[251] 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.

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 $3.30 to $11.31 per barrel of imported oil, with a most likely estimate of $7.10 per barrel of imports(all figures are in 2007 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 $0.078 to $0.269, with the actual value most likely to be $0.169 per gallon (again in 2007 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 2012-2016 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 MY 2012-2016 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, and that approximately half of these expenses could be reduced in proportion to a reduction in U.S. oil imports from the region, the estimated savings would range from \$0.02 to \$0.08 (in 2007 dollars) for each gallon of fuel savings that was reflected in lower U.S. imports of petroleum from the Persian Gulf. 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 \$0.05 per gallon, the midpoint of this range. NHTSA employs this estimate in its sensitivity analysis.

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 2012-2016 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.[252] 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.[253] 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.[254]

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 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.

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[252] 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.

[253] 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.

[254] This figure is calculated as 0.50 + 0.50*0.9 = 0.50 + 0.45 = 0.95.

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-7 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-7 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-7 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.

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 in 2010. 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.[255]

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[255] This document is available at http://www2.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/sem_finalrule_appendix15a.pdf (last accessed March 2, 2010).

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 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.[256]

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[256] 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.

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.[257]

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.[258] 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 2012-2016 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 2011 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, reduced domestic fuel refining using domestically-produced crude oil is assumed to reduce emissions during all four phases of fuel production and distribution.[259]

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[257] 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.

[258] 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.

[259] 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.

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.[260] 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.[261] 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.[262] 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 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

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[260] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model*, Version 1.8, June 2007, *available at* http://www.transportation.anl.gov/software/GREET/index.html (last accessed March 15, 2010).

[261] 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.

[262] 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.

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.[263] 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 5.4 cents, 2.3 cents and 0.1 cents per additional vehicle mile when expressed in 2007 dollars.[264] For pickup trucks and vans, FHWA's estimates correspond to 4.8 cents, 2.6 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 3.9 and 3.4 cents per vehicle-mile when converted to 2007 dollars.[265] 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.

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

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[263] 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)

[264] 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 March 15, 2010). 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.

[265] 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 March 15, 2010)

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 2012-2016 passenger cars and light trucks, NHTSA has employed a discount rate of 3% per year. The agency has also tested the sensitivity of these benefit and cost estimates to the use of a 7 percent discount rate.

The primary reason that NHTSA has 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.[266]

OMB guidance also 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.[267] Thus NHTSA has employed the 3 percent rate to discount projected future benefits and costs resulting from higher CAFE standards for MY 2012-2016 passenger cars and light trucks.

One important exception to the 3% 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 model year 2012-16 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-7 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 5 percent for the estimate lying between the group's central and highest estimates.

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

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[266] *Id.*

[267] Office of Management and Budget, Circular A-4, "Regulatory Analysis," September 17, 2003, 33. *Available at* http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf (last accessed March 15, 2010).

prices, however, NHTSA has also tested the sensitivity of these benefit and cost estimates to the use of a higher percent discount rate. 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.[268] Thus the agency has also tested the sensitivity of its benefit and cost estimates for alternative MY 2012-2016 CAFE standards to the use of a 7 percent real discount rate.

F. <u>Summary of Values used to Estimate Benefits</u>

Table VIII-8 summarizes the economic values used to estimate benefits.

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[268] *Id.*

Table VIII-8 Economic Values Used for Benefits Computations (2007 Dollars)

Fuel Economy Rebound Effect	10%
"Gap" between test and on-road MPG	20%
Value of refueling time per ($ per vehicle-hour)	$ 24.64
Average Percentage of Tank Refilled During Refueling	55%
Annual growth in average vehicle use	1.15%
Fuel Prices (2012-50 average, $/gallon)	
Retail gasoline price	$3.66
Pre-tax gasoline price	$3.29
Economic Benefits from Reducing Oil Imports ($/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)	$ 1,300
Nitrogen oxides (NOx) – vehicle use	$ 5,300
Nitrogen oxides (NOx) – fuel production and distribution	$5,100
Particulate matter ($PM_{2.5}$) – vehicle use	$ 290,000
Particulate matter ($PM_{2.5}$) – fuel production and distribution	$ 240,000
Sulfur dioxide (SO_2)	$ 31,000
Carbon dioxide (CO_2) emissions in 2010	$ 21
Annual Increase in CO_2 Damage Cost	variable
External Costs from Additional Automobile Use ($/vehicle-mile)	
Congestion	$ 0.054
Accidents	$ 0.023
Noise	$ 0.001
Total External Costs	$ 0.078
External Costs from Additional Light Truck Use ($/vehicle-mile)	
Congestion	$0.048
Accidents	$0.026
Noise	$0.001
Total External Costs	$0.075
Discount Rate Applied to Future Benefits[269]	3%

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[269] 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-7 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 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-9 and VIII-10, the societal impacts for passenger car and light truck CAFE standards under the preferred alternative is shown for model years 2012-2016. These tables include undiscounted values as well as their net present values discounted 3 percent. They also show changes in the physical units of measure that produced these values. Negative values in these tables reflect net reductions in fuel consumption or emissions and their resulting economic impacts, which represent benefits from the proposal, while positive 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 35.7 billion gallons of fuel and prevent 380 million metric tons of tailpipe 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 2012-2016. The preferred alternative for light trucks would save 25.4 billion gallons of fuel and prevent 275 million metric tons of tailpipe 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 2012-2016.

The total value of societal benefits of the preferred alternative for passenger cars and light trucks is $182 billion[270] over the lifetime of the MY 2012-16 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. Fuel savings account for 78 percent and CO_2 emissions account for 8 percent of the societal benefits.

Tables VIII-11 and VIII-12 summarize the societal benefits for all alternatives for passenger cars and light trucks at the 3 percent and 7 percent discount rates, respectively. 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-13 summarizes the fuel savings from all alternatives for passenger cars and light trucks.

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[270] The $182 billion estimate is based on a 3% discount rate for valuing future impacts.

Table VIII-9
Lifetime Benefits for Preferred Alternative by Model Year -- Passenger Cars

MY 2012

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	2,395,587 (kgal)	$6,573	$5,290	$4,156
Consumer Surplus from Additional Driving	6,826,369 (kmiles)	$491	$396	$312
Refueling Time Value	22,168,301 (hours)	$546	$452	$365
Petroleum Market Externalities	2,395,587 (kgal)	$385	$315	$251
Congestion Costs	6,826,369 (kmiles)	-$356	-$292	-$234
Noise Costs	6,826,369 (kmiles)	-$7	-$6	-$4
Crash Costs	6,826,369 (kmiles)	-$163	-$133	-$107
CO2	25 (mmT)	$643	$516	$516
CO	183,679 (tons)	$0	$0	$0
VOC	21,787 (tons)	$35	$28	$21
NOX	10,764 (tons)	$69	$52	$39
PM	530 (tons)	$154	$117	$86
SOX	2,975 (tons)	$112	$91	$73
Total		$8,482	$6,826	$5,474

MY 2013

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	5,152,718 (kgal)	$14,551	$11,814	$9,353
Consumer Surplus from Additional Driving	13,859,078 (kmiles)	$1,075	$874	$693
Refueling Time Value	44,980,471 (hours)	$1,108	$920	$746
Petroleum Market Externalities	5,152,718 (kgal)	$828	$680	$546
Congestion Costs	13,859,078 (kmiles)	-$733	-$603	-$485
Noise Costs	13,859,078 (kmiles)	-$14	-$11	-$9
Crash Costs	13,859,078 (kmiles)	-$327	-$268	-$215
CO2	54 (mmT)	$1,453	$1,174	$1,174
CO	173,993 (tons)	$0	$0	$0
VOC	37,362 (tons)	$59	$48	$38
NOX	15,020 (tons)	$96	$75	$57
PM	1,112 (tons)	$324	$257	$199
SOX	6,353 (tons)	$239	$196	$158
Total		$18,660	$15,155	$12,255

MY 2014

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	7,232,873 (kgal)	$20,836	$16,914	$13,395
Consumer Surplus from Additional Driving	19,545,328 (kmiles)	$1,532	$1,246	$988
Refueling Time Value	62,083,457 (hours)	$1,530	$1,269	$1,029
Petroleum Market Externalities	7,232,873 (kgal)	$1,162	$954	$766
Congestion Costs	19,545,328 (kmiles)	-$1,032	-$849	-$682
Noise Costs	19,545,328 (kmiles)	-$20	-$16	-$13
Crash Costs	19,545,328 (kmiles)	-$461	-$379	-$304
CO2	77 (mmT)	$2,102	$1,696	$1,696
CO	160,287 (tons)	$0	$0	$0
VOC	48,830 (tons)	$78	$63	$50
NOX	17,864 (tons)	$114	$90	$69
PM	1,547 (tons)	$451	$362	$284
SOX	8,901 (tons)	$335	$275	$221
Total		$26,627	$21,626	$17,499

MY 2015

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	9,446,003 (kgal)	$27,649	$22,471	$17,816
Consumer Surplus from Additional Driving	25,402,984 (kmiles)	$2,010	$1,636	$1,300
Refueling Time Value	80,958,399 (hours)	$1,995	$1,656	$1,343
Petroleum Market Externalities	9,446,003 (kgal)	$1,517	$1,247	$1,001
Congestion Costs	25,402,984 (kmiles)	-$1,343	-$1,106	-$888
Noise Costs	25,402,984 (kmiles)	-$25	-$21	-$17
Crash Costs	25,402,984 (kmiles)	-$599	-$492	-$395
CO2	101 (mmT)	$2,816	$2,274	$2,274
CO	143,844 (tons)	$0	$0	$0
VOC	61,141 (tons)	$97	$79	$63
NOX	20,851 (tons)	$133	$106	$82
PM	1,982 (tons)	$577	$467	$368
SOX	11,612 (tons)	$437	$359	$288
Total		$35,264	$28,677	$23,235

MY 2016

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	11,432,923 (kgal)	$33,971	$27,655	$21,958
Consumer Surplus from Additional Driving	30,779,447 (kmiles)	$2,449	$1,997	$1,589
Refueling Time Value	96,330,156 (hours)	$2,374	$1,972	$1,601
Petroleum Market Externalities	11,432,923 (kgal)	$1,837	$1,511	$1,214
Congestion Costs	30,779,447 (kmiles)	-$1,632	-$1,344	-$1,081
Noise Costs	30,779,447 (kmiles)	-$31	-$25	-$20
Crash Costs	30,779,447 (kmiles)	-$723	-$595	-$478
CO2	123 (mmT)	$3,487	$2,820	$2,820
CO	125,778 (tons)	$0	$0	$0
VOC	71,893 (tons)	$114	$93	$75
NOX	23,524 (tons)	$150	$120	$94
PM	2,365 (tons)	$689	$561	$447
SOX	14,045 (tons)	$528	$435	$349
Total		$43,214	$35,200	$28,567

MY 2012-2016, Combined Passenger Cars

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	35,660,103 (kgal)	$103,581	$84,145	$66,679
Consumer Surplus from Additional Driving	96,413,205 (kmiles)	$7,557	$6,149	$4,882
Refueling Time Value	306,520,784 (hours)	$7,553	$6,269	$5,085
Petroleum Market Externalities	35,660,103 (kgal)	$5,729	$4,708	$3,779
Congestion Costs	96,413,205 (kmiles)	-$5,096	-$4,194	-$3,370
Noise Costs	96,413,205 (kmiles)	-$96	-$79	-$64
Crash Costs	96,413,205 (kmiles)	-$2,273	-$1,868	-$1,499
CO2	380 (mmT)	$10,502	$8,479	$8,479
CO	787,580 (tons)	$0	$0	$0
VOC	241,013 (tons)	$383	$311	$247
NOX	88,022 (tons)	$561	$443	$341
PM	7,536 (tons)	$2,195	$1,763	$1,384
SOX	43,887 (tons)	$1,651	$1,357	$1,089
Total		$132,246	$107,483	$87,031

Table VIII-10
Lifetime Benefits for Preferred Alternative by Model Year -- Light Trucks

MY 2012

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	1,805,043 (kgal)	$5,102	$3,974	$3,041
Consumer Surplus from Additional Driving	4,054,226 (kmiles)	$384	$300	$230
Refueling Time Value	12,795,747 (hours)	$315	$255	$202
Petroleum Market Externalities	1,805,043 (kgal)	$290	$231	$181
Congestion Costs	4,054,226 (kmiles)	-$195	-$155	-$121
Noise Costs	4,054,226 (kmiles)	-$4	-$3	-$3
Crash Costs	4,054,226 (kmiles)	-$105	-$84	-$66
CO2	19 (mmT)	$523	$405	$405
CO	36,333 (tons)	$0	$0	$0
VOC	11,557 (tons)	$18	$14	$11
NOX	3,686 (tons)	$23	$18	$14
PM	388 (tons)	$113	$89	$68
SOX	2,217 (tons)	$83	$66	$52
Total		$6,549	$5,110	$4,015

MY 2013

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	3,698,295 (kgal)	$10,702	$8,364	$6,428
Consumer Surplus from Additional Driving	7,806,595 (kmiles)	$804	$630	$486
Refueling Time Value	23,242,410 (hours)	$573	$463	$368
Petroleum Market Externalities	3,698,295 (kgal)	$594	$473	$371
Congestion Costs	7,806,595 (kmiles)	-$375	-$299	-$234
Noise Costs	7,806,595 (kmiles)	-$8	-$6	-$5
Crash Costs	7,806,595 (kmiles)	-$203	-$162	-$127
CO2	40 (mmT)	$1,099	$851	$851
CO	25,256 (tons)	$0	$0	$0
VOC	22,147 (tons)	$35	$28	$22
NOX	5,894 (tons)	$38	$30	$23
PM	767 (tons)	$223	$177	$137
SOX	4,537 (tons)	$171	$136	$107
Total		$13,653	$10,684	$8,427

MY 2014

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	5,281,256 (kgal)	$15,558	$12,168	$9,362
Consumer Surplus from Additional Driving	11,323,656 (kmiles)	$1,153	$905	$698
Refueling Time Value	33,659,128 (hours)	$829	$670	$533
Petroleum Market Externalities	5,281,256 (kgal)	$848	$676	$530
Congestion Costs	11,323,656 (kmiles)	-$544	-$433	-$339
Noise Costs	11,323,656 (kmiles)	-$11	-$9	-$7
Crash Costs	11,323,656 (kmiles)	-$294	-$235	-$184
CO2	57 (mmT)	$1,606	$1,244	$1,244
CO	1,078 (tons)	$0	$0	$0
VOC	30,514 (tons)	$48	$39	$30
NOX	7,236 (tons)	$46	$37	$29
PM	1,082 (tons)	$315	$250	$196
SOX	6,476 (tons)	$244	$194	$152
Total		$19,800	$15,506	$12,243

MY 2015

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	6,504,296 (kgal)	$19,458	$15,229	$11,726
Consumer Surplus from Additional Driving	13,804,723 (kmiles)	$1,424	$1,118	$863
Refueling Time Value	40,605,771 (hours)	$1,001	$808	$643
Petroleum Market Externalities	6,504,296 (kgal)	$1,045	$832	$653
Congestion Costs	13,804,723 (kmiles)	-$663	-$528	-$414
Noise Costs	13,804,723 (kmiles)	-$14	-$11	-$9
Crash Costs	13,804,723 (kmiles)	-$359	-$286	-$224
CO2	71 (mmT)	$2,022	$1,566	$1,566
CO	-38,632 (tons)	$0	$0	$0
VOC	36,395 (tons)	$58	$46	$36
NOX	7,676 (tons)	$49	$40	$32
PM	1,338 (tons)	$390	$310	$243
SOX	7,973 (tons)	$300	$239	$187
Total		$24,711	$19,364	$15,302

MY 2016

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	8,061,224 (kgal)	$24,479	$19,169	$14,769
Consumer Surplus from Additional Driving	17,154,505 (kmiles)	$1,770	$1,390	$1,074
Refueling Time Value	49,147,269 (hours)	$1,211	$978	$778
Petroleum Market Externalities	8,061,224 (kgal)	$1,295	$1,032	$809
Congestion Costs	17,154,505 (kmiles)	-$823	-$656	-$514
Noise Costs	17,154,505 (kmiles)	-$17	-$14	-$11
Crash Costs	17,154,505 (kmiles)	-$446	-$355	-$278
CO2	88 (mmT)	$2,561	$1,984	$1,984
CO	-84,105 (tons)	$0	$0	$0
VOC	43,994 (tons)	$70	$56	$44
NOX	8,618 (tons)	$55	$45	$37
PM	1,661 (tons)	$484	$385	$301
SOX	9,878 (tons)	$372	$296	$232
Total		$31,010	$24,310	$19,225

MY 2012-2016, Combined Light Trucks

Societal Effect	Physical Units	Undiscounted Value	Present Discounted Value @3%	Present Discounted Value @7%
Lifetime Fuel Expenditures	25,350,115 (kgal)	$75,299	$58,903	$45,327
Consumer Surplus from Additional Driving	54,143,706 (kmiles)	$5,535	$4,342	$3,351
Refueling Time Value	159,450,326 (hours)	$3,929	$3,174	$2,523
Petroleum Market Externalities	25,350,115 (kgal)	$4,072	$3,244	$2,543
Congestion Costs	54,143,706 (kmiles)	-$2,599	-$2,070	-$1,623
Noise Costs	54,143,706 (kmiles)	-$54	-$43	-$34
Crash Costs	54,143,706 (kmiles)	-$1,408	-$1,121	-$879
CO2	275 (mmT)	$7,812	$6,049	$6,049
CO	-60,070 (tons)	$0	$0	$0
VOC	144,608 (tons)	$230	$183	$144
NOX	33,109 (tons)	$211	$170	$134
PM	5,236 (tons)	$1,525	$1,210	$945
SOX	31,081 (tons)	$1,169	$931	$730
Total		$95,722	$74,974	$59,212

Table VIII-11
Present Value of Lifetime Social Benefits by Alternative
(Millions of 2007 Dollars)
(3 percent discount rate)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	6,826	15,155	21,626	28,677	35,200	107,483
3% Annual Increase	3,397	8,374	12,331	16,760	23,122	63,984
4% Annual Increase	4,186	11,006	17,315	24,469	32,309	89,286
5% Annual Increase	6,152	15,404	24,075	32,114	40,905	118,649
6% Annual Increase	7,071	18,062	28,137	37,552	47,754	138,576
7% Annual Increase	8,038	20,627	32,225	42,010	52,606	155,507
Max Net Benefits	8,019	20,896	31,683	39,863	48,228	148,689
Total Cost = Total Benefit	8,666	22,374	33,916	42,737	51,659	159,352
Light Trucks						
Preferred Alternative	5,110	10,684	15,506	19,364	24,310	74,974
3% Annual Increase	687	3,920	7,635	11,604	14,940	38,786
4% Annual Increase	2,590	7,361	12,580	17,089	21,830	61,450
5% Annual Increase	4,003	10,407	17,686	23,206	28,324	83,626
6% Annual Increase	4,893	13,933	22,031	28,987	34,727	104,571
7% Annual Increase	5,634	16,326	25,550	32,714	38,229	118,453
Max Net Benefits	7,528	18,302	25,913	31,563	34,835	118,141
Total Cost = Total Benefit	7,631	18,954	27,294	33,381	37,262	124,522

Table VIII-12
Present Value of Lifetime Social Benefits by Alternative
(Millions of 2007 Dollars)
(7 percent discount rate)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	5,474	12,255	17,499	23,235	28,567	87,031
3% Annual Increase	2,727	6,778	9,980	13,585	18,774	51,844
4% Annual Increase	3,356	8,904	14,015	19,838	26,241	72,353
5% Annual Increase	4,941	12,472	19,493	26,030	33,185	96,122
6% Annual Increase	5,667	14,612	22,763	30,402	38,735	112,180
7% Annual Increase	6,448	16,692	26,080	34,028	42,669	125,917
Max Net Benefits	6,134	16,378	25,041	31,517	38,120	117,191
Total Cost = Total Benefit	6,957	18,112	27,453	34,625	41,897	129,044
Light Trucks						
Preferred Alternative	4,015	8,427	12,243	15,302	19,225	59,212
3% Annual Increase	545	3,099	6,035	9,178	11,823	30,679
4% Annual Increase	2,035	5,802	9,927	13,500	17,260	48,524
5% Annual Increase	3,129	8,189	13,929	18,300	22,365	65,913
6% Annual Increase	3,823	10,966	17,349	22,842	27,385	82,366
7% Annual Increase	4,404	12,838	20,108	25,767	30,132	93,248
Max Net Benefits	5,736	12,761	18,525	22,485	25,290	84,797
Total Cost = Total Benefit	6,039	14,926	21,502	26,237	29,295	97,999

Table VIII-13
Fuel Savings over Lifetimes of Model Year 2012-2016 Passenger Cars
and Light Trucks with Alternative Increases in CAFE Standards
(million gallons)

Passenger Cars						
Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Preferred Alternative	2,396	5,153	7,233	9,446	11,433	35,660
3% Annual Increase	1,197	2,845	4,120	5,509	7,490	21,161
4% Annual Increase	1,476	3,740	5,787	8,046	10,475	29,524
5% Annual Increase	2,157	5,230	8,066	10,630	13,381	39,463
6% Annual Increase	2,520	6,200	9,530	12,589	15,770	46,609
7% Annual Increase	2,855	7,086	10,933	14,080	17,419	52,374
Max Net Benefits	2,848	7,159	10,731	13,324	15,893	49,956
Total Cost = Total Benefit	3,071	7,673	11,492	14,295	17,086	53,619
Light Trucks						
Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Preferred Alternative	1,805	3,698	5,281	6,504	8,061	25,350
3% Annual Increase	234	1,349	2,589	3,882	4,935	12,988
4% Annual Increase	916	2,557	4,298	5,751	7,251	20,773
5% Annual Increase	1,434	3,631	6,076	7,856	9,463	28,460
6% Annual Increase	1,758	4,869	7,584	9,859	11,677	35,747
7% Annual Increase	2,019	5,718	8,813	11,139	12,866	40,555
Max Net Benefits	2,688	6,395	8,919	10,735	11,700	40,437
Total Cost = Total Benefit	2,724	6,621	9,392	11,348	12,507	42,591

H. Potential Impacts of the Final Standards on Consumer Welfare

There are two reasonable 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 the final rule would require, and the economy-wide or "social" perspective on the costs and benefits of requiring higher fuel economy. The agency's analysis of benefits from requiring higher fuel efficiency, presented previously in this Chapter, includes some categories that extend throughout the U.S. economy, such as reductions in the energy security costs associated with U.S. petroleum imports and in the economic damages expected to result from climate change. In contrast, other categories of benefits – principally the economic value of future fuel savings projected to result from higher fuel economy, and including savings in refueling time – will be experienced exclusively by the initial purchasers and subsequent owners of vehicle models whose fuel economy manufacturers elect to improve as part of their strategies for complying with higher CAFE standards. In short, it is important to distinguish between the "private" and "social" benefits and costs.

Although the economy-wide or "social" benefits from requiring higher fuel economy represent an important share of the total economic benefits from raising CAFE standards, NHTSA estimates that benefits *to vehicle buyers themselves* will significantly exceed the costs of complying with the stricter fuel economy standards this rule establishes, as Chapter X shows. Since the agency also assumes that the costs of new technologies manufacturers will employ to improve fuel economy will ultimately be shifted to vehicle buyers in the form of higher purchase prices, NHTSA concludes that the benefits to vehicle buyers from requiring higher fuel efficiency will far outweigh the costs they will be required to pay to obtain it. However, this raises the question of why current purchasing patterns do not result in higher average fuel economy, and why stricter fuel efficiency standards should be necessary to achieve that goal.

As an illustration, Table VIII-14 reports the agency's estimates of the average lifetime values of fuel savings for MY 2012-2016 passenger cars and light trucks calculated using future retail fuel prices, which are those likely to be used by vehicle buyers to project the value of fuel savings they expect from higher fuel economy. The table compares NHTSA's estimates of the average lifetime value of fuel savings for cars and light trucks to the price increases it projects to result as manufacturers attempt to recover their costs for complying with increased CAFE standards for those model years by increasing vehicle sales prices. As the table shows, the agency's estimates of the present value of lifetime fuel savings (discounted using the OMB-prescribed 3% rate) 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 2016, NHTSA projects that average lifetime fuel savings will exceed the average price increase by more than $2,000 for cars, and by more than $2,700 for light trucks.

Table VIII-14
Value of Lifetime Fuel Savings vs. Average Technology Cost Increase/Vehicle

Fleet	**Measure**	**Model Year**				
		2012	**2013**	**2014**	**2015**	**2016**
Passsenger Cars	**Value of Fuel Savings**	**$759**	**$1,469**	**$1,954**	**$2,480**	**$2,932**
	Average Price Increase	**$505**	**$573**	**$690**	**$799**	**$907**
	Difference	**$255**	**$897**	**$1,264**	**$1,680**	**$2,025**
Light Trucks	**Value of Fuel Savings**	**$828**	**$1,634**	**$2,277**	**$2,887**	**$3,700**
	Average Price Increase	**$322**	**$416**	**$621**	**$752**	**$961**
	Difference	**$506**	**$1,218**	**$1,656**	**$2,135**	**$2,739**

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 Table VIII-14 suggest that doing so would *reduce* the effective price of purchasing many new vehicle models, and thus to increase sales of new vehicles. More specifically, why would potential buyers of new vehicles hesitate to make investments in higher fuel economy that would produce the substantial economic returns illustrated by the comparisons presented in Table VIII-14? 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,[271] 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.[272]

Another explanation is that NHTSA's estimates of benefits and costs from requiring manufacturers to improve the fuel efficiency of their vehicle models do not match potential vehicle buyers' ex ante assessment of the likely benefits and costs from requiring higher fuel efficiency. 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 at the time of purchase, because NHTSA has incorrectly estimated some components of the benefits from saving fuel, or 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 agencies' calculations suggest, because they have shorter time horizons than the full vehicle lifetimes assumed by NHTSA and EPA, or because they discount future fuel future 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' rated and actual on-road MPG levels than the agencies estimate.

To illustrate the first of these possibilities, Table VIII-15 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 2016

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[271] 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://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf

[272] 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). "Out of Sight, Out of Mind: The Effectsof Expenses on Mutual Fund Flows," Journal of Business vol. 78, no. 6, pp. 2095-2020.

car or light truck when fuel savings are evaluated over different time horizons to the estimated increase in its price. This table shows that as reported previously in Table VIII-15, when fuel savings are evaluated over the entire expected lifetime of a MY 2016 car (approximately 14 years) or light truck (about 16 years), their discounted present value (using the OMB-prescribed 3% discount rate) lifetime fuel savings exceeds the estimated average price increase by more than $2,000 for cars and by more than $2,700 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 2016 car by about $1,300, and by somewhat more than $1,500 for a MY 2016 light truck. Finally, Table VIII-15 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 2009), the value of fuel savings exceeds the estimated increase in the price of a MY 2016 car by only about $350, and the corresponding difference is reduced to slightly more than $500 for a MY 2016 light truck.

Table VIII-15
Value of Fuel Savings vs. Vehicle Price Increases
with Alternative Assumptions about Vehicle Buyer Time Horizons

Vehicle	Measure	Value over Alternative Time Horizons		
		Expected Lifetime (1)	10 Years	Average Loan Term (2)
MY 2016 Passenger Car	Fuel Savings	$2,932	$2,180	$1,254
	Price Increase	$907	$907	$907
	Difference	$2,025	$1,273	$347
MY 2016 Light Truck	Fuel Savings	$3,700	$2,508	$1,484
	Price Increase	$961	$961	$961
	Difference	$2,739	$1,547	$523

(1) Expected lifetimes are approximately 14 years for cars and 16 years for light trucks.

(2) Average term on new-vehicle loans made by auto finance companies during 2009 was 62 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 March 1, 2010.

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; 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.[273] OMB estimates 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 well above the 3% assumed in NHTSA's evaluation.

Table VIII-16 shows the effect of higher discount rates on vehicle buyers' evaluation of the fuel savings projected to result from the CAFE standards established by this rule, again using MY 2016 passenger cars and light trucks as an example. As Table VIII-14 showed previously, average future fuel savings discounted at the OMB 3% consumer rate exceed the agency's estimated price increases by more than $2,000 for MY 2016 passenger cars and by more than

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[273] Office of Management and Budget, Circular A-4, "Regulatory Analysis," September 17, 2003, 33. *Available at* *http://www.whitehouse.gov/omb/assets/regulatory_matters_pdf/a-4.pdf* (last accessed March 1, 2009).

$2,700 for MY 2016 light trucks. If vehicle buyers instead discount future fuel savings at the average new-car loan rate during 2009 (6.7%), however, these differences decline to slightly more than $1,400 for cars and $1,900 for light trucks, as Table VIII-16 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 13.4% during 2009) reduces these differences to less than $800 for a MY 2016 passenger car and less than $1,100 for the typical MY 2016 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.

Table VIII-16
Value of Fuel Savings vs. Vehicle Price Increases
with Alternative Assumptions about Consumer Discount Rates

Vehicle	**Measure**	**Value at Alternative Discount Rates**			
		OMB Consumer Rate (3%)	**New Car Loan Rate (6.7%; 1)**	**OMB Investment Rate (7%)**	**Consumer Credit Card Rate (13.4%; 2)**
MY 2016 Passenger Car	**Fuel Savings**	**$2,932**	**$2,336**	**$2,300**	**$1,669**
	Price Increase	**$907**	**$907**	**$907**	**$907**
	Difference	**$2,025**	**$1,429**	**$1,393**	**$762**
MY 2016 Light Truck	**Fuel Savings**	**$3,700**	**$2,884**	**$2,836**	**$2,030**
	Price Increase	**$961**	**$961**	**$961**	**$961**
	Difference	**$2,739**	**$1,923**	**$1,875**	**$1,069**

(1) Average rate on 48-month new-vehicle loans made by commercial banks during 2009 was 6.72%; 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 March 1, 2010.

(2) Average rate on consumer credit card accounts at commercial banks during 2009 was13.4%; 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 March 1, 2010.

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. Doing so would reduce the amount by which future fuel savings exceed the estimated increase in the prices of MY 2016 vehicles to about $340 for passenger cars and $570 for light trucks. 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.[274] 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.

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 require 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, 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 2002 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.

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[274] Kubik, M. (2006). Consumer Views on Transportation and Energy. Second Edition. Technical Report: National Renewable Energy Laboratory. Docket NHTSA-2009-0050-0038.

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. Although the losses in buyers' welfare associated with these responses cannot be large enough to offset the estimated value of fuel savings reported in the agencies' analyses, they 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.[275]

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 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.[276] 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 modest when compared to those provided by 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, they are not likely to 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

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[275] 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.

[276] Greene, David L., "How Consumers Value Fuel Economy: A Literature Review," Draft report to U.S. Environmental Protection Agency, Oak Ridge National Laboratory, December 29, 2009; see Table 10, p. 37. (Docket NHTSA-2009-0059-0155) and 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.

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 prevents 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.

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.[277] 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.[278] 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.[279] 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 motivate buyers to purchase 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

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[277] 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).

[278] Larrick, R. P., and J.B. Soll (2008). "The MPG illusion." *Science* 320: 1593-1594. Docket EPA-HQ-OAR-2009-0472-0043.

[279] Sanstad, A., and R. Howarth (1994). "'Normal' Markets, Market Imperfections, and Energy Efficiency." Energy Policy 22(10): 811-818. Docket EPA-HQ-OAR-2009-0472-11289.

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, and as part of a sensitivity analysis, this section presents an alternative accounting of the benefits and costs of CAFE standards for MY 2012-2016 passenger cars and light trucks and discusses its implications.

Table VIII-17 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 Table VIII-17 also shows, 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.[280] 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 Table VIII-17 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 energy security externalities to the U.S. economy from reduced consumption and imports 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 energy security externalities, and increased costs from added driving.

Line 14 of Table VIII-17 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 of the table) resulting from the rule consist of the sum of private (line 6) and social (line 13) benefits, minus technology costs (line 14); as

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[280] 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.

expected, the figures reported in line 15 of the table are identical to those reported previously in the agency's customary format (see Chapter X).

Table VIII-17 highlights 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 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 because the substantial value of reductions in environmental and energy security externalities is almost exactly offset by the decline in fuel tax revenues and the increased costs associated with added vehicle use via the rebound effect of higher fuel economy.

As a consequence, the net economic benefits of the rule mirror closely its 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-17
Private, Social, and Total Benefits and Costs of MY 2012-16 CAFE Standards:
Passenger Cars plus Light Trucks

Entry	**Model Year**					**Total, 2012-2016**
	2012	**2013**	**2014**	**2015**	**2016**	
1 Value of Fuel Savings (at Retail Fuel Prices)	**$10.5**	**$22.9**	**$32.9**	**$42.5**	**$52.7**	**$161.6**
2 Savings in Refueling Time	**$0.7**	**$1.4**	**$1.9**	**$2.5**	**$3.0**	**$9.4**
3 Consumer Surplus from Added Driving	**$0.7**	**$1.5**	**$2.2**	**$2.8**	**$3.4**	**$10.5**
4 Total Private Benefits (=1+2+3)	**$11.9**	**$25.8**	**$37.0**	**$47.8**	**$59.0**	**$181.5**
5 Reduction in Private Benefits	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**
6 Net Private Benefits (=1+2)	**$11.9**	**$25.8**	**$37.0**	**$47.8**	**$59.0**	**$181.5**
7 Change in Fuel Tax Revenues	**-$1.3**	**-$2.7**	**-$3.8**	**-$4.8**	**-$5.9**	**-$18.5**
8 Reduced Health Damages from Criteria Emissions	**$0.5**	**$0.9**	**$1.3**	**$1.6**	**$2.0**	**$6.4**
9 Reduced Climate Damages from CO2 Emissions	**$0.9**	**$2.0**	**$2.9**	**$3.8**	**$4.8**	**$14.5**
10 Reduced Energy Security Externalities	**$0.5**	**$1.2**	**$1.6**	**$2.1**	**$2.5**	**$8.0**
11 Reduction in Externalities (=8+9+10)	**$1.9**	**$4.1**	**$5.9**	**$7.6**	**$9.3**	**$28.8**
12 Increased Costs of Congestion, etc.	**-$0.7**	**-$1.3**	**-$1.9**	**-$2.4**	**-$3.0**	**-$9.4**
13 Net Social Benefits (=7+11+12)	**$0.0**	**$0.1**	**$0.1**	**$0.3**	**$0.5**	**$1.0**
14 Technology Costs	**$5.9**	**$7.9**	**$10.5**	**$12.5**	**$14.9**	**$51.7**
15 Net Total Benefits (=6+12-14)	**$6.0**	**$17.9**	**$26.6**	**$35.5**	**$44.6**	**$130.7**

As discussed in detail previously, it is possible that NHTSA has overestimated 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, Table IV.G.6-5 shows the rule's cumulative economic impacts for MY 2012-16 passenger cars and light trucks under varying assumptions about the agency's potential overestimation of fuel savings and the value of potential changes in vehicle attributes such as performance, carrying capacity, or safety.

Table VIII-18 accounts for *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-15 and VIII-16 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 Table VIII-18 illustrates 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.[281] As Table VIII-18 shows, 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 Table IV.G.6-4 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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[281] 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-18
Effect of Overestimation of Fuel Savings or Omission of Welfare Losses on Net Private and Total Benefits of MY 2012-2016 CAFE Standards

	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)**	**$161.6**	**$161.6**	**$161.6**
2	**Savings in Refueling Time**	**$9.4**	**$9.4**	**$9.4**
3	**Consumer Surplus from Added Driving**	**$10.5**	**$10.5**	**$10.5**
4	**Total Private Benefits (=1+2+3)**	**$181.5**	**$181.5**	**$181.5**
5	**Reduction in Private Benefits**	**$0.0**	**-$45.4**	**-$90.7**
6	**Net Private Benefits (=1+2)**	**$181.5**	**$136.1**	**$90.7**
7	**Change in Fuel Tax Revenues**	**-$18.5**	**-$18.5**	**-$18.5**
8	**Reduced Health Damages from Criteria Emissions**	**$6.4**	**$6.4**	**$6.4**
9	**Reduced Climate Damages from CO2 Emissions**	**$14.5**	**$14.5**	**$14.5**
10	**Reduced Energy Security Externalities**	**$8.0**	**$8.0**	**$8.0**
11	**Reduction in Externalities (=8+9+10)**	**$28.8**	**$28.8**	**$28.8**
12	**Increased Costs of Congestion, etc.**	**-$9.4**	**-$9.4**	**-$9.4**
13	**Net Social Benefits (=7+11+12)**	**$1.0**	**$1.0**	**$1.0**
14	**Technology Costs**	**$51.7**	**$51.7**	**$51.7**
15	**Net Total Benefits (=6+12-14)**	**$130.7**	**$85.3**	**$40.0**

It is important to reemphasize that NHTSA views the alternative estimates of this rule's economic impacts presented in Table VIII-18 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. 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 final standards. Safety trade-offs associated with fuel economy increases have occurred in the past, and the agencies must be mindful of the possibility of future ones. These past safety trade-offs occurred because manufacturers chose to build smaller and lighter vehicles in response to CAFE standards rather than adding more expensive fuel-saving technologies (and maintaining vehicle size and structural strength), and the smaller and lighter vehicles did not fare as well in crashes as larger and heavier vehicles. Historically, the safest vehicles have been heavy and large, while the vehicles with the highest fatal-crash rates have been light and small, both because the crash rate is higher for small/light vehicles and because the fatality rate per crash is higher for small/light vehicle crashes.

However, given the relative cost-effectiveness of at least some approaches to mass reduction, it is reasonable to assume that the vehicle manufacturers will choose mass reduction as one means of achieving compliance with the final standards. Several manufacturers have already indicated that they plan to do so during the rulemaking time frame.[282]

The question of the effect of changes in vehicle mass on safety in the context of fuel economy is a complex question that poses serious analytic challenges and has been a contentious issue for many years. This contentiousness arises, at least in part, from the difficulty of isolating vehicle mass from other confounding factors (*e.g.*, driver behavior, or vehicle factors such as engine size and wheelbase). In addition, at least in the past, several vehicle factors have been closely related, such as vehicle mass, wheelbase, track width, and structural integrity. The issue has been addressed in the literature for more than two decades.

In its attempt to expand and refine its analysis of the potential safety impacts of the levels of mass reduction evaluated for the MYs 2012-2016 CAFE standards, NHTSA has changed its methodology somewhat between the NPRM and the final rule. We believe that this has led the agencies to a more thorough understanding of this issue.

The NPRM analysis, as discussed below, was based on NHTSA's 2003 report concerning mass and size reduction in MYs 1990-1999 vehicles, and evaluated a "worst-case scenario" in which the safety impacts of the combined reductions of both mass and size for those vehicles were determined for the future passenger car and light truck fleets.[283] Thus, in the NPRM analysis, mass and size could not be separated from one another, resulting in what NHTSA recognized was a larger safety disbenefit than was likely under the MYs 2012-2016 footprint-based CAFE standards. NHTSA emphasized, however, that actual fatalities would likely be less than these "worst-case" estimates, and possibly significantly less, based on the various factors discussed in the NPRM that could reduce the estimates, such as careful mass reduction through material substitution, etc.

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[282] While the manufacturers generally indicate that they plan to reduce mass without reducing size, their adherence to those plans would not remove all bases for any safety concerns.

[283] The analysis excluded 2-door cars.

For the final rule, as promised in the NPRM, NHTSA took a fresh look at its safety impacts analysis and determined that it was both possible and necessary to attempt to separate the effect of mass reductions from the effect of footprint reductions. NHTSA thus performed new statistical analyses of the MYs 1991-99 vehicle database from its 2003 report (now including rather than excluding 2-door cars), assessing relationships between fatality risk, mass, and footprint. The agency found that, using the one-step regression method of its 2003 report, the regression coefficients suggest that mass and footprint each accounted for about half the fatality increase associated with downsizing in a cross-sectional analysis of MYs 1991-1999 cars. They may be considered an "upper-estimate scenario," representing the potential safety effects of future mass reduction if it were accomplished in a manner that resembled straight mass reductions without any particular regard for safety (other than not to reduce footprint). However, when NHTSA applied the same regression method to LTVs, the coefficients indicated a significant societal fatality reduction when mass, but not footprint, is reduced in the heavier LTVs.[284] Fatalities are reduced primarily because mass reduction in the heavier LTVs will reduce risk to occupants of cars and lighter LTVs involved in collisions with these heavier LTVs.[285] Thus, even in the "upper-estimate scenario," the fatality increases associated with mass reduction in the passenger cars would be to a large extent offset by the benefits of mass reduction in the heavier LTVs.

NHTSA also attempted to quantify, for the final rule, a new "lower-estimate scenario," representing the potential safety effects if future vehicle design takes advantage of safety-conscious technologies such as material substitution that can reduce mass without perceptibly changing a car's shape or ride and maintain its structural strength without making it excessively rigid. If this occurs, it could limit the added risk close to only the effects of mass *per se* (the ability to transfer momentum to other vehicles or objects in a collision), resulting in estimated effects in passenger cars that are substantially smaller than in the upper-estimate scenario based directly on the regression results. NHTSA was also able to do this for both passenger cars and LTVs.

Overall, based on the new analyses, NHTSA estimated safety impacts markedly less than those estimated in the "worst-case scenario" presented in the NPRM. NHTSA believes the overall effect of mass reduction in cars and LTVs may be close to zero, and may possibly be beneficial in terms of the fleet as a whole if mass reduction is carefully undertaken in the future (as with careful material substitution that can reduce mass without perceptibly changing a car's shape or ride and maintain its structural strength without making it excessively rigid and other types of "smart design") and if the mass reduction in the heavier LTVs is greater (in absolute terms) than in passenger cars, as discussed further below and in NHTSA's report.

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[284] Conversely, the coefficients indicate a significant increase if footprint is reduced.

[285] We note that there may be some (currently non-quantifiable) welfare losses for purchasers of these heavier LTVs, the mass of which is reduced in response to these final standards. This is due to the fact that in certain crashes, as discussed below, more mass will always be helpful (although certainly in other crashes, the amount of mass reduction modeled by the agency will not be enough to have any significant impact on driver/occupant safety). However, we believe the effects of this will likely be minor. Consumer welfare impacts of the final rule are discussed in more detail in Chapter VIII above.

We emphasize that neither the CAFE standards nor our analysis mandates either mass reduction or any specific technology application. However, mass reduction is one of the technology applications available to manufacturers and is used by the Volpe model to aid in determining the capabilities of manufacturers and in predicting both cost and fuel consumption impacts of higher CAFE standards. In this Chapter, we will analyze the potential impacts of these mass reductions on vehicle safety, but for background, we first present a recent historical perspective of the debate.

Background

NHTSA has a longstanding interest in the relationship between vehicle factors and safety, both for establishing our safety standards and for establishing our CAFE standards. In July 1991, NHTSA published a study of the effects of passenger car downsizing during 1970-1982 titled *Effect of Car Size on Fatality and Injury Risk*. In this report, NHTSA concluded that changes in the size and weight composition of the new car fleet from 1970 to 1982 resulted in increases of nearly 2,000 deaths and 20,000 serious injuries per year over the number of deaths and serious injuries that would have occurred absent this downsizing.

Parties reviewing NHTSA's 1991 report identified a number of areas that could be improved. Suggestions included extending the analyses to include light trucks and vans, examining finer gradations to distinguish the relative impacts of weight reduction for the heavier cars versus those for the lighter cars, analyzing all crash modes, and doing more to isolate the effects of vehicle mass from behavioral and environmental variables.

NHTSA agreed that accommodating these suggestions would make the study more useful as a tool for NHTSA decisions on safety and fuel economy standards. Accordingly, NHTSA developed a more comprehensive analytic model to encompass all light vehicles, and to allow a finer look at safety impacts in different segments of the light vehicle population.

The study produced through the use of this model was NHTSA's first effort to estimate the effect of a 100-pound weight reduction in each of the important crash modes, and to do this separately for cars and light trucks. NHTSA recognized that the findings, whatever they were, would likely be controversial, so the agency chose to have the draft report peer-reviewed by the National Academy of Sciences before publishing the document. The Academy published its review on June 12, 1996.[286] The report expressed concerns about the methods used in the analyses and concluded, in part, "the Committee finds itself unable to endorse the qualitative conclusions in the reports about projected highway fatalities and injuries because of large uncertainties associated with the results. . ." These reservations were principally concerned with the question of whether the NHTSA analyses had adequately controlled for confounding factors, such as driver age, gender, and aggressiveness.

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[286] Transportation Research Board, Letter Report – Committee to Review Federal Estimates of the Relationship of Vehicle Weight to Fatality and Injury Risk, Accession Number 00723787. *See* http://onlinepubs.trb.org/onlinepubs/reports/letrept.html (last accessed March 15, 2010).

1. NHTSA's 1997 Report

NHTSA responded at length to the committee report, and revised its report to address the committee recommendations. The revised report was published as a finished document in 1997,[287] with a new Appendix F titled "Summary and Response to TRB's Recommendations on the Draft Report."

In this 1997 report, NHTSA concluded that, calibrated from 1985-93 cars and light trucks involved in crashes in calendar years 1989-1993, there was little overall effect for a 100-pound weight reduction in light trucks and vans, because increased fatalities of truck occupants were offset by a reduction of fatalities in the vehicles that collided with the lighter trucks, whereas a 100-pound reduction in cars was associated with an increase of about 300 fatalities per year. Based on this analysis and subsequent activities, the safety consequences of weight reduction have been considered by NHTSA in deciding upon the appropriate stringency of each of the new safety and fuel economy requirements since that time.

NHTSA's 1997 report did not end the public discussion of this issue. NHTSA followed its standard practice of publishing a notice announcing the report and inviting public comment on the 1997 report.[288] In addition to comments to NHTSA's docket, other papers analyzing the relationship of vehicle weight and safety were published. For instance, Dr. David L. Greene of the U.S. Department of Energy's Oak Ridge National Laboratory published a report titled *Why CAFE Worked* soon after NHTSA's 1997 report was released.[289] In section 5.2 of this report, Dr. Greene's introductory paragraph reads as follows:

> *Vehicle weight significantly affects the safety of the vehicle's occupants. Enough credible work has been done on this subject that this assertion cannot be seriously questioned (citations omitted).* On the other hand, the nature of the trade-off between vehicle mass and safety is often misunderstood, and the implications for fuel economy regulations are generally misinterpreted. *The relationship between fuel economy, mass, and public safety is complex, yet it is probably reasonable to conclude that reducing vehicle mass to improve fuel economy will require some trade-off with safety.* The rational person will realize that individuals, manufacturers, and governments are constantly making trade-offs between safety and cost, safety and other vehicle attributes, safety and convenience, etc. (citation omitted). *An essential feature of a rational economic consumer is the willingness to trade-off risk for money and, since fuel economy saves money, to trade-off safety for fuel economy.*

David L. Greene, 1997, *Why CAFE Worked*, ORNL/CP-94482, Oak Ridge National Laboratory, Oak Ridge, Tennessee, at 22 (Emphases added).

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[287] Kahane, C. J., 1997. Relationships Between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks, NHTSA Technical Report, DOT HS 808 570. This report is available online at http://www-nrd.nhtsa.dot.gov/Pubs/808570.PDF.

[288] *See* 62 FR 34491 (June 26, 1997).

[289] Dr. Greene's report is available online at http://www.osti.gov/bridge/servlets/purl/625225-KPQDOu/webviewable/625225.pdf (last accessed March 15, 2010).

It is noteworthy that Dr. Greene's published work explicitly acknowledges the vehicle weight-safety trade-off documented by NHTSA's studies of the real world crash data. As to Dr. Greene's concerns that the trade-off will be misunderstood, NHTSA has been clear on this point. NHTSA wants to ensure that the public, manufacturers, and governments are aware of the empirical data that demonstrate that there is a trade-off between vehicle mass and safety. Parties must understand this trade-off exists and the size of the trade-off should be quantified as accurately as possible, so it can be considered as part of the decision on average fuel economy standards.

2. The 2002 National Academy of Sciences Study

The next significant event in the vehicle weight and safety discussion began in October 2000, when the Department of Transportation's Appropriations Act for fiscal year 2001 was signed into law. That appropriations law included a provision directing DOT to fund a National Academy of Sciences (NAS) study on the effectiveness and impacts of CAFE standards. NAS released its final study in January 2002 (hereafter, the 2002 NAS Report).[290]

As part of a comprehensive look at the impacts of CAFE standards, it was necessary for the 2002 NAS Report to address the safety impacts of CAFE standards. In Chapter 2 of the study, NAS looked back at the safety impacts of past CAFE standards. Among other observations, NAS recognized that much of the increase in fuel economy between 1975 and 1988 was due to reductions in the size and weight of vehicles, which led to increased safety risks.[291] In fact, NAS noted

> The preponderance of evidence indicates that this downsizing of the vehicle fleet resulted in a hidden safety cost, namely travel safety would have improved even more had vehicles not been downsized.[292]

The committee then focused its analysis on the 1997 NHTSA analysis led by Dr. Kahane. Since there are many published papers on this subject in the literature, the question must be asked, "Why did the National Academy of Sciences choose the NHTSA analyses out of all the published papers?" The NAS committee clearly and unequivocally answered this in its report, where it found that "NHTSA's fatality analyses are still the most complete available in that they accounted for all crash types in which vehicles might be involved, for all involved road users, and for changes in crash likelihood as well as crashworthiness."[293] The NAS committee went on to find that "The April 1997 NHTSA analyses allow the committee to re-estimate the approximate effect of downsizing the fleet between the mid-1970s and 1993." In other words, a committee of the National Academy of Sciences found that NHTSA's analyses were the most thorough of all the published papers, and that NHTSA's analyses were sufficiently persuasive and rigorous to permit a reasonable estimate of the safety penalty associated with downsizing the fleet. In the committee's words:

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[290] *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards* (NRC, 2002).
[291] *Id.*, at 24.
[292] *Id.*, at 69-70.
[293] *Id.*, at 27.

> Thus, the majority of this committee believes that the evidence is clear that past downweighting and downsizing of the light-duty vehicle fleet, while resulting in significant fuel savings, has also resulted in a safety penalty. In 1993, it would appear that the safety penalty included between 1,300 and 2,600 motor vehicle crash deaths that would not have occurred had vehicles been as large and heavy as in 1976.[294].

While this look back is informative, the greater challenge is to use this understanding of the past to guide future actions. Again the NAS committee offered clear guidance in this regard. The NAS Report said:

> In summary, the majority of the committee finds that the downsizing and weight reduction that occurred in the late 1970s and early 1980s most likely produced between 1,300 and 2,600 crash fatalities and between 13,000 and 26,000 serious injuries in 1993. The proportion of these casualties attributable to CAFE standards is uncertain. It is not clear that significant weight reduction can be achieved in the future without some downsizing, and similar downsizing would be expected to produce similar results. *Even if weight reduction occurred without any downsizing, casualties would be expected to increase*. Thus, any increase in CAFE as currently structured could produce additional road casualties, unless it is specifically targeted at the largest, heaviest light trucks.
>
> For fuel economy regulations not to have an adverse impact on safety, they must be implemented using more fuel-efficient technology. Current CAFE requirements are neutral with regard to whether fuel economy is improved by increasing efficiency or by decreasing vehicle weight. One way to reduce the adverse impact on safety would be to establish fuel economy requirements as a function of vehicle attributes, particularly vehicle weight (see Chapter 5). …
>
> *If an increase in fuel economy is effected by a system that encourages either downweighting or the production and sale of more small cars, some additional traffic fatalities would be expected.* Without a thoughtful restructuring of the program, that would be the trade-off that must be made if CAFE standards are increased by any significant amount.[295]

(Emphasis added.)

This discussion by the NAS committee was an impetus for NHTSA to use its existing statutory authority to reform its light truck CAFE program. This involved moving away from the single flat standard for light trucks, because those standards' neutrality with regard to decreasing vehicle size/weight, in lieu of increasing efficiency to improve fuel economy, means they necessarily have a potential safety trade-off. In place of the single flat standard, NHTSA established an attribute-based standard that is a function of the vehicle's footprint. Under this attribute-based standard, the fuel economy target for a vehicle increases as the vehicle footprint is downsized. As long as vehicle manufacturers have to expend funds for the same levels of advanced technology for each footprint size, there is no incentive to change the vehicle to get a

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[294] *Id.*, at 28.
[295] *Id.*, at 77.

less demanding fuel economy target. Thus, the necessary safety trade-off under the single flat standard system is much less likely to arise under an attribute-based system.[296] That is not to suggest there are no safety consequences if vehicle mass is reduced – there are, as documented by NHTSA and explained by the National Academy of Sciences. However, the standards are no longer structured to confer an advantage to a manufacturer that makes footprint downsizing trade-offs. This is a key feature of the attribute-based fuel economy program NHTSA implemented for light trucks.

Two of the 13 NAS committee members dissented on the safety issues.[297] The dissent acknowledges that, "Despite these limitations, Kahane's analysis is far and away the most comprehensive and thorough analysis" of the safety issue.[298] The dissent's primary disagreement with the other 11 committee members centers on the large uncertainties associated with NHTSA's analyses. The dissent acknowledges NHTSA's efforts in the study led by Dr. Kahane to quantify the safety penalty, but concludes that the number of factors in real world crashes is so large and the controls used by the analytical models introduce so much uncertainty that it is not possible to definitively make any statements about a safety penalty.[299]

The majority of the committee responded to the dissent by saying:

> However, the committee does not agree that these concerns should prevent the use of NHTSA's careful analyses to provide some understanding of the likely effects of future improvements in fuel economy, if those improvements involve vehicle downsizing. The committee notes that many of the points raised in the dissent (for example, the dependence of the NHTSA results on specific estimates of age, sex, aggressive driving and urban vs. rural location) have been explicitly addressed in Kahane's response to the [NAS] review and were reflected in the final 1997 report. The estimated relationship between mass and safety were (sic) remarkably robust in response to changes in the estimated effects of these parameters. The committee also notes that the most recent NHTSA analyses yield results that are consistent with the agency's own prior estimates of the effect of vehicle downsizing (citations omitted) and with other studies of the likely effects of weight and size changes in the vehicle fleet (citation omitted). The consistency over time and methodology provides further evidence of the robustness of the adverse safety effects of vehicle size and weight reduction.[300]

In addition, the NAS Committee unanimously agreed that NHTSA should undertake additional research on the subject of fuel economy and safety, "including (but not limited to) a replication, using current field data, of its 1997 analysis of the relationship between vehicle size and fatality risk."[301] NHTSA concurred with this recommendation, and thereafter, NHTSA undertook a

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[296] As noted above, while use of the footprint based approach substantially reduces the incentive to reduce footprint, it does not inhibit the reduction of front, rear or side overhang. The overhangs provide valuable crush space for managing and reducing the crash forces experienced by vehicle occupants.

[297] One of the two dissenters was Dr. David Greene, the author of the 1997 report *Why CAFE Worked*, discussed *supra*.

[298] *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,* at 118.

[299] 2002 NAS Report, at Appendix A.

[300] *Id.*, at 27-28.

[301] *Id.*, at 6.

replication of the 1997 study, using the additional field data that had become available: NHTSA's 2003 study, led again by Dr. Kahane.

As Congress was developing the bill that ultimately became EISA, Congress considered NHTSA's reformed light truck CAFE program established under existing NHTSA authority in deciding what additional CAFE authority NHTSA should be given and what constraints should be put on that authority. Ultimately, EISA was enacted, which mandates that NHTSA establish an attribute-based CAFE system for cars and light trucks.

3. NHTSA's Updated 2003 Study

In October 2003, NHTSA published an updated study.[302] NHTSA's update again used regression models to calibrate crash fatality rates per billion miles for model year 1991-1999 passenger cars, pickup trucks, SUVs, and vans during calendar years 1995-2000. These rates were calibrated separately by vehicle weight, vehicle type, driver age and gender, urban/rural and other vehicle, driver, and environmental factors. One major point of note is that, as the analyses get more sophisticated and able to differentiate the safety trade-off among different types of vehicles, each analysis NHTSA has ever conducted based on this data continues to show that there is a safety trade-off for the existing light vehicle fleet as vehicle mass is reduced.

After controlling for vehicle, driver and environmental factors, the 2003 study found that:

- The association between vehicle weight and overall crash fatality rates in the heavier 1991-1999 light trucks and vans was not significant. Thus, there was no safety penalty for reducing weight in these vehicles.
- In the other three groups of 1991-1999 vehicles – the lighter light trucks and vans, the heavier cars, and especially the lighter cars – fatality rates increased as weights decreased.
  - Lighter light trucks and vans would have an increase of 234 fatalities per year per 100-pound weight reduction.
  - Heavier cars would have an increase of 216 fatalities per year per 100-pound weight reduction.
  - Lighter cars would have an increase of 597 fatalities per year per 100-pound weight reduction.
- There is a crossover weight, above which crash fatality rates increase for heavier light trucks and vans, because the added harm for other road users from the additional weight exceeds any benefits for the occupants of the vehicles. This occurs in the interval of 4,224 pounds to 6,121 pounds, with the most likely single point being 5,085 pounds. The fatality rate changes by less than ±1 percent per 100-pound weight increase over this range.

The draft report was reviewed before publication by experts in statistical analysis of crash data and related vehicle weight and safety issues: Drs. James H. Hedlund, Adrian K. Lund, and Donald W. Reinfurt. The review process is on record – the comments on the draft are available

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[302] Charles J. Kahane, "Vehicle Weight, Fatality Risk, and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks," DOT HS 809 662, October 2003. This report is available online at http://www-nrd.nhtsa.dot.gov/Pubs/809662.PDF .

in Docket NHTSA-2003-16318-0004. Consistent with NHTSA's standard practice, NHTSA published its analysis and sought public comment on it.[303] NHTSA then docketed a response to the public comments on November 9, 2004.[304] There were three principal criticisms of NHTSA's updated study, which are summarized below together with NHTSA's responses to each.

Criticism one: The analyses only considered the relationship of vehicle mass to fatality risk. It did not consider other attributes of vehicle size, such as track width and wheelbase. Dynamic Research Inc. (DRI) presented analyses that included all three of these variables, and its analysis indicated that mass was harmful (*i.e.*, reducing it would be positive for safety) while track width and wheelbase were beneficial. If true, this meant that weight reduction would benefit safety if track width and wheelbase were maintained.

Agency response: See later discussions.

Criticism two: Marc Ross, of the University of Michigan, and Tom Wenzel, of Lawrence Berkeley National Laboratory, commented that vehicle "quality" has a much stronger relationship with fatality risk than vehicle mass. They suggest that lighter cars have a higher fatality risk on average because they are usually the least expensive cars and, in many cases, the "poorest quality" cars. If true, weight reduction is fairly harmless, as long as the lighter cars are of the same "quality" as the heavier cars they replace.

Agency response: In their analyses, Ross and Wenzel did not adjust their rates for driver age and gender. Absent those adjustments, the analysis mingles the effects of what sort of people buy and drive the car with the intrinsic safety of the car, making its conclusions about the intrinsic safety of the car suspect, at best. On average, and considering all crash modes as well as both weight groups of cars, controlling for price has little effect on the weight-safety coefficients in NHTSA's analyses. As a final check, NHTSA ran an analysis of head-on collisions of two 1991-99 cars, since this is a pure measure of the vehicle's performance. The results were that the more expensive vehicle's driver had a slightly *higher* fatality risk than the less expensive vehicle's driver, although the difference was not statistically significant. This indicates that the lower fatality rates for more expensive cars in Ross and Wenzel's study are not due to expensive cars' superior performance in crashes. Accordingly, NHTSA determined the Ross and Wenzel comment did not warrant a change in NHTSA's report.

Criticism three: The Alliance of Automobile Manufacturers, DaimlerChrysler, William E. Wecker Associates, and Environmental Defense all question the accuracy and robustness of the report's calculation of a "crossover weight," above which weight reductions have a net benefit, instead of harm. NHTSA's report said that this crossover point occurs somewhere in the range of 4,224 pounds to 6,121 pounds (this is the "interval estimate"); with the most likely location of the crossover point at 5,085 pounds (this is the "point estimate"). Wecker suggested that NHTSA's interval estimate of from 4,224 to 6,121 pounds only takes sampling error into account. Wecker identified additional factors that it believed make this estimate not robust, and suggests that the interval estimate should be wider. The Alliance and DaimlerChrysler suggested

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[303] *See* 68 FR 66153 (Nov. 5, 2003).

[304] Docket No. NHTSA-2003-16318-0016.

that the crossover weight could be substantially greater than 5,085 pounds, in which case weight reductions for light trucks and vans in the 5-6,000 pound range would have detrimental net effects on safety. Conversely, Environmental Defense believes the crossover weight is well below 5,085 pounds, in which case there would be opportunities to reduce vehicle mass in many light trucks and vans without any safety penalty.

Agency response: While NHTSA's report estimates the crossover weight, the report expressly acknowledged the uncertainty about the exact location of the crossover weight. That is why the report highlighted the interval estimate, instead of the point estimate. It is important to note that the net weight-safety relationship remains close to zero for many hundreds of pounds above and below the point estimate for the crossover weight. As shown on pages 163-166 of NHTSA's 2003 report, the crash fatality rate changes by less than ±1 percent per 100-pound weight increase over a 1,200 pound range on either side of the point estimate for the crossover weight. The data and analysis in the report will not show a statistically significant relationship, in either direction, between weight and safety for the heavier light trucks and vans. That is the important information the report puts in front of the decision maker – i.e., the robust relationship between weight and safety that exists for most vehicles does not exist for the heavier light trucks and vans. With the available data, one cannot develop a precise point estimate for this crossover weight. Thus, NHTSA determined that its report did not require changes in response to these comments.

4. Analyses for the 2009 PRIA

Relevant findings of NHTSA's 2003 study by Dr. Chuck Kahane

The 2003 Kahane study[305] estimated the effect of 100-pound reductions in heavy light trucks and vans (LTVs), light LTVs, heavy passenger cars, and light passenger cars. It compared the fatality rates of LTVs and cars to quantify differences between vehicle types, given drivers of the same age/gender, etc. In this analysis, the effect of "weight reduction" was not limited to the effect of mass *per se* but includes all the factors that were naturally or historically confounded with mass in 1991-1999 cars, such as length, width, structural strength and size of the occupant compartment. The rationale is that adding length, width or strength to a car also makes it heavier. The one exception could be a sweeping replacement of existing materials with light, high-strength components. But when we look at cars of a certain era (namely, 1991-1999), we see they tend to be built in similar ways, and there is essentially a continuum from lighter and smaller cars to heavier, bigger and stronger cars. NHTSA emphasizes that if future weight reductions were to be achieved entirely by substituting stronger, lighter materials for existing materials – without any accompanying reduction in the size or structural strength of the vehicle – the fatality increases associated with such weight reductions would likely be smaller than the increases predicted by this model.[306]

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[305] "Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks", Charles J. Kahane, Ph. D., NHTSA, October 2003, DOT HS 809-662. This report is available online at http://www-nrd.nhtsa.dot.gov/Pubs/809662.PDF

[306] As stated elsewhere, however, at the time of the PRIA for the MYs 2012-2016 standards, NHTSA had not calibrated and predicted how much smaller. Because material substitution has not been applied very extensively in vehicles to date, there is insufficient crash experience to draw statistically valid conclusions directly about the effect of these substitutions.

Six different crash modes were analyzed in the 2003 Kahane report (principal rollover, fixed object, pedestrian/bicycle/motorcyclist, and multi-vehicle crashes with heavy truck, light trucks, and passenger cars). Summing all these crash modes together, the net effects per 100-pound weight reduction were:

- For passenger cars weighing less than 2,950 pounds – fatalities increased by 4.39 percent
- For passenger cars weighing 2,950 pounds or more – fatalities increased by 1.98 percent
- For light trucks weighing less than 3,870 pounds – fatalities increased by 2.90 percent
- For light trucks weighing 3,870 pounds or more – fatalities increased by 0.48 percent

In all of the above groups, fatalities increased with a reduction in weight, although by much less in the last group. However, further analysis of the 2003 Kahane study found that the net safety effect of removing 100 pounds from a light truck is zero in non-rollover crashes for the group of all light trucks with a curb weight greater than 3,900 lbs. Although there is much statistical uncertainty around those figures, we determined that there must be a crossover weight somewhere between 4,264 and 6,121 pounds, with a point estimate at 5,085 pounds, above which there is no safety penalty on individual LTVs for reducing weight.[307] This is because the added harm for other road users from the additional weight exceeds any benefits for the occupants of the vehicles.

The agency believes a number of conclusions can be drawn from the 2003 study:

- Heavier and larger vehicles are more crashworthy and less crash-prone.[308]
- The net impacts on safety, considering the six different crash modes, of reducing weight are negative for all but the larger light trucks. However, this type of analysis cannot examine extreme cases. For example, if there were a large mix shift from 50 percent passenger car and 50 percent light truck sales, to 80 percent compact or smaller passenger cars and 20 percent pickup truck sales, this analysis could not determine the net impacts on safety. Nothing in the manufacturers' plans suggests a drastic change in the mix of vehicles, however, nor is there any incentive, in our opinion, for such a change given NHTSA's attribute-based final rule on fuel economy.
- Lighter and smaller vehicles fare worse in single-vehicle collisions.
- Reducing weight and size increases the likelihood of rolling over. Increasing track width (part of the footprint calculation) increases a vehicle's stability and reduces its likelihood of rolling over.
- As stated above, in this historical data, where lower weight typically means smaller size, the analyses measure the effect of reducing weight and size at the same time. Analyses of historical data that enter mass and size attributes (such as wheelbase or track width) as separate independent variables may not calibrate the separate effects accurately because the high correlations among mass, wheelbase, and track width creates a condition of "near multicollinearity" that can adversely affect the accuracy of regression analyses.

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[307] Kahane, Charles J., PhD, Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks, October 2003. DOT HS 809 662. Page 161. Docket No. NHTSA-2003-16318 (http://www-nrd.nhtsa.dot.gov/Pubs/809662.PDF)

[308] See Kahane study, page xiv Table 3 for prorated fatal crash involvements per billion miles.

Furthermore, such analyses might be of limited utility in predicting effects of future weight-reduction technologies, such as material substitution. With these caveats, NHTSA presented initial analyses of its database in its 2004 response to the docket comments on its 2003 report. These initial analyses indicating that rollover is the only type of crash in which track width was the dominant factor. In the analyses of cars weighing less than 2,950 lbs., weight was substantially more important than track width or wheelbase in the other five crash modes investigated.[309]
- Reducing weight increases the likelihood of being killed in a fixed or non-fixed object crash. If a vehicle runs into a tree, the occupant is safer if the vehicle knocks that tree down, rather than if the tree stops the vehicle. A heavier vehicle has a better chance of knocking the tree down.

The 2003 Kahane report also examined the total fatality crash rates in all crash modes; including fatalities to occupants of the case vehicle (*i.e.*, in rollovers, single vehicle and multi-vehicle crashes), occupants of the other vehicle it collided with (to account for aggressive vehicles) and pedestrians. Kahane used VMT data based on CDS odometer readings and controlled for age and gender based on State data on non-culpable crash involvements (induced exposure). With these controls, the societal fatality rates per billion miles were:

Table IX-1
ADJUSTED FATAL-CRASH INVOLVEMENT RATES
PER BILLION CASE VEHICLE MILES, BY VEHICLE TYPE

(Case vehicles are MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000, adjusted for age/gender, rural/urban, day/night, speed limit, and other factors)

Vehicle Type and Size	**Average Curb Weight**	**Fatal Crash Involvements per Billion Miles**
Very small 4-door cars	2,105	15.73
Small 4-door cars	2,469	11.37
Mid-size 4-door cars	3,061	9.46
Large 4-door cars	3,596	7.12
Compact pickup trucks	3,339	11.74
Large (100-series)	4,458	9.56
Small 4-door SUVs	3,147	10.47
Mid-size 4-door SUVs	4,022	13.68
Large 4-door SUVs	5,141	10.03
Minivans	3,942	7.97

In other words, mid-size cars had somewhat lower societal fatal crash rates than SUVs that weighed considerably more. Large cars and minivans had the lowest rates.

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[309] See Kahane (Docket No. 2003-16318-16)

Results from analyses presented in the PRIA for the MYs 2012-2016 standards:

In the PRIA for the MYs 2012-2016 proposed standards, NHTSA estimated the potential "worst case" impact on safety based on the 2003 Kahane study,[310] which estimates the effect of 100-pound reductions in MYs 1991-1999 heavy light trucks and vans (LTVs), light LTVs, heavy passenger cars, and light passenger cars. The numbers in the PRIA represent a worst case estimate—that is, the estimate would only apply if all weight reductions come from reducing both weight and footprint in the same proportion that such designs impacted the original study. Kahane's conclusions are based upon a cross-sectional analysis of the actual on-road safety experience of MY 1991-1999 vehicles. For those vehicles, heavier usually also meant larger-footprint. Hence, the numbers in the new analyses predict the safety consequences that would occur in the unlikely event that weight reduction for MY 2012-2016 vehicles is accomplished mostly by making the vehicles smaller—that is, again, reducing mass *and* reducing footprint.

Exclusive reliance on making vehicles smaller and lighter in response to this rulemaking is unlikely for the following reasons. The flat CAFE standards in effect when those MY1991-1999 vehicles were produced had no penalty for such a strategy for improving fuel economy. In contrast, as discussed above, the current attribute-based CAFE standards do not encourage making vehicles smaller by reducing footprint. This structural change to the CAFE program means that the CAFE standards now favor the use of weight reduction strategies, like material substitution, downsizing the engine and adding turbocharging, that do not involve simply making the vehicle footprint smaller.

Given this structural change to the CAFE program, it is likely that a significant portion of the weight reduction in the MY 2012-2016 vehicles will be accomplished by strategies that have a lesser safety impact than the prevalent 1990s strategy of simply making the vehicles smaller, although NHTSA is unable to predict how large a portion. For example, a manufacturer could conceivably add length, width, or strength to a vehicle by replacing existing materials with light, high-strength components.

NHTSA did not at that time have information (on-road data) to calibrate and predict how much smaller those increases would be for any given mixture of material substitution and other methods of reducing mass, since the data on the safety effects of material substitution alone is not available due to the low numbers of vehicles in the current on-road fleet that have utilized this technology extensively. Nor did NHTSA have analyses to estimate the potential safety impacts of material substitution. We stated that even though NHTSA could not yet quantify these safety effects, we projected that they could be significantly less than those that would result from making smaller and lighter vehicles. We also stated that we were convinced that the safety effects would most likely be larger than zero in passenger cars for the following reasons:

- The following effects of mass *per se* (laws of physics) will persist whether mass is reduced by material substitution, making vehicles smaller, or any other method:

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[310] Kahane (2003).

  - The increased weight disadvantage in collisions with vehicles not covered by the regulation, such as medium-sized trucks (GVWR somewhat larger than 10,000 pounds).
  - In collisions with partially movable objects such as not-so-large trees.

- Our attribute-based standards have the excellent feature that they do not encourage reductions in footprint. However, weight can be removed by means other than material substitution or engine downsizing, in a manner that further increases risk to occupants, even <u>while maintaining footprint</u>:
  - By reducing the overhang in front of the front wheels and behind the rear wheels. These are protective structures whose removal would increase risk to occupants by reducing vehicle crush space.
  - By thinning or removing structures within the vehicle.

The agency used the relationships between weight and safety from Kahane (2003), expressed as percentage increases in fatalities per 100-pound weight reduction, and examined the weight impacts assumed in the PRIA CAFE analysis. However, there we explained that there are several identifiable safety trends already in place or expected to occur in the foreseeable future that are not accounted for in the historical study. For example, there are two important new safety standards that have already been issued and will be phasing in during the rulemaking time frame. 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.[311] 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.[312] 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. 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 analysis and year 2020.

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[311] We note that the Volpe model currently does not account for the weight of safety standards that will be added compared to the MY 2008 baseline, nor does it account for the societal cost of reductions in weight. However, both of these items will be added to the model for the final rule; doing so will raise the weight of every vehicle by roughly 17 pounds in MY 2016 (slightly less in earlier years), which will likely require manufacturers to add slightly more technology to reach the final standards than they were estimated to need to reach the proposed standards. However, NHTSA does not expect the impact of these roughly 17 pounds per vehicle to have a significant impact on the safety analysis.

[312] 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)

The worst case estimate was an increase of 493 fatalities over the lifetime of the MY 2016 passenger car and light truck fleet combined, compared to a continuation of the MY 2011 standards. The agency did not include a lower estimate or impact of mass *per se* on fatalities, for the reasons discussed above.

5. Comments on the 2009 PRIA analysis

Several dozen commenters addressed the safety issue. Claims and arguments made by commenters in response to the safety impacts analysis in the NPRM tended to follow several general themes, as follows:

- NHTSA's estimates are inaccurate because they do not account for:
    - While NHTSA's study only considers vehicles from MYs 1991-1999, more recently-built vehicles are safer than those, and future vehicles will be safer still, thus the safety impacts of mass reduction will be far less than NHTSA estimates;
    - Lighter vehicles are safer than heavier cars in terms of crash-avoidance, because they handle and brake better;
    - Fatalities are linked more to other factors than mass, which NHTSA did not analyze;
    - The structure of the standards reduces/contributes to potential safety risks from mass reduction;
    - NHTSA could mitigate additional safety risks from mass reduction, if there are any, by simply regulating safety more;
    - Casualty risks range widely for vehicles of the same weight or footprint, which skews regression analysis and makes computer simulation a better predictor of the safety impacts of mass reduction;
- DRI's analysis shows that lighter vehicles will save lives, and NHTSA reaches the opposite conclusion without disproving DRI's analysis, therefore NHTSA's analysis is likely wrong;
    - Possible reasons that NHTSA and DRI have reached different conclusions:
        - NHTSA's study should distinguish between reductions in size and reductions in weight like DRI's;
        - NHTSA's study should include two-door cars;
        - NHTSA's study should have used different assumptions;
        - NHTSA's study should include confidence intervals;
- NHTSA should include a "best-case" estimate in its study;
- NHTSA should not include a "worst-case" estimate in its study;

NHTSA recognizes that the issue of the potential safety impacts of mass reduction, which was one of the many factors considered in the balancing that led to the agencies' conclusion as to appropriate stringency levels for the MYs 2012-2016 standards, is of great interest to the public and could possibly be a more significant factor in regulators' and manufacturers' decisions with regard to future standards beyond MY 2016. NHTSA is committed to analyzing this issue thoroughly and holistically going forward, based on the best available science, in order to further its twin missions of safety and energy conservation. We respond to the claims raised by commenters in turn below.

NHTSA's estimates are inaccurate because NHTSA's study only considers vehicles from MYs 1991-1999, but more recently-built vehicles are safer than those, and future vehicles will be safer still, thus the safety impacts of mass reduction will be far less than NHTSA estimates

A number of commenters (CAS, Adcock, NACAA, NJ DEP, NY DEC, UCS, and Wenzel) argued that the 2003 Kahane report, on which the "worst-case scenario" in the NPRM was based, is outdated because it considers the relationship between vehicle weight and safety in MYs 1991-1999 passenger cars. These commenters generally stated that data from MYs 1991-1999 vehicles provide an inaccurate basis for assessing the relationship between vehicle weight and safety in current or future vehicles, because the fleets of vehicles now and in the future are increasingly different from that 1990s fleet (more crossovers, fewer trucks, lighter trucks, etc.), with different vehicle shapes and characteristics, different materials, and more safety features. Several of these commenters argued that NHTSA should conduct an updated analysis for the final rule using more recent data – Wenzel, for example, stated that an updated regression analysis that accounted for the recent introduction of crossover SUVs would likely find reduced casualty risk, similar to DRI's previous finding using fatality data. CEI, in contrast, argued that the "safety trade-off" would not be eliminated by new technologies and attribute-based standards, because additional weight inherently makes a vehicle safer to its own occupants.

Several commenters (Adcock, CARB, Daimler, NESCAUM, NRDC, Public Citizen, UCS and Wenzel) suggested that NHTSA's analysis was based on overly pessimistic assumptions about how manufacturers would choose to reduce mass in their vehicles, because manufacturers have a strong incentive in the market to build vehicles safely. Many of these commenters stated that several manufacturers have already committed publicly to fairly ambitious mass reduction goals in the mid-term, but several stated further that NHTSA should not assume that manufacturers will reduce the same amount of mass in all vehicles, because it is likely that they will concentrate mass reduction in the heaviest vehicles, which will improve compatibility and decrease aggressivity in the heaviest vehicles. Daimler emphasized that all vehicles will have to comply with the Federal Motor Vehicle Safety Standards, and will likely be designed to test well in NHTSA's NCAP tests.

Other commenters (Aluminum Association, CARB, CAS, ICCT, MEMA, NRDC, U.S. Steel) also emphasized the need for NHTSA to account for the safety benefits to be expected in the future from use of advanced materials for lightweighting purposes and other engineering advances. The Aluminum Association stated that advanced vehicle design and construction techniques using aluminum can improve energy management and minimize adverse safety effects of their use,[313] but NHTSA's safety analysis could not account for those benefits if it were based on MYs 1991-1999 vehicles. CAS, ICCT, and U.S. Steel discussed similar benefits for more recent and future vehicles built with high strength steel (HSS), although U.S. Steel

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[313] The Aluminum Association (NHTSA-2009-0059-0067.3) stated that its research on vehicle safety compatibility between an SUV and a mid-sized car, done jointly with DRI, shows that reducing the weight of a heavier SUV by 20% (a realistic value for an aluminum-intensive vehicle) could reduce the combined injury rate for both vehicles by 28% in moderately severe crashes. The commenter stated that it would keep NHTSA apprised of its results as its research progressed. Based on the information presented, NHTSA believes that this research appears to agree with NHTSA's latest analysis, which finds that a reduction in weight for the heaviest vehicles may improve overall fleet safety.

cautioned that given the stringency of the proposed standards, manufacturers would likely be encouraged to build smaller and lighter vehicles in order to achieve compliance, which fare worse in head-on collisions than larger, heavier vehicles.

Agency response:

NHTSA, in consultation with EPA and DOE, plans to begin updating the MYs 1991-1999 database on which the safety analyses in the NPRM and final rule are based in the next several months. As this task will take at least a year to complete, beginning it immediately after the NPRM would not have enabled the agency to complete it and then conduct a new analysis during the period between the NPRM and the final rule.

For purposes of this final rule, however, we believe that using the same MYs 1991-1999 database as that used in the 2003 Kahane study provides a reasonable basis for attempting to estimate safety impacts due to reductions in mass. While there have been some changes in the light truck fleet mix (perhaps most notably, the introduction of crossover vehicles), the passenger car fleet has changed relatively little overall since the 1990s.[314] Additionally, while commenters often stated that updating the database would help to reveal the effect of recently-introduced lightweight vehicles with extensive material substitution, there have in fact not yet been a significant number of vehicles with substantial mass reduction/material substitution to analyze. Such vehicles, examples of which include the Audi A8, may make up some visible percent of the on-road fleet, but they must also show up in the crash databases for NHTSA to be able to add them to its analysis, and so far they do not show up there in sufficient numbers to impact any analysis that might be performed. Thus, for purposes of the present analysis, the agency does not anticipate much of a difference in result for passenger cars in comparing MYs 1991-1999 to MYs 2000-2009. For light trucks, there may or may not be an impact on the weight/footprint relationship with changes in that fleet mix, comparing MYs 1991-1999 to MYs 2000-2009 light trucks. NHTSA expects that further analysis of historical data files will provide the most robust basis practicable for estimating the potential safety impacts that might occur with future reductions in vehicle mass. However, it recognizes that estimates derived from analysis of historical data, like estimates from any other type of analysis (including simulation-based analysis, which cannot feasibly cover all relevant scenarios), will be uncertain in terms of predicting actual future outcomes with respect to a vehicle fleet, driving population, and operating environment that does not yet exist.

NHTSA recognizes that more recent vehicles have more safety features than 1990s vehicles, which are likely to make them safer overall. To account for this, NHTSA did adjust the results of both its NPRM and final rule analysis to include known safety improvements, like ESC and increases in seat belt use, that have occurred since MYs 1991-1999. However, simply because newer vehicles have more safety countermeasures, does not mean that the weight/safety

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[314] NHTSA notes the CAS' comments regarding changes in the vehicle fleets since the introduction of CAFE standards in the late 1970s, but believes they apply more to the differences between late 1970s through 1980s vehicles and 2010s vehicles than to the differences between 1990s and 2010s vehicles. NHTSA believes that the CAS comments regarding the phase-out of 1970s vehicles and their replacement with safer, better fuel-economy-achieving 1980s vehicles paint with rather too large a brush to be relevant to the main discussion of whether the 2003 Kahane report database can reasonably be used to estimate safety impacts of mass reduction for the MYs 2012-2016 fleet.

relationship necessarily changes. More likely, it would change the target population (the number of fatalities) to which one would apply the weight/safety relationship. Thus, we still believe that mass reduction for passenger cars make them less safe, in certain crashes, than if mass had not been reduced.[315]

As for NHTSA's assumptions about mass reduction, in its analysis, NHTSA generally assumed that lighter vehicles could be reduced in weight by 5 percent while heavier light trucks could be reduced in weight by 10 percent. NHTSA recognizes that manufacturers might choose a different mass reduction scheme than this, and that its quantification of the estimated impact on safety would be different if they did. We emphasize that our estimates are based on the assumptions we have employed and are intended to help the agency consider the potential impact of the final standards on vehicle safety. Thus, based on our analysis, reductions in weight for the heavier light trucks would have positive overall safety impacts,[316] while mass reductions for passenger cars and smaller light trucks would have negative overall safety impacts.

NHTSA's estimates are inaccurate because they do not account for the fact that lighter vehicles are safer than heavier cars in terms of crash-avoidance, because they handle and brake better, and thus fatalities will be reduced

ICCT stated that lighter vehicles are better able to avoid crashes because they "handle and brake slightly better," arguing that size-based standards encourage lighter-weight car-based SUVs with "significantly better handling and crash protection" than 1996-1999 mid-size SUVs, which will reduce both fatalities and fuel consumption. ICCT stated that NHTSA did not include these safety benefits in its analysis. DRI also stated that its 2005 report found that crash avoidance improves with reduction in curb weight and/or with increases in wheelbase and track, because "Crash avoidance can depend, amongst other factors, on the vehicle directional control and rollover characteristics." DRI argued that, therefore, "These results indicate that vehicle weight reduction tends to decrease fatalities, but vehicle wheelbase and track reduction tends to increase fatalities."

Agency response:

In fact, NHTSA's regression analysis of crash fatalities per million registration years measures the effects of crash avoidance, if there are any, as well as crashworthiness. Given that the empirical data for passenger cars show a trend of higher crash rates for lighter cars, it is unlikely that lighter cars have, in the net, superior crash avoidance, although the agency recognizes that they may have advantages in certain individual situations.

NHTSA does not agree that mass reduction will always improve crash avoidance—the relationship of vehicle mass to rollover and directional stability is more complex than

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[315] If one has a vehicle (vehicle A), and both downweights the vehicle and adds new safety equipment to it, thus creating a variant (vehicle A_1), the variant might conceivably have a level of overall safety for its occupants is equal to that of the original vehicle (vehicle A). However, vehicle A_1 might not be as safe as second variant (vehicle A_2) of vehicle A, one that is produced by adding to vehicle A the same new safety equipment added to the first variant, but this time without any downweighting.

[316] This is due to the beneficial impact on the occupants of vehicles struck by the downweighted larger vehicles.

commenters imply. For rollover, it is true that if heavy pickups were always more top-heavy than lighter pickups of the same footprint, their higher center of gravity could make them more rollover-prone, yet some mass can be placed so as to lower a vehicle's center of gravity and make it less rollover-prone. For mass reduction to be beneficial in rollover crashes, then, it must take center of gravity height into account, which can involve a much more extensive vehicle redesign, which can in turn be more expensive.

Similarly, for directional stability, it is true that having more mass increases the "understeer gradient" of cars – *i.e.*, it reinforces their tendency to proceed in a straight line and slows their response to steering input, which would be harmful where prompt steering response is essential, such as in a double-lane-change maneuver to avoid an obstacle. Yet more mass and a higher understeer gradient could help when it is better to remain on a straight path, such as on a straight road with icy patches where wheel slip might impair directional stability. Thus, while NHTSA recognizes that less vehicle mass can sometimes improve crash avoidance capability, NHTSA believes that commenters have overlooked the situations when more vehicle mass can help in other kinds of crash avoidance.

Further, our research suggests that additional vehicle mass may be even more helpful when the average driver's response to a vehicle's maneuverability is taken into account. Lighter cars have historically (1976-2009) had higher collision-involvement rates than heavier cars – even in multi-vehicle crashes where directional and rollover stability is not particularly an issue.[317] Based on our analyses using nationally-collected FARS and GES data, drivers of lighter cars are more likely to be the culpable party in a 2-vehicle collision, even after controlling for footprint, the driver's age, gender, urbanization, and region of the country.

Thus, based on this data, it appears that lighter cars may not be driven as well as heavier cars, although it is unknown why this is so. If poor drivers intrinsically chose light cars (self-selection), it might be evidenced by an increase in antisocial driving behavior (such as DWI, drug involvement, speeding, or driving without a license) as car weight decreases, after controlling for driver age and gender – in addition to the increases in merely culpable driver behavior (such as failure to yield the right of way). But analyses in NHTSA's 2003 report did not show an increase in antisocial driver behavior in the lighter cars paralleling their increase in culpable involvements.

Another hypothesis is that certain aspects of lightness and/or smallness in a car give a driver a perception of greater maneuverability that ultimately results in driving with less of a "safety margin," *e.g.*, encouraging them to weave in traffic. That may appear paradoxical at first glance, as maneuverability is, in the abstract, a safety plus. Yet the situation is not unlike powerful engines that could theoretically enable a driver to escape some hazards, but in reality have long been associated with high crash and fatality rates.[318]

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[317] NHTSA (2000). *Traffic Safety Facts 1999.* Report No. DOT HS 809 100. Washington, DC: National Highway Traffic Safety Administration, p. 71; Najm, W.G., Sen, B., Smith, J.D., and Campbell, B.N. (2003). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System*, Report No. DOT HS 809 573. Washington, DC: National Highway Traffic Safety Administration, p. 48.

[318] Robertson, L.S. (1991), "How to Save Fuel and Reduce Injuries in Automobiles," *The Journal of Trauma*, Vol. 31, pp. 107-109; Kahane, C.J. (1994). Correlation of NCAP Performance with Fatality Risk in Actual Head-On

NHTSA's estimates are inaccurate because fatalities are linked more to other factors than mass, which NHTSA did not analyze

Tom Wenzel stated that the safety record of recent model year crossover SUVs indicates that weight reduction in this class of vehicles (small to mid-size SUVs) resulted in a reduction in fatality risk. Wenzel argued that NHTSA should acknowledge that other vehicle attributes may be as important, if not more important, than vehicle weight or footprint in terms of occupant safety, such as unibody construction as compared to ladder-frame, lower bumpers, and less rigid frontal structures, all of which make crossover SUVs more compatible with cars than truck-based SUVs.

Marc Ross commented that fatalities are linked more strongly to intrusion than to mass, and stated that research by safety experts in Japan and Europe suggests the main cause of serious injuries and deaths is intrusion due to the failure of load-bearing elements to properly protect occupants in a severe crash. Ross argued that the results from this project have "overturned the original views about compatibility," which thought that mass and the mass ratio were the dominant factors. Since footprint-based standards will encourage the reduction of vehicle weight through materials substitution while maintaining size, Ross stated, they will help to reduce intrusion and consequently fatalities, as the lower weight reduces crash forces while maintaining size preserves crush space. Ross argued that this factor was not considered by NHTSA in its discussion of safety. ICCT agreed with Ross' comments on this issue.

In previous comments on NHTSA rulemakings and in several studies, Wenzel and Ross have argued generally that vehicle design and "quality" is a much more important determinant of vehicle safety than mass. In comments on the NPRM, CARB, NRDC, Sierra Club, and UCS echoed this theme.

ICCT commented as well that fatality rates in the EU are much lower than rates in the U.S., even though the vehicles in the EU fleet tend to be smaller and lighter than those in the U.S. fleet. Thus, ICCT argued, "This strongly supports the idea that vehicle and highway design are far more important factors than size or weight in vehicle safety." ICCT added that "It also suggests that the rise in SUVs in the U.S. has not helped reduce fatalities." CAS also commented that Germany's vehicle fleet is both smaller and lighter than the American fleet, and has lower fatality rates.

Agency response:

NHTSA agrees that there are many features that affect safety. While crossover SUVs have lower fatality rates than truck-based SUVs, there are no analyses that attribute the improved safety to mass alone, and not to other factors such as the lower center of gravity or the unibody construction of these vehicles. While a number of improvements in safety can be made, they do not negate the fact that another 100 lbs. could make a passenger car or crossover vehicle safer for its occupants, because of the effects of mass per se, as discussed in the FRIA. Moreover, in the

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Collisions, NHTSA Technical Report No. DOT HS 808 061. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/808061.PDF, pp. 4-7.

2004 response to docket comments, NHTSA explained that the significant relationship between mass and fatality risk persisted even after controlling for vehicle price or nameplate, suggesting that vehicle "quality" as cited by Wenzel and Ross is not necessarily more important than vehicle mass.

As for reductions in intrusions due to material substitution, while NHTSA agrees generally that the use of new and innovative materials may have the potential to reduce crash fatalities, such vehicles have not been introduced in large numbers into the vehicle fleet. NHTSA will continue to monitor the situation, but ultimately the impacts of different materials on overall safety in the real world (not just in simulations) will need to be analyzed when vehicles with these materials are on the road in sufficient quantities to provide statistically significant results. For example, a vehicle that is designed to be much stiffer to reduce intrusion is likely to have a more severe crash pulse and thus impose greater forces on the occupants during a crash, and might not necessarily be good for elderly and child occupant safety in certain types of crashes. Such trade-offs make it difficult to estimate overall results accurately without real world data. NHTSA will continue to evaluate and analyze such real world data as it becomes available, and will keep the public informed as to the agency's progress.

ICCT's comment illustrates the fact that different vehicle fleets in different countries can face different challenges. NHTSA does not believe that the fact that the EU vehicle fleet is generally lighter than the U.S. fleet is the exclusive reason, or even the primary factor, for the EU's lower fatality rates. The data ICCT cites do not account for significant differences between the U.S. and the EU such as in belt usage, drunk driving, rural/urban roads, driving culture, etc.

The structure of the standards reduces/contributes to potential safety risks from mass reduction

Since switching in 2006 to setting attribute-based light truck CAFE standards, NHTSA has emphasized that one of the benefits of a footprint-based standard is that it discourages manufacturers from building smaller, less safe vehicles to achieve CAFE compliance by "balancing out" their larger vehicles, and thus avoids a negative safety consequence of increasing CAFE stringency.[319] Some commenters on the NPRM (Daimler, IIHS, NADA, NRDC, Sierra Club *et al.*) agreed that footprint-based standards would protect against downsizing and help to mitigate safety risks, while others stated that there would still be safety risks even with footprint-based standards – CEI, for example, argued that mass reduction inherently creates safety risks, while IIHS and Porsche expressed concern about footprint-based standards encouraging manufacturers to manipulate wheelbase, which could reduce crush space and worsen vehicle handling.

Some commenters also focused on the shape and stringency of the target curves and their potential effect on vehicle safety. IIHS agreed with the agencies' tentative decision to cut off the target curves at the small-footprint end. Regarding the safety impact of the curves requiring less

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[319] We note that commenters were divided on whether they believed there was a clear correlation between vehicle size/weight and safety (CEI, Congress of Racial Equality, Heritage Foundation, IIHS, Spurgeon, University of PA Environmental Law Project) or whether they believed that the correlation was less clear, for example because they believed that vehicle design was more important than vehicle mass (CARB, Public Citizen).

stringent targets for larger vehicles, while IIHS stated that increasing footprint is good for safety, CAS, Wenzel, and the UCSB students stated that decreasing footprint may be better for safety in terms of risk to occupants of other vehicles. Daimler, Wenzel, and the University of PA Environmental Law Project commented generally that more similar passenger car and light truck targets at identical footprints (as Wenzel put it, a single target curve) would improve fleet compatibility and thus, safety, by encouraging manufacturers to build more passenger cars instead of light trucks.

Agency response:

NHTSA continues to believe that footprint-based standards help to mitigate potential safety risks from downsizing if the target curves maintain sufficient slope, because, based on the agency's analysis, larger-footprint vehicles are safer than smaller-footprint vehicles.[320] Maintaining sufficient slope creates a disincentive for manufacturers to produce smaller-footprint vehicles because as footprint decreases, the corresponding fuel economy/GHG emission target becomes more stringent.[321] The shape of the footprint curves themselves have been designed to be approximately "footprint neutral" within the sloped portion of the functions – that is, to neither encourage manufacturers to increase the footprint of their fleets, nor to decrease it. Upsizing also is discouraged through a "cut-off" at larger footprints. For both cars and light trucks there is a "cut-off" that affects vehicles smaller than 41 square feet. The agencies recognize that for manufacturers who make small vehicles in this size range, this cut off 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. The cut off may also create some 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. In addition, vehicles in this market segment are the lowest price point for the light-duty automotive market, with a number of models in the $10,000 to $15,000 range. In order to justify selling more vehicles in this market in order to generate fuel economy or CO2 credits (that is, for this final rule to be the incentive for selling more vehicles in this small car segment), a manufacturer would need to add additional technology to the lowest price segment vehicles, which could be challenging. Therefore, due to these two reasons (a likely limit in the market place for the smallest sized cars and the potential consumer acceptance difficulty in adding the necessary technologies in order to generate fuel economy and CO2 credits), the agencies believe that the incentive for manufacturers to increase the sale of vehicles smaller than 41 square feet due to this rulemaking, if present, is small. For further discussion on these aspects of the standards, please see Section II.C above and Chapter 2 of the joint TSD.

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[320] See the FRIA.

[321] We note, however, that vehicle footprint is not synonymous with vehicle size. Since the footprint is only that portion of the vehicle between the front and rear axles, footprint-based standards do not discourage downsizing the portions of a vehicle in front of the front axle and to the rear of the rear axle, or to other portions of the vehicle outside the wheels. The crush space provided by those portions of a vehicle can make important contributions to managing crash energy. At least one manufacturer has confidentially indicated plans to reduce overhang as a way of reducing mass on some vehicles during the rulemaking time frame. Additionally, simply because footprint-based standards create no incentive to downsize vehicles, does not mean that manufacturers may not choose to do so if doing so makes it easier to meet the overall standard (as, for example, if the smaller vehicles are so much lighter that they exceed their targets by much greater amounts).

Nevertheless, we recognize that footprint-based standards are not a panacea – our analysis continues to show that mass reduction can increase safety risk in passenger cars even if footprint is maintained, and there are ways that manufacturers may increase footprint that either improve or reduce vehicle safety, as indicated by IIHS and Porsche.

With regard to whether the agencies should set separate curves or a single one, NHTSA also notes in Section II.C that EPCA requires NHTSA to establish standards separately for passenger cars and light trucks, and thus concludes that the standards for each fleet should be based on the characteristics of vehicles in each fleet. In other words, the passenger car curve should be based on the characteristics of passenger cars, and the light truck curve should be based on the characteristics of light trucks—thus to the extent that those characteristics are different, an artificially-forced convergence would not accurately reflect those differences. However, such convergence could be appropriate depending on future trends in the light vehicle market, specifically further reduction in the differences between passenger car and light truck characteristics. While that trend was more apparent when car-like 2WD SUVs were classified as light trucks, it seems likely to diminish for the model year vehicles subject to these rules as the truck fleet will be more purely “truck-like” than has been the case in recent years.

NHTSA’s estimates are inaccurate because NHTSA could mitigate additional safety risks from mass reduction, if there are any, by simply regulating safety more

Since NHTSA began considering the potential safety risks from mass reduction in response to increased CAFE standards, some commenters have suggested that NHTSA could mitigate those safety risks, if any, by simply regulating more. In response to the safety analysis presented in the NPRM, several commenters stated that NHTSA should develop additional safety regulations to require vehicles to be designed more safely, whether to improve compatibility (Adcock, NY DEC, Public Citizen, UCS), to require seat belt use (CAS, UCS), to improve rollover and roof crush resistance (UCS), or to improve crashworthiness generally by strengthening NCAP and the star rating system (Adcock). Wenzel commented further that “Improvements in safety regulations will have a greater effect on occupant safety than FE standards that are structured to maintain, but may actually increase, vehicle size.”

Agency response:

NHTSA appreciates the commenters’ suggestions and notes that the agency is continually striving to improve motor vehicle safety consistent with its mission. As noted above, improving safety in other areas affects the target population that the mass/footprint relationship could affect, but it does not necessarily change the relationship.

The safety analysis presented in the final rule evaluates the relative safety risk when vehicles are made lighter than they might otherwise be absent the final MYs 2012-2016 standards. It does consider the impact of known safety regulations as they are projected to affect the target population.

Casualty risks range widely for vehicles of the same weight or footprint, which skews regression analysis and makes computer simulation a better predictor of the safety impacts of mass reduction

Wenzel commented that he had found, in his most recent work, after accounting for drivers and crash location, that there is a wide range in casualty risk for vehicles with the same weight or footprint. Wenzel stated that for drivers, casualty risk does generally decrease as weight or footprint increases, especially for passenger cars, but the degree of variation in the data for vehicles (particularly light trucks) at a given weight or footprint makes it difficult to say that a decrease in weight or footprint will necessarily result in increased casualty risk. In terms of risk imposed on the drivers of other vehicles, Wenzel stated that risk increases as light truck weight or footprint increases.

Wenzel further stated that because a regression analysis can only consider the average trend in the relationship between vehicle weight/size and risk, it must "ignore" vehicles that do not follow that trend. Wenzel therefore recommended that the agency employ computer crash simulations for analyzing the effect of vehicle weight reduction on safety, because they can "pinpoint the effect of specific vehicle designs on safety," and can model future vehicles which do not yet exist and are not bound to analyzing historical data. Wenzel cited, as an example, a DRI simulation study commissioned by the Aluminum Association (Kebschull 2004), which used a computer model to simulate the effect of changing SUV mass or footprint (without changing other attributes of the vehicle) on crash outcomes, and showed a 15 percent net decrease in injuries, while increasing wheelbase by 4.5 inches while maintaining weight showed a 26 percent net decrease in serious injuries.

Agency response:

NHTSA has reviewed Mr. Wenzel's draft report for DOE to which he referred in his comments, but based on its own work does not find such a wide range of safety risk for vehicles with the same weight, although we agree there is a range of risk for a given footprint. In the recent study presented in the FRIA, NHTSA undertook a similar analysis in which we correlated weight to fatality risk for vehicles of essentially the same footprint.[322] The "decile analysis" shows that societal fatality risk generally increases and rarely decreases for lighter relative to heavier cars of the same footprint. Thus, our conclusion is different from that of Mr. Wenzel. We agree that there is a wide range in casualty risk among cars of the same footprint, but we find that that casualty risk is correlated with weight. The correlation shows that heavier cars have lower overall societal fatality rates than lighter cars of very similar footprint.

As for whether computers crash simulations are a better tool than statistical regression analyses for evaluating the influence of vehicle weight on fleet safety, although NHTSA agrees that simulation can be beneficial in certain circumstances, we disagree that it is a better predictor across the board of whether future lighter vehicles in fact will be more or less safe. Vehicle crash dynamics are complex and chaotic – small changes in initial crash conditions (such as impact angle or closing speed) can have large effects on injury outcome. This condition is a consequence of variations in the deformation mode of individual components (*e.g.,* buckling,

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[322] Subsections 2.4 and 3.3 of 2010 Kahane report, below.

bending, crushing, material failure, etc.) and how those variations affect the creation and destruction of load paths between the impacting object and the occupant compartment during the crash event. It is therefore difficult to predict and assess structural interactions using computational methods when one does not have a detailed, as-built geometric and material model. Even when a complete model is available, prudent engineering assessments require extensive physical testing to verify crash behavior and safety. Despite all this, NHTSA recognizes that detailed crash simulations can be useful in estimating the relative structural effects of isolated design changes over a limited range of crash conditions.

Simplified crash simulations can also be valuable tools, but only when employed as part of a comprehensive analytical program. They are especially valuable in evaluating the relative impact and associated confidence intervals of feasible design alternatives. For example, the method employed by Nusholtz *et al*.[323] could be used by a vehicle designer to estimate the benefit of incremental changes in mass or wheelbase as well as the tradeoffs that might be made between them once that designer has settled on a preliminary design. A key difference between the research by Nusholtz and the research by Kebschull that Mr. Wenzel cited[324] is in their suggested applications. The former is useful in evaluating proposed alternatives early in the design process – Nusholtz specifically warns that the model provides only "general insights into the overall risk … and cannot be used to obtain specific response characteristics." Mr. Wenzel implies the latter can "isolate the effect of specific design changes, such as weight reduction" and thus quantify the fleet-wide effect of substantial vehicle redesigns. Yet while Kebschull reports injury reductions to three significant digits, there is no validation that vehicle structures of the proposed weight and stiffness are even feasible with current technology. Thus, while NHTSA agrees that computer simulations can be useful tools, NHTSA recognizes the value of statistical regression analysis for determining fleet-wide effects, precisely because it inherently incorporates all important real-world factors in safety assessments.

DRI's analysis shows that lighter vehicles will save lives, and NHTSA reaches the opposite conclusion without disproving DRI's analysis, therefore NHTSA's analysis is likely wrong

The difference between NHTSA's results and DRI's results for the effect of mass reduction on vehicle safety has been at the crux of this issue for several years. While NHTSA offered some theories in the NPRM as to why DRI might have found a safety benefit for mass reduction, the agency's work since then has enabled the agency to identify what we believe is the most likely

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[323] Nusholtz, G.S., G. Rabbiolo, and Y. Shi, "Estimation of the Effects of Vehicle Size and Mass on Crash-Injury Outcome Through Parameterized Probability Manifolds," Society of Automotive Engineers (2003), Document No. 2003-01-0905. *Available at* http://www.sae.org/technical/papers/2003-01-0905 (last accessed Feb. 15, 2010).

[324] Mr. Wenzel cites the report by Kebschull et al [2004, DRI-TR-04-04-02] as an example of what he regards as the effective use of computer crash simulation. NHTSA does not concur that this analysis represents a viable analytical method for evaluating the fleet-wide tradeoffs between vehicle mass and societal safety. The simulation method employed was not a full finite element representation of each major structural component in the vehicles in question. Instead, an Articulated Total Body (ATB) representation was constructed for each of two representative vehicles. In the ATB model, large structural subsystems were represented by a single ellipsoid. Consolidated load-deflection properties of these subsystems and the joints that tie them together were "calibrated" for an ATB vehicle model by requiring that it reproduce the acceleration pulse of a physical NHTSA crash test. NHTSA notes that vehicle simulation models that are calibrated to a single crash test configuration (*e.g.*, a longitudinal NCAP test into a rigid wall) are often ill-equipped to analyze alternative crash scenarios (*e.g.*, vehicle-to-vehicle crashes at arbitrary angles and lateral offsets).

reason for DRI's findings. The near multicollinearity of the variables of curb weight, track width, and wheelbase creates some degree of concern that any regression models with those variables could inaccurately calibrate their effects. However, the specific two-step regression model used by DRI increases this concern, because it weakens relationships between curb weight and dependent variables by splitting the effect of curb weight across the two regression steps.

The comments below are in response to NHTSA's theories in the NPRM about the source of the differences between NHTSA's and DRI's results. The majority of them are answered more fully in NHTSA's analysis, but we respond to them in this document as well for purposes of completeness.

NHTSA and DRI may have reached different conclusions because NHTSA's study does not distinguish between reductions in size and reductions in weight like DRI's

Several commenters (CARB, CBD, EDF, ICCT, NRDC, and UCS) stated that DRI had been able to separate the effect of size and weight in its analysis, and in so doing proved that there was a safety benefit to reducing weight without reducing size. The commenters suggested that if NHTSA properly distinguished between reductions in size and reductions in weight, it would find the same result as DRI.

Agency response:

In the new analysis presented in the FRIA, NHTSA did attempt to separate the impacts of vehicle size and weight by performing regression analyses with footprint (or alternatively track width and wheelbase) and curb weight as separate independent variables. For passenger cars, NHTSA found that the regressions attribute the fatality increase due to downsizing about equally to mass and footprint – that is, the impact of reducing mass alone is about half the impact of reducing mass *and* reducing footprint. Unlike DRI's results, NHTSA's regressions for passenger cars did not find a safety benefit to reducing weight without reducing size. NHTSA believes that this is an artifact of DRI's two-step regression model.

NHTSA and DRI may have reached different conclusions because NHTSA's study does not include two-door cars like DRI's

One of NHTSA's primary theories in the NPRM as to why NHTSA and DRI's results differed related to DRI's inclusion in its analysis of 2-door cars. NHTSA had excluded those vehicles from its analysis on the grounds that 2-door cars had a disproportionate crash rate (perhaps due to their inclusion of muscle and sports cars) which appeared likely to skew the regression. Several commenters argued that NHTSA should have included 2-door cars in its analysis. DRI and James Adcock stated that 2-door cars should not be excluded because they represent a significant portion of the light-duty fleet, while CARB and ICCT stated that because DRI found safety benefits whether 2-door cars were included or not, NHTSA should include 2-door cars in its analysis. Wenzel also commented that NHTSA should include 2-door cars in subsequent analyses, stating that while his analysis of MY 2000-2004 crash data from 5 states indicates that, in general, 4-door cars tend to have lower fatality risk than 2-door cars, the risk is even lower when he accounts for driver age/gender and crash location. Wenzel suggested that the increased fatality risk in the 2-door car population seemed primarily attributable to the sports cars, and that that was not sufficient grounds to exclude all 2-door cars from NHTSA's analysis.

Agency response:

NHTSA agrees that 2-door cars can be included in the analysis, and retracts previous statements that DRI's inclusion of them was incorrect. In its 2010 analysis, NHTSA finds that it makes little difference to the results whether 2-door cars are included, partially included, or excluded from the analysis. Thus, analyses of 2-door and 4-door cars combined, as well as other combinations, have been included in the analysis. That said, no combination of 2-door and 4-door cars resulted in NHTSA's finding a safety benefit due to mass reduction.

NHTSA and DRI may have reached different conclusions due to different assumptions

DRI commented that the differences found between its study and NHTSA's may be due to the different assumptions about the linearity of the curb weight effect and control variable for driver age, vehicle age, road conditions, and other factors. NHTSA's analysis was based on a two-piece linear model for curb weight with two different weight groups (less than 2,950 lbs., and greater than or equal to 2.950 lbs). The DRI analysis assumed a linear model for curb weight with a single weight group. Additionally, DRI stated that NHTSA's use of eight control variables (rather than three control variables like DRI used) for driver age introduces additional degrees of freedom into the regressions, which it suggested may be correlated with the curb weight, wheelbase, and track width, and/or other control variables. DRI suggested that this may also affect the results and cause or contribute to the differences in outcomes between NHTSA and DRI.

Agency response:

The FRIA accompanying today's final rule documents that NHTSA analyzed its database using both a single parameter for weight (a linear model) and two parameters for weight (a two-piece linear model). In both cases, the logistic regression responded identically, allocating the same way between weight, wheelbase, track width, or footprint.[325] Thus, NHTSA does not believe that the differences between its results and DRI's results are due to whether the studies used a single weight group or two weight groups.

The FRIA also documents that NHTSA examined NHTSA's use of eight control variables for driver age (ages 14-30, 30-50, 50-70, 70+ for males and females separately , versus DRI's use of three control variables for age (FEMALE = 1 for females, 0 for males, YOUNGDRV = 35-AGE for drivers under 35, 0 for all others, OLDMAN = AGE-50 for males over 50, 0 for all others; OLDWOMAN = AGE-45 for females over 45, 0 for all others) to see if that affected the results. NHTSA ran its analysis using the eight control variables and again using three control variables for age, and obtained similar results each time.[326] Thus, NHTSA does not believe that the differences between its results and DRI's results are due to the number of control variables used for driver age.

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[325] Subsections 2.2 and 2.3 of 2010 Kahane report, below.

[326] *Id.*

NHTSA's and DRI's conclusions may be similar if confidence intervals are taken into account

DRI commented that NHTSA has not reported confidence intervals, while DRI has reported them in its studies. Thus, DRI argued, it is not possible to determine whether the confidence intervals overlap and whether the differences between NHTSA's and DRI's analyses are statistically significant.

Agency response:

NHTSA has included confidence intervals for the main results of the 2010 analysis, as shown in Chapter IX of the FRIA. For passenger cars, the NHTSA results are a statistically significant increase in fatalities with a 100 pound reduction while maintaining track width and wheelbase (or footprint); the DRI results are a statistically significant decrease in fatalities with a 100 pound reduction while maintaining track width and wheelbase. The DRI results are thus outside the confidence bounds of the NHTSA results.

NHTSA should include a "best-case" estimate in its study

Several commenters (Center for Auto Safety, NRDC, Public Citizen, Sierra Club *et al.*, and Wenzel) urged NHTSA to include a "best-case" estimate in the final rule, showing scenarios in which lives were saved rather than lost. Public Citizen stated that there would be safety benefits to reducing the weight of the heaviest vehicles while leaving the weight of the lighter vehicles unchanged, and that increasing the number of smaller vehicles would provide safety benefits to pedestrians, bicyclists, and motorcyclists. Sierra Club *et al.* stated that new materials, smart design, and lighter, more advanced engines can all improve fuel economy while maintaining or increasing vehicle safety. Both Center for Auto Safety and Sierra Club argued that the agency should have presented a "best-case" scenario to balance out the "worst-case" scenario presented in the NPRM, especially if NHTSA itself believed that the worst-case scenario was not inevitable. NRDC requested that NHTSA present both a "best-case" and a "most likely" scenario. Wenzel simply stated that NHTSA did not present a "best-case" scenario, despite DRI's finding in 2005 that fatalities would be reduced if track width was held constant.

Agency response:

NHTSA has included an "upper estimate" and a "lower estimate" in the new 2010 analysis. The lower estimate assumes that mass reduction will be accomplished entirely by material substitution or other techniques that do not perceptibly change a vehicle's shape, structural strength, or ride quality. The lower estimate examines specific crash modes and is meant to reflect the increase in fatalities for the specific crash modes in which a reduction in mass *per se* in the case vehicle would result in a reduction in safety: namely, collisions with larger vehicles not covered by the regulations (*e.g.*, trucks with a GVWR over 10,000 lbs), collisions with partially-movable objects (*e.g.*, some trees, poles, parked cars, etc.), and collisions of cars or light LTVs with heavier LTVs – as well as the specific crash modes where a reduction in mass *per se* in the case vehicle would benefit safety: namely, collisions of heavy LTVs with cars or lighter LTVs. The effects of reduced mass will generally persist in these crashes regardless of how the mass is reduced – NHTSA believes that this is the effect of mass *per se*. The lower estimate attempts to quantify that scenario, although any such estimate is hypothetical and subject to considerable uncertainty. NHTSA believes that a "most likely" scenario would be insupportable, and depend entirely upon agency assumptions about how manufacturers intend to reduce mass in their vehicles. While we can speculate upon the potential effects of different methods of mass reduction, we cannot predict with any certainty what manufacturers will ultimately do.

NHTSA should not include a "worst-case" estimate in its study

NRDC, Public Citizen and Sierra Club *et al.* commented that NHTSA should remove the "worst-case scenario" estimate from the rulemaking, generally because it was based on an analysis that evaluated historical vehicles, and future vehicles would be sufficiently different to render the "worst-case scenario" inapplicable.

Agency response:

NHTSA stated in the NPRM that the "worst-case scenario" addressed the effect of a kind of downsizing (*i.e.,* mass reduction accompanied by footprint reduction) that was not likely to be a consequence of attribute-based CAFE standards, and that the agency would refine its analysis of such a scenario for the final rule. NHTSA has not used the "worst-case scenario" in the final rule. Instead, we present three scenarios: the first is an estimate based directly on the regression coefficients of weight reduction *while maintaining footprint* in the statistical analyses of historical data. As discussed above, presenting this scenario is possible because NHTSA attempted to separate the effects of weight and footprint reduction in the new analysis. However, even the new analysis of LTVs produced some coefficients that NHTSA did not consider entirely plausible. NHTSA also presents an "upper estimate" in which those coefficients for the LTVs were adjusted based on additional analyses and a "lower estimate," which estimates the effect if mass reduction is accomplished entirely by safety-conscious technologies such as material substitution.

Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991-1999 and Other Passenger Cars and LTVs

March 24, 2010

Charles J. Kahane, NCSA, NHTSA

1. Summary

1.1 The need for a new analysis of fatality risk, mass, and footprint

On September 28, 2009, NHTSA and EPA issued a joint Notice of Proposed Rulemaking to establish light-duty vehicle Corporate Average Fuel Economy (CAFE) standards and greenhouse gas emission standards for model years 2012-2016.[327] These "footprint-based" standards are intended to discourage downsizing by setting higher mpg levels for smaller footprints, but would not similarly discourage mass reduction that maintains footprint. Footprint is a measure of a vehicle's size, defined roughly as the wheelbase times the average of the front and rear track widths. Several technologies, most notably substitution of light, high-strength materials for conventional materials, have the potential to reduce weight while maintaining a vehicle's footprint and its structural strength.

In considering what technologies are available for improving fuel economy, including mass reduction, an important corollary issue for NHTSA to consider is the potential effect mass reduction may have on safety, specifically, the likely effect on fatal crashes of mass reduction that maintains footprint. The relationship between a vehicle's mass, size, and fatality risk is complex, and it varies in different types of crashes. In 1997 and 2003, NHTSA published statistical analyses of historical crash data that estimated fatal-crash rates as a function of a single parameter, the vehicle mass (its curb weight).[328] These models implicitly assume that mass reduction would be accompanied by historically commensurate reductions in other size parameters such as track width and wheelbase. They may be used to estimate the potential impact of downsizing (reducing mass and size) but are less useful for analysis of mass reduction (reducing mass while maintaining size parameters such as footprint).

NHTSA's Preliminary Regulatory Impact Analysis (PRIA) of August 2009 presented a "worst-case" scenario for the potential safety impact, based on its 2003 statistical analysis of model year 1991-1999 vehicles.[329] The agency acknowledged that the scenario estimated the effect of downsizing, not mass reduction that maintains footprint, and did not reflect the most likely

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[327] 74 Fed. Reg. 49454 (September 28, 2009).

[328] Kahane, C. J. (1997). *Relationships Between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Technical Report. DOT HS 808 570. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/808570.PDF; Kahane, C. J. (2003). *Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks*, NHTSA Technical Report. DOT HS 809 662. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/809662.PDF.

[329] NHTSA (2009). *Preliminary Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks*. Washington, DC: National Highway Traffic Safety Administration, http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/MY2012-2016_CAFE_PRIA.pdf, pp. 430-440, also found in NHTSA Docket No. NHTSA-2009-0059-0016.1.

impact of the regulation.[330] The agency at that time did not yet have sufficient basis for quantifying “reasonable upper and lower ends of the potential range of estimated fatalities” but hoped to “refine its analysis for the final rule.”[331]

During 2003-2005, Dynamic Research, Inc. (DRI) published statistical analyses of historical crash data that estimated fatal-crash rates as a function of three parameters: curb weight, wheelbase, and track width.[332] DRI’s analyses attributed substantial reductions in fatality risk to lower curb weight, offset by increased risk with lower wheelbase or track width. DRI’s results have been frequently cited in comments to the CAFE docket as evidence that mass reduction while maintaining track width and wheelbase – footprint – would likely be beneficial, not harmful to safety.[333]

In response and in the interest of deepening our understanding of these issues, during the past months, the agency has extensively reviewed the literature on vehicle mass, size, and fatality risk. NHTSA now agrees with DRI and other commenters that it is essential to analyze the effect of mass independently from the effects of size parameters such as wheelbase, track width, or footprint – and that the PRIA’s “worst-case” scenario based on downsizing (in which weight, wheelbase, and track width could all be changed) is not useful for that purpose. The agency should instead provide estimates that better reflect the more likely impact of the regulation - estimating the effect of mass reduction that maintains footprint.

But it is more difficult to analyze multiple, independent parameters than a single parameter (e.g., curb weight): specifically, there is a concern that the near multicollinearity of the parameters – the strong, natural and historical correlation of mass and size – can lead to inaccurate statistical estimates of their effects.[334] NHTSA has performed new statistical analyses of its historical database of passenger cars and LTVs (light trucks and vans) from its 2003 report (but now including also 2-door cars), assessing relationships between fatality risk, mass, and footprint. They are described in Sections 2.2 (cars) and 3.2 (LTVs) of this report. While concerns with

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[330] While NHTSA recognizes that the footprint-based standards are intended, in part, to discourage downsizing by giving a higher mpg “target” to smaller-footprint vehicles, NHTSA also recognizes that manufacturers will choose whatever compliance strategy is most effective for them, which may include downsizing if the corresponding increase in fuel economy is enough to exceed the “penalty” of the higher target. Such downsizing may not be reflected in footprint reductions for existing models, but may be reflected in the introduction of smaller models to replace larger models that could be phased out in response to increasingly stringent fuel economy standards.

[331] *Ibid*., p. 434.

[332] 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.

[333] International Council on Clean Transportation, Docket No. NHTSA-2009-0059-0093.1; California Air Resources Board, Docket No. EPA-HQ-OAR-2009-0472-7189.1.

[334] Greene, W. H. (1993). *Econometric Analysis*, Second Edition. New York: Macmillan Publishing Company, pp. 266-268; Allison, P.D. (1999), *Logistic Regression Using the SAS System*. Cary, NC: SAS Institute Inc., pp. 48-51. This report will show variance inflation factor (VIF) scores in the 5-7 range for curb weight, wheelbase, and track width (or, alternatively, curb weight and footprint) in NHTSA’s database, exceeding the 2.5 level where near multicollinearity begins to become a concern in logistic regression analyses.

near multicollinearity are inherent in regression analyses with multiple size/mass parameters, the agency believes that the analysis approach in this report, namely a single-step regression analysis, may reduce those concerns and models the trends in the historical data. The results differ substantially from DRI's, based on a two-step regression analysis. Sections 2.3 and 2.4 of this report attempt to account for the differences primarily by applying selected techniques from DRI's analyses to NHTSA's database.

The statistical analyses – logistic regressions – of trends in MY 1991-1999 vehicles generate one set of estimates of the possible effects of reducing mass by 100 pounds while maintaining footprint. While these effects might conceivably carry over to future mass reductions, there are two reasons, which will be discussed in Sections 2.1 and 2.5, that future safety impacts of mass reduction could differ from projections from historical data:

- The statistical analyses are "cross-sectional" analyses that estimate the increase in fatality rates for vehicles weighing n-100 pounds relative to vehicles weighing n pounds, across the spectrum of vehicles on the road, from the lightest to the heaviest. They do not directly compare the fatality rates for a specific make and model before and after a 100–pound reduction from that model (an approach that might be considered in future analyses). Instead, they use the differences across makes and models as a surrogate for the effects of actual reductions within a specific model; those cross-sectional differences could include trends that are statistically, but not causally related to mass.

- The manner in which mass changed across MY 1991-1999 vehicles might not be consistent with future mass reductions, due to the availability of newer materials and design methods.

Therefore, Sections 2.5 and 3.4 of this report supplement those estimates with one or more scenarios in which some of the logistic regression coefficients are replaced by numbers based on additional analyses and judgment of the likely effect of mass *per se* (the ability to transfer momentum to other vehicles or objects in a collision) and of what trends in the historical data could be avoided by current mass-reduction technologies such as materials substitution. The various scenarios may be viewed as a plausible range of point estimates for the effects of mass reduction while maintaining footprint, but they should not be construed as upper and lower bounds. Furthermore, being point estimates, they are themselves subject to uncertainties, such as, for example, the sampling errors associated with statistical analyses.

NHTSA intends to undertake a formal peer review of this report in accordance with OMB guidelines. The Agency will publish the results of the peer review and any necessary revisions to this report once that process is complete.

1.2 Principal findings and conclusions

NHTSA's 2003 weight-safety report created a database of fatal crashes and vehicle registrations or VMT for model year 1991-1999 passenger cars and LTVs, permitting cross-sectional analyses of the fatality rate per million vehicle years or per billion miles by mass and/or size attributes, while controlling for driver age, gender, and other factors, in a single step of logistic regression.[335]

Passenger cars: This database with the one-step regression method of the 2003 report estimates an increase of 700-800 fatalities when curb weight is reduced by 100 pounds and footprint is reduced by 0.65 square feet (the historic average footprint reduction per 100-pound mass reduction in cars when cars are downsized; as stated above, downsizing is unlikely in MY 2012-2016 cars). The regression attributes the fatality increase about equally to curb weight and to footprint. The results are approximately the same whether 2-door cars are fully included or partially included in the analysis or whether only 4-door cars are included (as in the 2003 report). Regressions by curb weight, track width and wheelbase produce findings quite similar to the regressions by curb weight and footprint, but the results with the single "size" variable, footprint, rather than the two variables, track width and wheelbase vary even less with the inclusion or exclusion of 2-door cars.

In Section 2.3, a two-step regression method that resembles (without exactly replicating) the approach by DRI, when applied to the same (NHTSA's) crash and registration data, estimates a large benefit when mass is reduced, offset by even larger fatality increases when track width and wheelbase (or footprint) are reduced. NHTSA believes that the effects estimated by this method are inaccurate, due to the near multicollinearity of the parameters (curb weight, track width, and wheelbase)[336] even though the analysis is theoretically unbiased.[337] Almost any analysis incorporating those parameters has a possibility of inaccurate coefficients due to near multicollinearity; however, the author, based on experience with other regression analyses of crash data, believes this two-step method augments the possibility of estimating inaccurate coefficients for curb weight, because it weakens relationships between curb weight and dependent variables by splitting the effect of curb weight across the two regression steps.

In Section 2.4, as a check on the results from the regression methods, NHTSA also performed what we refer to as "decile" analyses: simpler, tabular data analysis that compares fatality rates of cars of different mass but similar footprint. Decile analysis is not a precise tool because it does not control for confounding factors such as driver age and gender or the specific type of car. But it may be helpful in identifying the general directional trend in the data when footprint is held constant and curb weight varies. The decile analyses show that fatality risk in MY 1991-1999 cars generally increased and rarely decreased for lighter relative to heavier cars of the same footprint. They suggest that the historical, cross-sectional trend was generally in the lighter ↔ more fatalities direction and not in the opposite direction implied by the regression coefficients from the method that resembles DRI's approach.

The regression coefficients from NHTSA's one-step method suggest that mass and footprint each accounted for about half the fatality increase associated with downsizing in a cross-sectional

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[335] Kahane, (2003), Chapter 3 (car) and Chapter 4 (LTVs).

[336] As evidenced by VIF scores in the 5-7 range in NHTSA's database, exceeding the 2.5 level where near multicollinearity begins to become a concern in logistic regression analyses.

[337] Section 2.3 will try to explain why the two-step method, when applied to NHTSA's 2003 database, produces results a lot like DRI's, but it does not claim that DRI obtained their results from their own database for exactly those reasons. NHTSA did not analyze DRI's database. The two-step method is "theoretically unbiased" in the sense that it seeks to estimate the same parameters as the one-step analysis.

analysis of 1991-1999 cars. They estimate the historical difference in <u>societal</u> fatality rates (i.e., including fatalities to occupants of all the vehicles involved in the collisions, plus any pedestrians) of cars of different curb weights but the same footprint. They may be considered an “upper-estimate scenario” of the effect of future mass reduction – if it were accomplished in a manner that resembled the historical cross-sectional trend – i.e., without any particular regard for safety (other than not to reduce footprint).

However, NHTSA believes that future vehicle design is likely to take advantage of safety-conscious technologies such as materials substitution that can reduce mass without perceptibly changing a car’s shape or ride and maintain its structural strength without making it excessively rigid. This could avoid much of the risk associated with lighter and smaller vehicles in the historical analyses, especially the historical trend toward higher crash-involvement rates for lighter and smaller vehicles.[338] It could thereby shrink the added risk close to just the effects of mass *per se* (the ability to transfer momentum to other vehicles or objects in a collision). Section 2.5 of this report attempts to quantify a “lower-estimate scenario” for the potential effect of mass reduction achieved by safety-conscious technologies; the estimated effects are substantially smaller than in the upper-estimate scenario based directly on the regression results.

We note that the preceding paragraph is conditional. Nothing in the CAFE standard requires manufacturers to use material substitution or, more generally, take a safety-conscious approach to mass reduction. (Footprint-based standards do not specify how or where to remove mass while maintaining footprint. For that matter, they do not even categorically forbid downsizing; they discourage it.) Federal Motor Vehicle Safety Standards include performance tests that verify historical improvements in structural strength and crashworthiness, but few FMVSS provide test information that sheds light about how a vehicle rides or otherwise helps explain the trend toward higher crash-involvement rates for lighter and smaller vehicles. It is possible that using material substitution could avoid the historical trend in this area, but that remains to be studied as manufacturers introduce more and more of these vehicles into the on-road fleet in coming years.

LTVs: The principal difference between LTVs and passenger cars is that mass reduction in the heavier LTVs is estimated to have significant societal benefits, in that it reduces the fatality risk for the occupants of cars and light LTVs that collide with the heavier LTVs. By contrast, footprint (size) reduction in LTVs has a harmful effect (for the LTVs’ own occupants), as in cars. The regression method of the 2003 report applied to the database of that report estimates a societal increase of 231 fatalities when curb weight is reduced by 100 pounds <u>and</u> footprint is reduced by 0.975 square feet (the historic average footprint reduction per 100-pound mass reduction in LTVs). But the regressions attribute an overall <u>reduction</u> of 266 fatalities to the 100-pound mass reduction and an increase of 497 fatalities to the .975-square-foot footprint reduction. The regression results constitute one of the scenarios for the possible societal effects of future mass reduction in LTVs.

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[338] IIHS Advisory No. 5, July 1988, http://www.iihs.org/research/advisories/iihs_advisory_5.pdf; IIHS News Release, February 24, 1998, http://www.iihs.org/news/1998/iihs_news_022498.pdf; Auto Insurance Loss Facts, September 2009, http://www.iihs.org/research/hldi/fact_sheets/CollisionLoss_0909.pdf. Some aspects of vehicle performance could improve, such as stopping distance or steering response, as will be discussed in Section 2.1

However, NHTSA cautions that some of the regression coefficients, even by NHTSA's preferred method, might not accurately model the historical trend in the data, possibly due to near multicollinearity of curb weight and footprint (also present in the car analyses) but perhaps also because of the interaction of both of these variables with LTV type, as will be discussed in Section 3.1.[339] Based on supplementary analyses and discussion in Sections 3.3 and 3.4, this report defines an additional upper-estimate scenario that NHTSA believes may more accurately reflect the historical trend in the data and a lower-estimate scenario that may come closer to the effects of mass *per se*. All three scenarios, however, attribute a societal fatality reduction to mass reduction in the heavier LTVs.

Overall effects of mass reduction while maintaining footprint in cars and LTVs: The immediate purpose of this report's analyses of relationships between fatality risk, mass, and footprint is to develop the four parameters that the Volpe model (developed for NHTSA by the Volpe National Transportation Center) needs in order to predict the safety effects, if any, of the modeled mass reductions in MY 2012-2016 cars and LTVs over the lifetime of those vehicles. The four numbers are the overall percentage increases or decreases, per 100-pound mass reduction while holding footprint constant, in crash fatalities involving: (1) cars < 2,950 pounds (which was the median curb weight of cars in MY 1991-1999), (2) cars ≥ 2,950 pounds, (3) LTVs < 3,870 pounds (which was the median curb weight of LTVs in those model years), and (4) LTVs ≥ 3,870 pounds. Here are the percentage effects for each of the three alternative scenarios:

Fatality Increase (%) per 100-Pound Mass Reduction While Maintaining Footprint

	Actual Regression Result Scenario	**Upper-Estimate Scenario**[340]	**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

In all three scenarios, the estimated effects of a 100-pound mass reduction while maintaining footprint are an increase in cars < 2,950 pounds, substantially smaller increases in cars ≥ 2,950 pounds and LTVs < 3,870 pounds, and a societal benefit for LTVs ≥ 3,870 pounds (because it reduces fatality risk to occupants of cars and lighter LTVs they collide with). These are the estimated effects of reducing each vehicle by exactly 100 pounds. However, the actual mass reduction will vary by make, model, and year. The aggregate effect on fatalities can only be estimated by attempting to forecast, as NHTSA has using inputs to the Volpe model, the mass reductions by make and model. It should be noted, however, that a 100-pound reduction would be 5 percent of the mass of a 2000-pound car but only 2 percent of a 5000-pound LTV. Thus, a

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[339] For example, mid-size SUVs of the 1990s typically had high mass relative to their short wheelbase and footprint (and exceptionally high rates of fatal rollovers); minivans typically have low mass relative to their footprint (and low fatality rates); heavy-duty pickup trucks used extensively for work tend to have more mass, for the same footprint, as basic full-sized pickup trucks that are more often used for personal transportation.

[340] For passenger cars, the upper-estimate scenario <u>is</u> the actual-regression-result scenario.

forecast that mass will decrease by an equal or greater percentage in the heavier vehicles than in the lightest cars would be proportionately more influenced by the benefit for mass reduction in the heavy LTVs than by the fatality increases in the other groups; it is likely to result in an estimated net benefit under one or more of the scenarios. It should also be noted, again, that the three scenarios are point estimates and are subject to uncertainties, such as the sampling errors associated with the regression results. In the scenario based on actual regression results, the 1.96-sigma sampling errors in the above estimates are ±0.91 percentage points for cars < 2,950 pounds and also for cars ≥ 2,950 pounds, ±0.82 percentage points for LTVs < 3,870 pounds, and ±1.18 percentage points for LTVs ≥ 3,870 pounds. In other words, the fatality increase in the cars < 2,950 pounds and the societal fatality reduction attributed to mass reduction in the LTVs ≥ 3,870 pounds are statistically significant. The sampling errors associated with the scenario based on actual regression results perhaps also indicate the general level of statistical noise in the other two scenarios.

2. Analyses of Passenger Cars

2.1 Review

The key issue – mass versus "size" – has been variously perceived over the years. Soon after it became possible to statistically analyze large crash databases, researchers saw that lighter [and smaller] cars had higher fatality and injury rates – e.g., Mela's analysis of New York State data in 1974.[341] During the 1980s and 1990s, NHTSA and others pursued increasingly complex analyses that attempted to isolate the effect of car mass from other covariant factors such as driver age.[342] By 2002, the majority opinion of the National Academy of Sciences' expert panel was that "the downsizing and weight reduction that occurred in the late 1970s and early 1980s most likely produced between 1,300 and 2,600 crash fatalities and between 13,000 and 26,000 serious injuries in 1993."[343]

However, a dissent by two panel members in an appendix to the NAS report argued that mass (dissociated from size) ought to have little influence on fatality risk except in determining the risk in one vehicle relative to another in a multi-vehicle collision – and even this has little net societal effect because, as one vehicle gets lighter and the risk for its own occupants increases, the risk will decrease for the occupants of the other vehicle by a more-or-less equal amount. Societal harm might increase in limited scenarios, such as collisions with a somewhat moveable object or with a substantially heavier vehicle (whose occupants are at little risk and would benefit less than the harm added for the occupants of the light vehicle). Because mass reduction *per se*, intuitively, should not have a large overall effect, the dissenters concluded it might not have much effect in the future.

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[341] Mela, D. F. (1974). "How Safe Can We Be in Small Cars?" *International Congress on Automotive Safety, 3rd,* NHTSA Technical Report. DOT HS 801 481. Washington, DC: National Highway Traffic Safety Administration.
[342] NHTSA (1991). *Effect of Car Size on Fatality and Injury Risk*. Washington, DC: National Highway Traffic Safety Administration; Kahane (1997).
[343] NAS (2002). *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, DC: National Research Council, p. 77.

Even the early studies recognized mass and "size" as theoretically separate although historically confounded factors. Unlike mass, the right kind of "size" intuitively helps a vehicle without increasing harm to occupants of other vehicles in a crash. For example, a wide track increases stability and reduces the likelihood of a rollover; crush space can protect a vehicle's occupants. At first the issue seemed to be only of academic interest, because historic (especially 1975-1980) reductions in vehicle mass were accomplished by manufacturers reducing size when they redesigned a model, or by consumers simply retiring large, heavy cars and purchasing small, light cars of a different model.

The issue became more directly relevant after 2000. The 2002 NAS report proposed restructuring CAFE in a way that would discourage harmful downsizing, for example, by setting higher CAFE targets for smaller vehicles. In response, NHTSA developed footprint-based standards for MY 2008-2011 light trucks that were intended to discourage downsizing (by setting higher mpg levels for smaller footprints) but do not similarly discourage mass reductions that maintain footprint. "Footprint" is roughly defined as the wheelbase times the average of the front and rear track widths, and it is a measure of a vehicle's "size." Congress subsequently mandated an "attribute-based" approach for both passenger car and light truck CAFE standards in the Energy Independence and Security Act (EISA) of 2007. Several technologies, most notably substitution of light, high-strength materials for conventional materials, have been proposed and in some cases implemented to reduce mass while maintaining not only footprint but also the structural strength of a vehicle.

The statistical analyses published by DRI in 2003 and 2005, often cited in the literature, have substantially advanced the belief that footprint-based standards can completely resolve the mass-safety issue. These regression analyses included curb weight, wheelbase, and track width as three separate independent variables and estimated an effect for each of them – unlike NHTSA's 1997 and 2003 analyses that use a single attribute, curb weight, which implicitly incorporated the size reductions that historically accompanied lower mass. DRI's analyses, if correct, make it possible to estimate the effects of mass reduction with or without accompanying size reduction.[344] Intuitively, the fatality increase ought to be substantially smaller if track width and wheelbase are maintained than if all three attributes are reduced. In fact, though, DRI's regression results went beyond this. A 100-pound mass reduction in passenger cars, while maintaining wheelbase and track width was associated with a reduction of 580 fatalities, not an increase. If wheelbase is also reduced by 1.01 inches and track width by 0.34 inches (the historic average reductions of these attributes per 100-pound mass reduction[345]), that adds 368 and 191 fatalities, respectively, resulting in a negligible net effect of 21 lives saved [580 – (368 + 191)]. These numbers have been widely interpreted in the literature to suggest that future mass reductions that maintain footprint, accomplished by technologies such as material substitution, have a potential for net safety benefits.

Hypothetical relationships between mass and fatality risk in cross-sectional analyses: There is a strong historical trend of lighter cars having higher fatality rates for their own occupants. The two obvious factors contributing to the trend are that lighter cars have been, on the average,

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[344] Van Auken and Zellner (2003); Van Auken and Zellner (2005a); Van Auken and Zellner (2005b).

[345] Van Auken and Zellner (2003), pp. 34-35 estimated these historical values (0.34 and 1.01, respectively) by a regression of track width by curb weight and another regression of track width by wheelbase in their MY 1985-1998 database. Exactly the same values were obtained by regressions in NHTSA's MY 1991-1999 database.

smaller than heavy cars and that, in a collision between two vehicles, increasing the mass differential between the two vehicles (all else staying the same), increases the risk for the occupants of the lighter vehicle relative to the occupants of the heavier vehicle. But the first factor might "drop out of the equation" if the analysis controls for size – e.g., by adding size parameters such as track width and wheelbase as independent variables. The second factor might drop out if the dependent variable is the societal fatality rate including the fatalities in the partner vehicles – because the increase in fatality risk for the occupants of the light vehicle is offset by lower fatality risk for the occupants of the other vehicles in the collision. With these two factors out of the picture, would mass still have any residual relationship with societal fatality risk in an analysis that controls for footprint – such as the DRI analysis – and if there is a residual relationship, in what direction?

DRI addressed those questions in two sections on the "theoretical basis for the independent effects of vehicle mass and size on crash avoidance…crashworthiness and compatibility."[346] Their formulas indicate that wheelbase and track width should be protective because they enhance directional stability (preventing loss of control), static stability (preventing rollover), and crush space for the occupant's ride-down (reducing injury severity). The vehicle's mass *per se* "does not explicitly appear in these equations."[347] At most, mass may be an indirect factor. For example, if heavy cars were generally more top-heavy than lighter cars of the same footprint, their higher center of gravity could make them more rollover-prone.[348] But the relationship of mass and center-of-gravity (cg) height is not unidirectional, because sometimes added mass lowers the cg – e.g., four-wheel-drive equipment. Mass is a factor that may increase the "understeer gradient" of cars – i.e., reinforce their tendency to proceed in a straight line and slows their response to steering input.[349] That would be harmful where prompt steering response is essential, such as in a double-lane-change maneuver to avoid an obstacle. But it might help in some circumstances (e.g., a relatively straight icy road) if it is better to remain on a straight path.

There are several additional reasons to expect a residual relationship in some types of crashes between mass reduction in passenger cars and increased fatality risk, even after controlling for footprint and including risk to the occupants of the other vehicle. Some of these factors might be expected in any analysis; others may be characteristic of cross-sectional analyses of recent-past vehicles (e.g., MY 1991-1999 cars). Some are effects of mass *per se*; others, the effects of factors that are related to mass (causally and/or statistically), but not particularly related to footprint. (The applicability of these factors to LTVs will be reconsidered in Section 3.1).

- Societal effects of mass *per se*:
    - A heavy car may be able to knock down a medium-size tree and continue moving forward, whereas a light car would have come to a complete stop – and likewise for collisions with other partially moveable objects such as unoccupied parked vehicles, deformable poles, or large animals. This is not merely an academic point, but a matter of real importance, as shown in Partyka's analysis of frontal impacts of passenger cars into trees or poles in NHTSA's Crashworthiness Data

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[346] Van Auken and Zellner (2005b), pp. 10-22.
[347] *Ibid*., p. 12.
[348] *Ibid*., p. 13.
[349] *Ibid*., p. 12.

System: 56% of the heaviest cars significantly damaged the tree or pole, as compared to only 28-32% of the subcompact or compact cars.[350] "Significant damage to a tree or pole" includes cracking, sheering, or tilting a tree or pole; uprooting a tree; separating a pole from its base; or damage that resulted in replacement of the pole. In other words, the extra mass reduced the velocity change experienced by the car (its ΔV) in approximately ¼ of the frontal collisions with fixed objects.

  - In a collision with a medium-size truck or an LTV[351] with GVWR ≥ 10,000 pounds (not yet regulated by CAFE), a heavy car will transfer more of its momentum to the truck than a light car, reducing the heavy car's ΔV and the fatality risk of its own occupants. (The fatality risk in the truck is so low that its slight increase in ΔV will not offset the benefit for the car's occupants.)

  - Similarly, when relatively light cars (< 3,000 pounds) hit average LTVs (curb weight ≥ 4,000 pounds), there are substantially more fatalities in the cars than in the LTVs. A further reduction in the mass of the cars will increase societal fatality risk, because the increase in the cars' occupant fatalities would exceed the reduction of occupant fatalities in the partner LTVs.[352] Unlike the two preceding items, the fatality increase can be offset by also reducing mass in LTVs (as will be analyzed in Section 3). But it is a factor in this report's as well as DRI's cross-sectional analyses of the effect of car mass in crashes with LTVs, which specifically estimate the effect of a reduction in car mass <u>while the LTV stays unchanged</u>.

- <u>Structural strength</u>: Mass and structural strength are independent concepts. But in MY 1991-1999 vehicles, when there was less use of some high-strength materials that are now gradually becoming more customary in vehicles, less mass for the same footprint may have meant a structurally weaker vehicle. (This factor and those that follow are not effects of mass *per se*.)

- <u>Factors that are fundamentally size-related but were not correlated with footprint in MY 1991-1999 cars</u>: If these "size" features were more correlated with a car's mass than with its footprint in MY 1991-1999, the regressions would tend to attribute the associated fatality increases in the smaller/lighter cars primarily to mass, not footprint. Prime examples:

  - Structure on the front and side of a car, beyond the wheels (overhang) that adds protective crush space to the vehicle.

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[350] Partyka, S.C. (1995). *Impacts with Yielding Fixed Objects by Vehicle Weight*. NHTSA Technical Report. DOT HS 808 574. Washington, DC: National Highway Traffic Safety Administration.

[351] Light trucks and vans, includes pickup trucks, SUVs, minivans, and full-size vans.

[352] Kahane (2003), pp. 105, 107, and 159; *New Crash Tests Demonstrate the Influence of Vehicle Size and Weight on Safety in Crashes*, IIHS News Release, April 14, 2009, http://www.iihs.org/news/rss/pr041409.html.

  - The low sills of small cars that make them vulnerable in side impacts.[353]

  - The pedestrian-unfriendly frontal profile of small cars: because the hood is short, the pedestrian's head is more likely to contact rigid structures such as the windshield header.[354] This is evidently not an issue of mass *per se*, but in the MY 1991-1999 cars, high rates of pedestrian fatalities are statistically associated with low mass, not short wheelbase or narrow track width, as will be seen in the analyses of this report.

- Possible driver-vehicle interface factors: Historically (1976-2009), small, light cars have had higher collision-involvement rates (with or without injury) than larger, heavier cars, even after controlling for urbanization.[355] The higher incidence of smaller cars going out of control and running off the road explains some of this phenomenon. But in 1999-2000, 84 percent of cars' crash involvements (with or without injury) were collisions with other vehicles and less than 2 percent of those collisions involved loss of control[356] – yet small, light cars had higher crash rates there, too. The high crash rates suggest there may be another factor – namely that, at least historically, small, light cars have not been driven as well as large, heavy cars.

  - Recent analyses of FARS and the General Estimates System[357] furnish evidence that small, light cars are less well driven. They show that drivers of lighter cars are more likely to be the culpable party in a 2-vehicle collision – even after

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[353] Kahane (2003), pp. 249-273 indicates the high fatality risk when light cars are hit in the side by LTVs and that the height mismatch (called D_AHOF in the report) accounts for a significant portion of the increased risk.

[354] Kahane (2003), pp. 98-99; Blodgett, R. J. (1983). *Pedestrian Injuries and the Downsizing of Cars*. Paper No. 830050. Warrendale, PA: Society of Automotive Engineers; MacLaughlin, T.F., and Kessler, J.W. (1990). *Pedestrian Head Impact Against the Central Hood of Motor Vehicles – Test Procedure and Results*. Paper No. 902315. Warrendale, PA: Society of Automotive Engineers.

[355] In 1988, the Highway Loss Data Institute (HLDI) reported that "small cars have consistently more injury and collision claims than large cars. This has been true for every year that HLDI has published insurance claim information [1976 onwards]" (IIHS Advisory No. 5, July 1988, http://www.iihs.org/research/advisories/iihs_advisory_5.pdf; a chart shows claims were more frequent for small cars than large cars within urban areas and likewise within rural areas); in 1998 HLDI announced, "Claims for crash damage are more frequent for small cars than for large ones" (News Release, February 24, 1998, http://www.iihs.org/news/1998/iihs_news_022498.pdf); and in 2009, "Small 4-door cars had higher frequencies than larger 4-door cars" (Auto Insurance Loss Facts, September 2009, http://www.iihs.org/research/hldi/fact_sheets/CollisionLoss_0909.pdf).

[356] NHTSA (2000). *Traffic Safety Facts 1999.* Report No. DOT HS 809 100. Washington, DC: National Highway Traffic Safety Administration, p. 71; Najm, W.G., Sen, B., Smith, J.D., and Campbell, B.N. (2003). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System,* Report No. DOT HS 809 573. Washington, DC: National Highway Traffic Safety Administration, p. 48.

[357] The FARS analysis is based on MY 1991-1999 case vehicles involved in fatal crashes during CY 1991-2008. "Culpability" includes, for example, being the striking vehicle in a front-to-rear collision, being on the wrong side of the centerline prior to a head-on collision, and failing to yield the right of way at an intersection or a left turn across traffic. An empirical problem with fatal-crash data is the tendency of a surviving driver to blame the deceased driver when there is no physical evidence or witnesses to the contrary – and when a lighter and heavier vehicle collide, the driver of the heavier vehicle is more likely to survive. Therefore, the analysis was limited to 29,814 collisions of MY 1991-1999 "case" cars with another vehicle in which one driver or the other was judged culpable (but not both) and in which (1) both drivers died; (2) neither driver died (only passengers died); (3) the "other" vehicle was a heavy truck (because the car driver will almost always be a fatality, regardless of whether the car was light or heavy); or (4) the other vehicle was a motorcycle (because the car driver will almost never be a fatality).

controlling for footprint (vehicle stability factors), the driver's age, gender, urbanization, and region of the country – at least in head-on collisions, left turns across traffic, and right-angle intersection collisions, the three predominant types of fatal 2-vehicle collisions. (But in front-to-rear collisions, which account for only a small portion of fatal 2-vehicle collisions, the lighter car is less likely to be the culpable [frontally-impacting] vehicle.) Specifically, in FARS, the log-odds of being the culpable party in a 2-vehicle collision (other than front-to-rear collisions) increases by an estimated 1.8 percent as cars get 100 pounds lighter, after controlling for driver age and gender, in MY 1991-1999 cars < 2,950 pounds (2,950 pounds was the median curb weight of cars in those model years). Footprint has little or no association with culpability in these analyses – i.e., they statistically associate a higher likelihood of culpability with lower mass, not smaller footprint.[358]

- The preceding are <u>statistical</u> analyses; they indicate that lighter (and smaller) cars are less well driven, but they do not say why. One hypothesis ("self-selection") is that, for some reason, less effective drivers are more likely to choose lighter vehicles. Another hypothesis ("driver-vehicle interface") is that certain aspects of lightness and/or smallness in a car give a driver a perception of greater maneuverability that ultimately results in driving with less of a "safety margin," for example weaving in traffic. That may appear paradoxical at first glance, as maneuverability is, in the abstract, a plus. But the situation is not unlike powerful engines that theoretically enable a driver to escape some hazards but in reality have long been associated with high crash and fatality rates.[359]

- The issue of self-selection versus driver-vehicle interface will become important when and if the results of historical analyses are used to predict the effect of future mass reductions, as will be discussed later in the report. If it is primarily self-selection, if the entire fleet were to proportionally lose mass, it presumably would not make everyone's driving proportionally worse. But the issue is largely irrelevant for the historical analyses themselves. Statistical relationship found in these analyses do not necessarily imply that the lower mass is causing the higher fatal-crash rate. If lighter MY 1991-1999 cars were driven less well, <u>regardless of the reason</u>, the cross-sectional analysis should associate a higher fatal-crash rate with lower mass, even after controlling for footprint, driver age/gender, and other factors.

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[358] With culpability as the dependent variable and mass, footprint, driver age/gender, and vehicle age as independent variables, the estimated effects were a statistically significant 1.8% increase in the log-odds of culpability per 100-pound mass reduction in cars < 2,950 pounds, a corresponding 1.0% increase for cars ≥ 2,950 pounds, and a 0.04% increase per square-foot reduction of footprint. Because half of the involvements in collisions with other vehicles are culpable involvements, a 1.8% increase in culpable involvements corresponds to a 0.9% increase in all involvements with other vehicles (assuming no change in the non-culpable involvements). The effect in unweighted CY 1995-2000 GES (primarily nonfatal crashes) was a significant 1.4% increase in the log-odds of culpability per 100-pound mass reduction in cars < 2,950 pounds (in weighted GES, a non-significant 1.1% increase).

[359] Robertson, L.S. (1991), "How to Save Fuel and Reduce Injuries in Automobiles," *The Journal of Trauma*, Vol. 31, pp. 107-109; Kahane, C.J. (1994). Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions, NHTSA Technical Report No. DOT HS 808 061. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/808061.PDF, pp. 4-7.

- If less effective drivers intrinsically chose light cars (self-selection), it might have been evidenced by an increase in antisocial driving behavior such as DWI, drug involvement, speeding, or driving without a license as car mass decreases, after controlling for driver age and gender – in addition to the increases in merely culpable driver behavior such as failure to yield the right of way. But analyses in NHTSA's 2003 report did not show an increase in antisocial driver behavior in the lighter cars paralleling their increase in culpable involvements.[360] However, poor drivers are not necessarily more likely to engage in antisocial driving behaviors; they might just be less skilled or less experienced.

In summary, there are reasons for a residual association of lower mass with increased societal fatality risk in cross-sectional analyses of MY 1991-1999 cars, even after controlling for footprint. Mass reduction may have little effect in some types of crashes and may have benefits in some situations discussed above (e.g., a lower cg in some vehicles, greater steering response), but a strong overall association of lower mass with lower risk is not expected in the analyses of the major types of crashes for passenger cars.

The first goal of this report is to estimate the effect of a 100-pound mass reduction while maintaining footprint, based on the methods and database of NHTSA's 2003 report. If that estimate differs substantially from DRI's, the second task is to review the methods in the DRI analysis, account for why the results are different, and offer a judgment of which method more accurately models the historical data. A third task is to contemplate to what extent the results might be relevant to predicting the effect of future mass reductions accomplished by technologies little used in the past and to develop a range of scenarios for the possible effects of mass reduction in passenger cars.

2.2 Effect of mass and footprint with NHTSA's 2003 database and method

Curb weight was the only attribute of vehicle mass or size in NHTSA's 2003 weight-safety report. Table 2-1, reproduced from p. xi of that report, shows the analysis, using only data on 4-door non-police cars, associates an increase of 813 fatalities with a mass reduction of 100 pounds (with implicit, accompanying "size" reductions) applied to the baseline 1999 on-road fleet of passenger cars. For example, in calendar year 1999, cars weighing less than 2,950 pounds were involved in first-event-rollover crashes resulting in 995 baseline fatalities. When curb weight is the only size parameter in the analysis, the regression associates a 5.08 percent increase in fatality risk with a 100-pound mass reduction (which under these circumstances implicitly includes commensurate reductions in track width and wheelbase), amounting to 51 additional fatalities.

The numbers are societal effects: the baseline and the increase for the multi-vehicle collision types include the fatalities in the other vehicle as well as in the case vehicle. In cars weighing less than 2,950 pounds, the fatality increases in the various crash types add up to 597. In cars weighing 2,950 pounds or more, the fatality increases add up to 216. The sum for both car weight groups and all crash types is an increase of 813 fatalities, in the baseline year 1999. (The increase would be smaller now, as fatalities in crashes involving passenger cars have decreased;

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[360] Kahane (2003), pp. 94-95 and 210-214.

that decrease is incorporated into the Volpe model used to predict effects of future mass reductions.) The 1.96-sigma confidence bounds for the sampling error are 813 ± 200.5; the confidence interval ranges from 612 to 1014.[361]

TABLE 2-1: MODEL FROM NHTSA 2003 REPORT (4-DOOR NON-POLICE CARS ONLY, CURB WEIGHT ONLY PARAMETER)

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB RED	FATALITY INCREASE
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	0.0508	51
	FIXED OBJECT	3,357	0.0322	108
	PED/BIKE/MOTORCYCLE	1,741	0.0348	61
	HEAVY TRUCK	1,148	0.0596	68
	CAR LT 2950 LBS	934	0.0496	46
	CAR GE 2950 LBS	1,342	0.0248	33
	LTV	4,091	0.0563	230
CARS LT 2950 LBS				597
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	0.0470	34
	FIXED OBJECT	2,822	0.0167	47
	PED/BIKE/MOTORCYCLE	1,349	-0.0062*	-8
	HEAVY TRUCK	822	0.0206	17
	CAR LT 2950 LBS	1,342	0.0159	21
	CAR GE 2950 LBS	677	0.0318	22
	LTV	3,157	0.0262	83
CARS GE 2950 LBS				216
				813

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

The main patterns in Table 2-1 are:

- The absolute fatality increase is almost three times as large in cars < 2,950 pounds as in the cars ≥ 2,950 pounds.

- The mass-size-safety effect is in the lighter/smaller ↔ more fatalities direction in each type of crash, except collisions of cars ≥ 2,950 pounds with pedestrians, where it is close to zero and not statistically significant.[362] The observed societal effect is also fairly small for cars ≥ 2,950 pounds in collisions with other cars, as the fatality increase in the case vehicle is offset by a reduction in the other vehicle.

- In absolute terms, the largest fatality increases are in collisions with LTVs and with fixed objects, because they account for the largest shares of the baseline crashes.

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[361] Sampling error is computed as in Kahane (2003), p. 108, footnote 51, but without the "adjustment for self-selection," because it is a possible bias in the results, not a sampling-error component. Sampling error has two components: (1) Basic sampling error in the regression coefficients for vehicle mass, accumulated on a root-sum-of-squares basis across crash types (but additive across small and large cars and across the two car-to-car results). (2) Additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc. It contributes a .0038 coefficient of variation for the entire estimate.

[362] As evidenced by Wald $\chi^2 < 3.84$ for the logistic regression's coefficient for curb weight.

- In relative terms, the strongest percentage increases are in collisions with heavy trucks and in rollovers.

Below is a summary of the database and general method of the 2003 report, as described more fully in Chapters 2 and 3 of that report, and the specific analysis that generated the estimates in Table 2-1. The database comprises MY 1991-1999 passenger cars in CY 1995-2000. The objective is to analyze fatal-crash involvement rates (weighted by the number of fatalities in the crash) per vehicle registration year. Because the CDS odometer readings showed that annual mileage neither increased nor decreased as car mass increased, it is similar to analyzing fatal-crash rates per mile of travel. The Fatality Analysis Reporting System has complete and accurate counts of fatal crashes and R. L. Polk's National Vehicle Population Profile has complete and accurate counts of vehicle registrations. The fatal-crash rate per registration year is a "natural" statistic whose meaning is clearer than, for example, the fatal-crash rate per 100 police-reported crashes, which can vary a lot from State to State depending on what is a reportable crash, and from individual to individual, depending on whether a person chooses to report a non-injury crash or just deal with it privately.

Ideal for analysis would be a regression of the fatal-crash rate per registration year at various times of the day by actual vehicle mass including the number of passengers, the fuel level at the time of the crash, and the mass of any cargo being carried, controlling for driver age and other factors that may be correlated with vehicle mass. But the Polk data do not specify who drove the car, when, or where. Induced-exposure crashes from eight State files – non-culpable involvements in collisions with another vehicle – supply this information. The involvements are a surrogate for exposure because they measure how often the non-culpable vehicles are hit by culpable vehicles. "The induced exposure concept assumes that the not-at-fault driver in a two-vehicle crash is reflective of what is 'on the road' at that point in time, and that the sample of all not-at-fault drivers can be used to predict the characteristics of all non-accident involved drivers on the roadway (i.e., exposure characteristics)."[363]

The database actually consists of fatal-crash involvements from FARS (for all States plus DC) and nonfatal induced-exposure involvements from the eight State files. These crash-involvement records, fatal and nonfatal, include information on the driver's age and gender, the time of day, and the type of road where the crash occurred. However, each non-fatal involvement is allocated its fair share of the nation's vehicle registration years, as follows: the vehicle years add up to the national total for MY 1991-1999 cars in CY 1995-2000; the sum of the vehicle years allocated to each of the eight State files is proportional to the number of MY 1991-1999 cars registered in that State (thus, if a State has low reporting thresholds and many reported crashes, the number of vehicle years allocated to each crash will be relatively smaller; similarly, if crashes are under-reported for some makes and models, the vehicle years allocated to each crash will increase).[364]

The analyses are disaggregate logistic regressions on the database of fatal and nonfatal crash involvements. The dependent variable is whether or not the involvement was fatal. The independent variables are the mass-size attributes – in Table 2-1, just curb weight, entered as a

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[363] Stutts, J. C., and Martell, C. (1992), "Older Driver Population and Crash Involvement Trends, 1974-1988." *Accident Analysis and Prevention*, Vol. 28, pp. 317-327; see also Kahane (2003), starting at p. 31 for details on how induced-exposure data was incorporated into NHTSA's analysis.

[364] Kahane (2003), pp. 36-39.

two-piece linear variable, so it will produce separate coefficients for cars < and ≥ 2,950 pounds – the driver's age and gender, the road type and time of day, and whether the car was equipped with air bags and ABS. Although the database consists of crash involvements, when the fatal involvements are weighted by the number of fatalities in the crash and the nonfatal involvements are weighted by their share of the nation's registration years, the analyses become regressions of the fatality rate per vehicle registration year. In other words, the database allows analysis of fatalities per registration year in a single regression step, a relatively simple procedure compared to, say, NHTSA's 1997 report.[365]

Six types of fatal crash involvements are analyzed separately: first-event rollovers; collisions with fixed objects, pedestrians-bicyclists-motorcyclists, heavy trucks, other passenger cars,[366] and LTVs.

Adding track width and wheelbase to the analysis: DRI sent its 2003 analyses to the docket of public comments on NHTSA's 2003 report. As discussed above, in DRI's analyses of its own database, models with curb weight, track width, and wheelbase as three separate independent variables attributed a substantial <u>benefit</u> to mass reduction, offset by fatality increases if track width and/or wheelbase were reduced.

In its 2004 public response[367] to DRI, NHTSA cautioned that regressions with three separate mass-size attributes are quite risky, because the attributes are highly correlated with one another. Greene, in his textbook, *Econometric Analysis,* has defined a relationship between independent variables called "near multicollinearity" and described its symptoms: "(1) Small changes in the data can produce wide swings in the parameter estimates. (2) Coefficients may have very high standard errors and low significance levels in spite of the fact that they are jointly highly significant and the R^2 in the regression is quite high. (3) Coefficients will have the wrong sign or an implausible magnitude."[368]

The question of whether curb weight, track width, and wheelbase (or, alternatively, curb weight and footprint) are nearly multicollinear is crucial and requires further discussion. In NHTSA's database of MY 1991-1999 cars, including 2-door as well as 4-door cars, curb weight's actual registration-weighted correlation coefficients (r, not r-squared) are .796 with track width, .868 with wheelbase, and .893 with footprint. These are high correlations; it is hardly surprising that wide, long cars usually weigh more than narrow, short ones. But are they "too high" – i.e., so high that there is a concern that regression analyses will estimate inaccurate coefficients? That could depend on relationships among these variables, relationships between these variables and other independent variables and the dependent variable, and the type of regression model.

One guideline for assessing multicollinearity is the variance inflation factor (VIF) test. It is a test of the independent variables that does not take the dependent variable into account, and it returns a VIF score of 1 or more on each independent variable. In logistic regressions, "there is no

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[365] Kahane (2003), pp. 75-78.

[366] However, the results for collisions with other passenger cars are shown as two separate lines in each table and the effect is doubled in the line where the case and other cars are in the same weight category (and are both reduced by 100 pounds), as explained in Kahane (2003), p. 102.

[367] Kahane (2004).

[368] Greene (1993), pp. 266-268.

formal cutoff value to use with VIF for determining presence of multicollinearity. Values of VIF exceeding 10 are often regarded as indicating multicollinearity, but in weaker models, which is often the case in logistic regression, values above 2.5 may be a cause for concern."[369] Allison "begins to get concerned" when he sees VIF scores over 2.5.[370]

To test VIF, NHTSA's 2003 database was aggregated by car group (e.g., all Toyota Camrys produced in a 5-MY run from one redesign to the next, plus their corporate cousins Lexus ES), make, model, model year and body type (because the database uses a lookup table to assign a vehicle's curb weight, wheelbase, and track width based on those factors). The data points are weighted by the aggregate vehicle registration years – i.e., their proportion of the on-road vehicle fleet in CY 1995-2000. VIF is computed for a list of independent variables that includes curb weight, track width, wheelbase (or, alternatively, footprint instead of track width and wheelbase), plus the dichotomous variables indicating the type of passenger car (e.g. MUSCL2DR, which equals 1 for muscle cars and 0 for all other cars).

For the full database including all 2-door and 4-door cars, the test for curb weight, track width, and wheelbase produced VIF scores of 6.4, 3.0, and 6.5, respectively. The test for curb weight and footprint produced scores of 6.1 and 5.8, respectively. Similar scores are produced when subgroups of 2-door cars (e.g., muscle cars) are excluded, or for 4-door cars alone.

In other words, the VIF scores are all in the intermediate area between 2.5, where near multicollinearity begins to be a concern for logistic regressions, especially the "weaker" models, and 10, where regression may be inadvisable. Basically, they are signals to proceed with caution, examine regression results for symptoms of near multicollinearity (coefficients with "wrong sign or an implausible magnitude" and "wide swings in the parameter estimates"), look at other analysis results (such as the decile analyses that will be presented in Section 2.4), and exercise judgment whether the results are accurate estimates – with the understanding that (1) apparent symptoms of near multicollinearity may be due to other causes while, conversely, regressions that do not exhibit obvious symptoms could nevertheless estimate inaccurately; (2) analysts may differ in their judgments on what is a "wrong" sign or an "implausible" magnitude.

The literature cited above did not specify what makes a logistic-regression model "strong" or "weak." It may simply have meant that the maximum-likelihood estimation used in logistic regression is in general a weaker approach than least-squares. However, the results in this section and the next one as well as the author's experience with other regression analyses of crash data suggest it may also pertain to the relationships between the independent variables and the dependent variable (which, by the way, is not tested by VIF, a test that only considers the

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[369] Schadler, A. *Multicollinearity in Logistic Regression*. Lexington, KY: University of Kentucky Center for Statistical Computing Support. http://www.uky.edu/ComputingCenter/SSTARS/MulticollinearityinLogisticRegression.htm.

[370] Allison, P.D. (1999), *Logistic Regression Using the SAS System*. Cary, NC: SAS Institute Inc., pp. 48-51.

independent variables).[371] Where, say, mass and footprint both likely have strong, independent relationships with fatality risk, the regressions tend not to display obvious symptoms of near multicollinearity. But where one of them has a weak relationship, either intrinsically or because a specific regression procedure splits up a strong effect into several weaker ones, symptoms are more likely to appear.

NHTSA's 2004 response to the public comments on its 2003 report presented an analysis of its own database, again limited to 4-door cars exactly as in Table 2-1, but with separate variables for curb weight, track width and wheelbase. NHTSA's 2004 document only showed the curb-weight coefficients from that analysis, but Table 2-2 shows all of the coefficients and the absolute fatality increases when those coefficients are applied to CY 1999 baseline fatalities.[372]

TABLE 2-2: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
DATA LIMITED TO 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0121*	-12	0.0475	47	0.0071*	7	42
	FIXED OBJECT	3,357	0.0197	66	0.0145	49	-0.0041*	-14	101
	PED/BIKE/MOTORCYCLE	1,741	0.0328	57	0.0114	20	-0.0127	-22	55
	HEAVY TRUCK	1,148	0.0529	61	0.0134	15	-0.0089*	-10	66
	CAR LT 2950 LBS	934	0.0282	26	0.0189	18	0.0002*	0	44
	CAR GE 2950 LBS	1,342	0.0141	19	0.0095	13	0.0001*	0	32
	LTV	4,091	0.0478	196	0.0144	59	-0.0079*	-32	222
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CARS LT 2950 LBS				413		220		-71	562
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0176*	-13	0.0475	34	0.0071*	5	26
	FIXED OBJECT	2,822	0.0050*	14	0.0145	41	-0.0041*	-12	43
	PED/BIKE/MOTORCYCLE	1,349	-0.0058*	-8	0.0114	15	-0.0127	-17	-10
	HEAVY TRUCK	822	0.0147*	12	0.0134	11	-0.0089*	-7	16
	CAR LT 2950 LBS	1,342	0.0057*	8	0.0095	13	0.0001*	0	20
	CAR GE 2950 LBS	677	0.0114*	8	0.0189	13	0.0002*	0	21
	LTV	3,157	0.0183	58	0.0144	45	-0.0079*	-25	78
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CARS GE 2950 LBS				79		172		-56	195
				======		======		======	======
				492		392		-127	757

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

The combined, overall effect of the mass-size parameters is quite similar in Table 2-2 (757 increase) and Table 2-1 (813 increase). Moreover, in both tables, the absolute fatality increase is almost three times as large in cars < 2,950 pounds (the median curb weight of passenger cars in MY 1991-1999) as in the cars ≥ 2,950 pounds. The difference, of course, is that Table 2-1 attributes the entire effect to curb weight (the only parameter in the analysis, implicitly including the size reductions that historically accompanied mass reduction) whereas Table 2-2 allocates the fatality reduction between curb weight, track width, and wheelbase.

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[371] Kahane, C. J. (1982). *An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214*, NHTSA Technical Report. DOT HS 806 314. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/806314.PDF, pp. 274-280; Kahane, C. J. (1989). *An Evaluation of Door Locks and Roof Crush Resistance of Passenger Cars - Federal Motor Vehicle Safety Standards 206 and 216*, NHTSA Technical Report. DOT HS 807 489. Washington, DC: National Highway Traffic Safety Administration, http://www-nrd.nhtsa.dot.gov/Pubs/807489.PDF, pp. 87-138; Kahane (1997), pp. 112-119; Kahane (2003), pp. 167-173.

[372] Coefficients have changed slightly from the 2004 document because track width was unknown for some of the car groups in 2004, but is known for all groups now.

Unlike the DRI analyses, curb weight continues to have an effect in the lighter ↔ more fatalities direction in all crash types except rollovers, where there are non-significant[373] effects in the opposite direction. With NHTSA's data, wheelbase has little net effect. There are small effects in the shorter ↔ fewer fatalities direction in four types of crashes, and close to zero effect in the other two; the coefficient for wheelbase is statistically significant only in the analysis of collisions with pedestrians. The combined effect for reducing wheelbase by 1.01" is a reduction of 127 fatalities, small compared to DRI's estimated benefit of 580 lives for reducing mass by 100 pounds.

Track width is the dominant variable in rollovers, as might be expected, given its contribution to static stability. Track width also has a moderate but statistically significant effect in the narrower ↔ more fatalities direction in all the other types of crashes, a fatality increase of 1-1½ percent per 0.34-inch reduction of track width. These effects add up to 392 fatalities, approximately half of the 757 total for all three parameters.

Curb weight continues to be the dominant variable for cars < 2,950 pounds and to have statistically significant effects in all five types of non-rollover crashes. In the five non-rollover modes, the fatality increases add up to 425 for curb weight compared to just 173 for track width and -78 for wheelbase.

Curb weight is substantially less of a factor for cars ≥ 2,950 pounds, adding up to 92 fatalities in the non-rollover crashes, versus 138 for track width. After controlling for track width and wheelbase, curb weight has a statistically significant effect for cars ≥ 2,950 pounds only in the collisions with LTVs.

Nevertheless, for all cars and all types of crashes, the estimated effect of reducing mass by 100 pounds while holding track width and wheelbase constant is an <u>increase</u> of 492 fatalities, with 1.96 sigma confidence bounds ranging from an increase of 263 to an increase of 721. This point estimate and confidence interval diverges sharply from DRI's estimated 580 <u>reduction</u>. The point estimate (but not its lower confidence bound) also exceeds the 392 attributed to a reduction in track width.

Adding 2-door cars to the analysis: NHTSA's 2004 response to public comments on its 2003 report stressed one explanation for the discrepancy between DRI's results and Table 2-2, above: "The DRI results are strongly biased as a consequence of including 2-door cars in the analysis…. Two-door muscle and sports cars [have] a short wheelbase relative to their weight [and]…the highest fatality rates of all cars… [If these cars are included,] the regression analysis…[is likely to] tell you that you can make any car safer…by increasing wheelbase and/or reducing weight [because that would fit the data included in the analysis]."[374] NHTSA's exclusion of 2-door cars has been criticized because they constitute over 20 percent of passenger cars and have more diversity of design and proportions than 4-door cars. Specifically, DRI, in their 2005 supplement, asserted that even when they limited <u>their</u> analyses to MY 1991-1998 4-door cars, mass reduction still had substantial benefits (although the effect of wheelbase was smaller than in

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[373] As evidenced by Wald $\chi^2 < 3.84$ for the logistic regression's coefficient for curb weight.

[374] Kahane (2004); see also Kahane (2003), pp. 171-173 for a discussion of the sensitivity of NHTSA's earlier, 1997 analysis to the inclusion or exclusion of 2-door cars.

their analyses including 2-door cars). DRI continued to assert that 2-door cars should be included in the analysis.[375]

Indeed, if the database and analysis method are statistically robust (i.e., if small changes in the database do not greatly affect the results), the inclusion or exclusion of 2-door cars ought not to make a big difference. Intuitively, if removing 100 pounds increases fatality risk in 4-door cars by x percent, it ought to have about the same effect in 2-door cars, as the design of the doors is only a small factor in the overall performance of the car. The 2003 report limited its analyses to 4-door models that were not police cars because that subgroup presents "a fairly continuous spectrum of vehicles and drivers," creating "an ideal situation for regression analysis."[376] But that was fine tuning for extra precision. Adding in some models with unusual use patterns or dimensions could alter the results to some extent, but these models ought not to change a coefficient from a strong plus to a strong minus, because they simply are not that large a proportion of the on-road fleet – and if they do, NHTSA agrees that the entire database and/or analysis method is probably unsatisfactory.

The original 2003 database actually includes all the 2-door MY 1991-1999 cars; they were excluded from the analyses in NHTSA's 2003 report. The analysis of curb weight, track width and wheelbase in Table 2-2 can be extended to include some or all 2-door cars, specifically:

- Including all 2-door cars plus all 4-door non-police cars

- Including all 2-door cars except muscle cars (such as Mustang, Corvette, Camaro, or Toyota Supra) plus all 4-door non-police cars

- Including all 2-door cars except muscle cars and sporty cars (such as Ford Probe, Honda Prelude, Toyota Celica and any convertible) plus all 4-door non-police cars

Table 2-3 presents the results of these three analyses and repeats, for comparison, the analysis limited to 4-door cars was already shown in Table 2-2.

The overall mass-size-safety effect (the grand-total fatality increase at the lower right of each of the four sub-tables) is robust, varying only from a low of 694 in the analysis excluding muscle cars to a high of 760 in the analysis including all 2-door cars as well as 4-door cars.

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[375] Van Auken and Zellner, (2005b).

[376] *Ibid*., pp. 41-42.

TABLE 2-3: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE

3.1 BASED ON ALL 2-DOOR CARS AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0040*	-4	0.0291	29	0.0248	25	50
	FIXED OBJECT	3,357	0.0129	43	-0.0037*	-13	0.0194	65	96
	PED/BIKE/MOTORCYCLE	1,741	0.0393	68	0.0065	11	-0.0177	-31	49
	HEAVY TRUCK	1,148	0.0455	52	0.0108	12	-0.0069*	-8	57
	CAR LT 2950 LBS	934	0.0304	28	0.0080*	7	-0.0028*	-3	33
	CAR GE 2950 LBS	1,342	0.0152	20	0.0040*	5	-0.0014*	-2	24
	LTV	4,091	0.0423	173	0.0096	39	-0.0041*	-17	195
CARS LT 2950 LBS				382		92		30	504
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0092*	-7	0.0291	21	0.0248	18	28
	FIXED OBJECT	2,822	0.0145	41	-0.0037*	-11	0.0194	55	58
	PED/BIKE/MOTORCYCLE	1,349	0.0037*	5	0.0065	9	-0.0177	-24	-10
	HEAVY TRUCK	822	0.0157	13	0.0108	9	-0.0069*	-6	16
	CAR LT 2950 LBS	1,342	0.0131	18	0.0040*	5	-0.0014*	-2	21
	CAR GE 2950 LBS	677	0.0262	18	0.0080*	5	-0.0028*	-2	21
	LTV	3,157	0.0232	73	0.0096	30	-0.0041*	-13	91
CARS GE 2950 LBS				161		69		26	256
				543		161		56	760

3.2 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0122*	-12	0.0374	37	0.0140*	14	39
	FIXED OBJECT	3,357	0.0055*	18	0.0118	39	0.0008*	3	61
	PED/BIKE/MOTORCYCLE	1,741	0.0359	63	0.0096	17	-0.0175	-30	49
	HEAVY TRUCK	1,148	0.0431	49	0.0147	17	-0.0081*	-9	57
	CAR LT 2950 LBS	934	0.0250	23	0.0185	17	-0.0103*	-10	31
	CAR GE 2950 LBS	1,342	0.0125	17	0.0092	12	-0.0052*	-7	22
	LTV	4,091	0.0409	167	0.0137	56	-0.0081	-33	190
CARS LT 2950 LBS				326		196		-73	449
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0047*	-3	0.0374	27	0.0140*	10	33
	FIXED OBJECT	2,822	0.0155	44	0.0118	33	0.0008*	2	79
	PED/BIKE/MOTORCYCLE	1,349	-0.0007*	-1	0.0096	13	-0.0175	-24	-12
	HEAVY TRUCK	822	0.0118*	10	0.0147	12	-0.0081*	-7	15
	CAR LT 2950 LBS	1,342	0.0112	15	0.0092	12	-0.0052*	-7	21
	CAR GE 2950 LBS	677	0.0224	15	0.0185	13	-0.0103*	-7	21
	LTV	3,157	0.0221	70	0.0137	43	-0.0081	-26	88
CARS GE 2950 LBS				149		153		-57	245
				475		349		-130	694

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

TABLE 2-3 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE

3.3 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0092*	-9	0.0369	37	0.0150*	15	43
	FIXED OBJECT	3,357	0.0112*	38	0.0147	49	-0.0015*	-5	82
	PED/BIKE/MOTORCYCLE	1,741	0.0359	63	0.0106	18	-0.0167	-29	52
	HEAVY TRUCK	1,148	0.0406	47	0.0157	18	-0.0067*	-8	57
	CAR LT 2950 LBS	934	0.0204*	19	0.0211	20	-0.0061*	-6	33
	CAR GE 2950 LBS	1,342	0.0102*	14	0.0106	14	-0.0030*	-4	24
	LTV	4,091	0.0433	177	0.0143	59	-0.0073	-30	206
CARS LT 2950 LBS				347		215		-66	496
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0080*	-6	0.0369	26	0.0150*	11	31
	FIXED OBJECT	2,822	0.0112	32	0.0147	41	-0.0015*	-4	69
	PED/BIKE/MOTORCYCLE	1,349	-0.0030*	-4	0.0106	14	-0.0167	-22	-12
	HEAVY TRUCK	822	0.0093*	8	0.0157	13	-0.0067*	-5	15
	CAR LT 2950 LBS	1,342	0.0072*	10	0.0106	14	-0.0030*	-4	20
	CAR GE 2950 LBS	677	0.0144*	10	0.0211	14	-0.0061*	-4	20
	LTV	3,157	0.0195	62	0.0143	45	-0.0073	-23	84
CARS GE 2950 LBS				110		169		-53	227
				458		384		-119	723

3.4 BASED ON 4-DOOR NON-POLICE CARS ONLY

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0121*	-12	0.0475	47	0.0071*	7	42
	FIXED OBJECT	3,357	0.0197	66	0.0145	49	-0.0041*	-14	101
	PED/BIKE/MOTORCYCLE	1,741	0.0328	57	0.0114	20	-0.0127	-22	55
	HEAVY TRUCK	1,148	0.0529	61	0.0134	15	-0.0089*	-10	66
	CAR LT 2950 LBS	934	0.0282	26	0.0189	18	0.0002*	0	44
	CAR GE 2950 LBS	1,342	0.0141	19	0.0095	13	0.0001*	0	32
	LTV	4,091	0.0478	196	0.0144	59	-0.0079*	-32	222
CARS LT 2950 LBS				413		220		-71	562
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0176*	-13	0.0475	34	0.0071*	5	26
	FIXED OBJECT	2,822	0.0050*	14	0.0145	41	-0.0041*	-12	43
	PED/BIKE/MOTORCYCLE	1,349	-0.0058*	-8	0.0114	15	-0.0127	-17	-10
	HEAVY TRUCK	822	0.0147*	12	0.0134	11	-0.0089*	-7	16
	CAR LT 2950 LBS	1,342	0.0057*	8	0.0095	13	0.0001*	0	20
	CAR GE 2950 LBS	677	0.0114*	8	0.0189	13	0.0002*	0	21
	LTV	3,157	0.0183	58	0.0144	45	-0.0079*	-25	78
CARS GE 2950 LBS				79		172		-56	195
				492		392		-127	757

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

The overall effect of the individual parameters is almost equally robust, except, ironically (given NHTSA's previously cited objection to the inclusion of muscle cars), the effect of mass is strongest (543) and track width weakest (161) when muscle cars are included. The regression including muscle cars apparently focused not on the short wheelbase of these cars but their wide track; muscle cars have exceptionally many fatal collisions with fixed objects. The regression apparently sensed a statistical association between muscle cars' wide track and high fatality rates and it contributed enough to give track width an overall coefficient in the narrower ↔ fewer fatalities direction. But in the remaining three analyses, the effect of reducing mass by 100 pounds varied only from 458 to 492 additional fatalities, the effect of reducing track width by 0.34 inches varied only from 349 to 392, while the effect of reducing wheelbase by 1.01 inches varied from a reduction of 119 to 130 fatalities. It makes little difference whether 2-door cars are included, partially included, or excluded – even the muscle cars make little difference except in the analysis of collisions with fixed objects.

For example, in the analysis excluding muscle cars but including other 2-door and 4-door cars (Table 2-3.2), the point estimate for reducing mass by 100 pounds is an increase of 475 fatalities, with 1.96-sigma sampling-error confidence bounds ranging from 260 to 690; for reducing track width by 0.34 inches, point estimate is an increase of 349 fatalities with confidence bounds from 166 to 532; and for reducing wheelbase by 1.01 inches, the point estimate is a non-significant reduction of 130 fatalities, with confidence bounds ranging from a reduction of 325 to an increase of 65.

Unlike DRI, none of the analyses estimate a benefit for reducing mass, except for a negligible, consistently non-significant benefit in first-event rollovers (which may be plausible if higher mass, given the same footprint, is somewhat associated with a higher center of gravity). In the five non-rollover crash types, mass is the dominant factor for cars < 2,950 pounds, with a statistically significant effect in the lighter ↔ more fatalities direction in most of the analyses in Table 2-3. Mass also makes a contribution in non-rollover crashes for cars ≥ 2,950 pounds, with statistically significant effects in that direction in about half of the analyses in Table 2-3.

Inclusion or exclusion of 2-door cars is not the issue; NHTSA retracts the remarks on that subject in its 2004 response to public comments on its 2003 report and in subsequent discussions.

Analyses of curb weight and footprint: There are two good reasons to consider regressions on NHTSA's 2003 database with just the two size-mass parameters mass and footprint rather than the three parameters mass, track width, and wheelbase.

- It most directly and simply addresses the issue at hand, footprint-based CAFE: what is the historical effect of changing mass given constant footprint?
- The majority of the regressions in Table 2-3 generated a coefficient in the shorter ↔ fewer fatalities direction for wheelbase that may be inaccurate and, if so, also taints the coefficients for mass and track width. Although substituting footprint for track width and wheelbase produces similar or at best marginally lower VIF scores (the test for curb weight, track width, and wheelbase produced VIF scores of 6.4, 3.0, and 6.5, whereas the test for curb weight and footprint produced scores of 6.1 and 5.8), the literature suggests that combining parameters is generally advisable for alleviating multicollinearity.[377]

Table 2-4 estimates the effects of reducing mass by 100 pounds or footprint by 0.65 square feet (the historic average footprint reduction per 100-pound mass reduction[378]) in MY 1991-1999 cars in CY 1995-2005, including the fatality increase if the percentage change is applied to CY 1999 baseline fatalities. The analyses include all the 4-door non-police cars in the 2003 database, plus some or all 2-door cars. Table 2-4 is identical to Table 2-3, except footprint substitutes for track width and wheelbase.

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[377] Allison (1999), p. 51; Schadler.

[378] Estimated by a regression of footprint by curb weight in NHTSA's MY 1991-1999 database. Also, in MY 1991-1999 cars, the average wheelbase was 104" and the average track width was 58.34", which is a footprint of 42.13 square feet. If the wheelbase is reduced by 1.01" to 102.99" and the track width by 0.34" to 58", the footprint decreases to 41.48 square feet, which is .65 square feet less than 42.13.

The only coefficients in the smaller ↔ fewer fatalities direction for footprint in Table 2-4 are in the collisions with pedestrians, and they are all negligible and not statistically significant. The effect of footprint is very strong in rollovers (a 6% fatality increase per square-foot reduction of footprint). The effect is a significant 1.5 percent in collisions with fixed objects and a borderline-significant circa 1 percent in collisions with heavy trucks, cars, and LTVs.

There are some coefficients in the lighter ↔ fewer fatalities direction for mass in rollovers and for cars ≥ 2,950 pounds only in collisions with pedestrians. These, too, are mostly negligible. Only the rollover effect for cars ≥ 2,950 pounds in the last sub-table (based on 4-door cars alone) reaches significance at the .05 level.

The overall effect of downsizing (the grand-total fatality increase at the lower right of each the four sub-tables) – reducing mass by 100 pounds <u>and</u> footprint by 0.65 square feet – is robust, varying from a low of 730 in the analysis excluding only muscle cars to a high of 804 in the analysis limited to 4-door cars.

The effect of reducing mass by 100 pounds while holding footprint constant is likewise robust, ranging from an increase of 386 to 512 fatalities. The effect varies even less, from 386 to 426 in the three analyses without the muscle cars. In the analysis excluding muscle cars but including other 2-door and 4-door cars (Table 2-4.2), the point estimate for reducing mass by 100 pounds is an increase of 410 fatalities, with 1.96-sigma sampling-error confidence bounds ranging from 195 to 625.

Conversely, the effect of reducing footprint by 0.65 square feet while holding mass constant ranges from 254 in the analysis including all 2-door cars up to 378 in the analysis limited to 4-door cars. Without the muscle cars, the range is just 321 to 378. In the analysis excluding muscle cars (Table 2-4.2), the point estimate for reducing footprint by 0.65 square feet is an increase of 321 fatalities, with 1.96-sigma sampling-error confidence bounds ranging from 126 to 516.

TABLE 2-4: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .65 SQ FT OF FOOTPRINT

4.1 BASED ON ALL 2-DOOR CARS AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0073*	-7	0.0593	59	52
	FIXED OBJECT	3,357	0.0161	54	0.0124	42	96
	PED/BIKE/MOTORCYCLE	1,741	0.0357	62	-0.0064*	-11	51
	HEAVY TRUCK	1,148	0.0435	50	0.0068*	8	58
	CAR LT 2950 LBS	934	0.0288	27	0.0074*	7	34
	CAR GE 2950 LBS	1,342	0.0144	19	0.0037*	5	24
	LTV	4,091	0.0402	164	0.0083	34	198
CARS LT 2950 LBS				370		143	513
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0144*	-10	0.0593	42	32
	FIXED OBJECT	2,822	0.0148	42	0.0124	35	77
	PED/BIKE/MOTORCYCLE	1,349	-0.0006*	-1	-0.0064*	-9	-9
	HEAVY TRUCK	822	0.0142*	12	0.0068*	6	17
	CAR LT 2950 LBS	1,342	0.0122	16	0.0037*	5	21
	CAR GE 2950 LBS	677	0.0244	17	0.0074*	5	22
	LTV	3,157	0.0213	67	0.0083	26	94
CARS GE 2950 LBS				142		111	253
				512		254	766

4.2 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0171*	-17	0.0606	60	43
	FIXED OBJECT	3,357	0.0040*	13	0.0154	52	65
	PED/BIKE/MOTORCYCLE	1,741	0.0324	56	-0.0023*	-4	52
	HEAVY TRUCK	1,148	0.0411	47	0.0101*	12	59
	CAR LT 2950 LBS	934	0.0220	21	0.0134*	13	33
	CAR GE 2950 LBS	1,342	0.0110	15	0.0067*	9	24
	LTV	4,091	0.0384	157	0.0096	39	196
CARS LT 2950 LBS				292		180	473
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0118*	-8	0.0606	43	35
	FIXED OBJECT	2,822	0.0132	37	0.0154	43	81
	PED/BIKE/MOTORCYCLE	1,349	-0.0048*	-6	-0.0023*	-3	-10
	HEAVY TRUCK	822	0.0097*	8	0.0101*	8	16
	CAR LT 2950 LBS	1,342	0.0094*	13	0.0067*	9	22
	CAR GE 2950 LBS	677	0.0188*	13	0.0134*	9	22
	LTV	3,157	0.0195	62	0.0096	30	92
CARS GE 2950 LBS				117		140	257
				410		321	730

* Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

TABLE 2-4 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .65 SQ FT OF FOOTPRINT

4.3 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0146*	-15	0.0608	61	46
	FIXED OBJECT	3,357	0.0088*	30	0.0170	57	86
	PED/BIKE/MOTORCYCLE	1,741	0.0322	56	-0.0003*	-1	55
	HEAVY TRUCK	1,148	0.0384	44	0.0127	15	59
	CAR LT 2950 LBS	934	0.0174*	16	0.0202	19	35
	CAR GE 2950 LBS	1,342	0.0087*	12	0.0101	14	25
	LTV	4,091	0.0406	166	0.0111	45	211
CARS LT 2950 LBS				309		209	518
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0148*	-11	0.0608	44	33
	FIXED OBJECT	2,822	0.0085*	24	0.0170	48	72
	PED/BIKE/MOTORCYCLE	1,349	-0.0072*	-10	-0.0003*	-0	-10
	HEAVY TRUCK	822	0.0071*	6	0.0127	10	16
	CAR LT 2950 LBS	1,342	0.0053*	7	0.0101	14	21
	CAR GE 2950 LBS	677	0.0106*	7	0.0202	14	21
	LTV	3,157	0.0169	53	0.0111	35	88
CARS GE 2950 LBS				77		163	241
				386		372	759

4.4 BASED ON 4-DOOR NON-POLICE CARS ONLY

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0186*	-19	0.0688	68	50
	FIXED OBJECT	3,357	0.0185	62	0.0140	47	109
	PED/BIKE/MOTORCYCLE	1,741	0.0305	53	0.0042*	7	60
	HEAVY TRUCK	1,148	0.0513	59	0.0085*	10	69
	CAR LT 2950 LBS	934	0.0276	26	0.0224	21	47
	CAR GE 2950 LBS	1,342	0.0138	19	0.0112	15	34
	LTV	4,091	0.0458	187	0.0109	44	232
CARS LT 2950 LBS				387		213	600
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0285	-20	0.0688	49	29
	FIXED OBJECT	2,822	0.0020*	6	0.0140	39	45
	PED/BIKE/MOTORCYCLE	1,349	-0.0106*	-14	0.0042*	6	-9
	HEAVY TRUCK	822	0.0116*	10	0.0085*	7	17
	CAR LT 2950 LBS	1,342	0.0042*	6	0.0112	15	21
	CAR GE 2950 LBS	677	0.0084*	6	0.0224	15	21
	LTV	3,157	0.0148	47	0.0109	34	81
CARS GE 2950 LBS				39		166	204
				426		378	804

* Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

These regressions appear to model the cross-sectional trend in MY 1991-1999 cars, as will be supported later in the report by the analyses of the effect of curb weight within deciles of footprint and the effect of footprint within deciles of curb weight. A caveat is that the presence of nearly multicollinear parameters can reduce the accuracy of the coefficients. The analysis including muscle cars is slightly tainted by the high track width and high fatality rate of those cars and does not attribute enough of the fatality increase to footprint; limiting to 4-door cars needlessly excludes too much of the data. But either of the two middle analyses – excluding muscle cars, or excluding muscle and sporty cars but including other 2-door cars – is satisfactory. Results are similar. In either case, just over half of the overall fatality increase for downsizing is attributed to mass reduction (410 of 730, or 386 of 759), just under half to footprint reduction (321 of 730, or 372 of 759).

The validity of the results for MY 1991-1999 cars does not necessarily make them appropriate for predicting the effects of mass reductions in the future, as future mass reduction may likely employ technologies that were rarely applied in 1991-1999 or new technologies that were unavailable in 1991-1999.

One feature of all the regressions so far is that mass is expressed as a two-piece linear variable. NHTSA's 2003 report selected that approach because the data clearly showed a stronger association between mass and fatality risk in the lighter cars than in the heavier cars.[379] Actually, mass appears as two variables, UNDRWT00 and OVERWT00, defined as follows: if the curb weight is less than 2,950, set UNDRWT00 = .01 (curb weight – 2,950) and set OVERWT00 = 0; and if the curb weight is 2,950 or more, set UNDRWT00 = 0 and set OVERWT00 = .01 (curb weight – 2,950). However, when mass is entered in the regressions of Table 2-4 as a simple, linear variable instead of UNDRWT00 and OVERWT00 (as in the analyses of DRI and NHTSA's 1997 report), these new regressions still generate nearly identical coefficients for footprint as the regressions in Table 2-4. (Of course, they generate a single coefficient for mass that applies to both the lighter and the heavier cars – inaccurately, NHTSA believes.) This appears to be an intrinsic feature of logistic regression, independent of the data: expressing a quantity as a simple or a two-piece linear variable does not affect how the regression allocates between this quantity and the other independent variables.[380] For the same reason, the coefficients for the mass and footprint parameters are barely changed if age and gender are expressed by the parameters YOUNGDRV, OLDMAN, OLDWOMAN, and FEMALE (as in NHTSA's 1997 report and DRI's analyses) rather than M14_30, M30_50, M50_70, M70_96, F14_30, F30_50, F50_70, F70_96, and DRVMALE (as in NHTSA's 2003 report and Table 2-4).

As a last consistency check, Table 2-5 estimates the effects of a 100-pound mass reduction, where mass is the only size-mass parameter in the regression (and where the 100-pound mass reduction implicitly incorporates, on the average, a 0.65 square foot reduction of footprint, too).

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[379] Kahane (2003), p. 76.

[380] In its comments to the EPA docket (EPA 0472-7238.1, pp. 8-10) DRI raised the issue, asking whether the different formulations of the mass variable might be contributing to the difference between NHTSA's and DRI's results.

TABLE 2-5: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION IN CURB WEIGHT (PLUS ACCOMPANYING SIZE REDUCTIONS)

5.1 BASED ON ALL 2-DOOR CARS AND 4-DOOR NON-POLICE CARS

```
                                            BASELINE   EFFECT OF   FATALITY
CAR WEIGHT GROUP     CRASH TYPE            FATALITIES  100 LB RED  INCREASE

CARS LT 2950 LBS    1ST EVENT ROLLOVER         995      0.0541        54
                    FIXED OBJECT             3,357      0.0286        96
                    PED/BIKE/MOTORCYCLE      1,741      0.0291        51
                    HEAVY TRUCK              1,148      0.0502        58
                    CAR LT 2950 LBS            934      0.0364        34
                    CAR GE 2950 LBS          1,342      0.0182        24
                    LTV                      4,091      0.0485       198
----------------                                                  ------
CARS LT 2950 LBS                                                     515

CARS GE 2950 LBS    1ST EVENT ROLLOVER         715      0.0500        36
                    FIXED OBJECT             2,822      0.0279        79
                    PED/BIKE/MOTORCYCLE      1,349     -0.0060*       -8
                    HEAVY TRUCK                822      0.0214        18
                    CAR LT 2950 LBS          1,342      0.0162        22
                    CAR GE 2950 LBS            677      0.0324        22
                    LTV                      3,157      0.0302        95
----------------                                                  ------
CARS GE 2950 LBS                                                     263
                                                                  ======
                                                                     778
```

5.2 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

```
                                            BASELINE   EFFECT OF   FATALITY
CAR WEIGHT GROUP     CRASH TYPE            FATALITIES  100 LB RED  INCREASE

CARS LT 2950 LBS    1ST EVENT ROLLOVER         995      0.0452        45
                    FIXED OBJECT             3,357      0.0193        65
                    PED/BIKE/MOTORCYCLE      1,741      0.0301        52
                    HEAVY TRUCK              1,148      0.0512        59
                    CAR LT 2950 LBS            934      0.0352        33
                    CAR GE 2950 LBS          1,342      0.0176        24
                    LTV                      4,091      0.0480       196
----------------                                                  ------
CARS LT 2950 LBS                                                     474

CARS GE 2950 LBS    1ST EVENT ROLLOVER         715      0.0558        40
                    FIXED OBJECT             2,822      0.0299        84
                    PED/BIKE/MOTORCYCLE      1,349     -0.0072*      -10
                    HEAVY TRUCK                822      0.0206        17
                    CAR LT 2950 LBS          1,342      0.0165        22
                    CAR GE 2950 LBS            677      0.0330        22
                    LTV                      3,157      0.0298        94
----------------                                                  ------
CARS GE 2950 LBS                                                     270
                                                                  ======
                                                                     744
```

* Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

```
TABLE 2-5 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION IN CURB WEIGHT (PLUS ACCOMPANYING SIZE
                     REDUCTIONS)

5.3 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

                                            BASELINE   EFFECT OF   FATALITY
CAR WEIGHT GROUP     CRASH TYPE            FATALITIES  100 LB RED  INCREASE

CARS LT 2950 LBS    1ST EVENT ROLLOVER         995      0.0482        48
                    FIXED OBJECT             3,357      0.0257        86
                    PED/BIKE/MOTORCYCLE      1,741      0.0319        56
                    HEAVY TRUCK              1,148      0.0510        59
                    CAR LT 2950 LBS            934      0.0376        35
                    CAR GE 2950 LBS          1,342      0.0188        25
                    LTV                      4,091      0.0531       217
----------------                                                  ------
CARS LT 2950 LBS                                                     526

CARS GE 2950 LBS    1ST EVENT ROLLOVER         715      0.0470        34
                    FIXED OBJECT             2,822      0.0270        76
                    PED/BIKE/MOTORCYCLE      1,349     -0.0075*      -10
                    HEAVY TRUCK                822      0.0208        17
                    CAR LT 2950 LBS          1,342      0.0161        22
                    CAR GE 2950 LBS            677      0.0322        22
                    LTV                      3,157      0.0288        91
----------------                                                  ------
CARS GE 2950 LBS                                                     251
                                                                  ======
                                                                     777


5.4 BASED ON 4-DOOR NON-POLICE CARS ONLY

                                            BASELINE   EFFECT OF   FATALITY
CAR WEIGHT GROUP     CRASH TYPE            FATALITIES  100 LB RED  INCREASE

CARS LT 2950 LBS    1ST EVENT ROLLOVER         995      0.0508        51
                    FIXED OBJECT             3,357      0.0322       108
                    PED/BIKE/MOTORCYCLE      1,741      0.0348        61
                    HEAVY TRUCK              1,148      0.0596        68
                    CAR LT 2950 LBS            934      0.0496        46
                    CAR GE 2950 LBS          1,342      0.0248        33
                    LTV                      4,091      0.0563       230
----------------                                                  ------
CARS LT 2950 LBS                                                     597

CARS GE 2950 LBS    1ST EVENT ROLLOVER         715      0.0470        34
                    FIXED OBJECT             2,822      0.0167        47
                    PED/BIKE/MOTORCYCLE      1,349     -0.0062*       -8
                    HEAVY TRUCK                822      0.0206        17
                    CAR LT 2950 LBS          1,342      0.0159        21
                    CAR GE 2950 LBS            677      0.0318        22
                    LTV                      3,157      0.0262        83
----------------                                                  ------
CARS GE 2950 LBS                                                     216
                                                                  ======
                                                                     813

* Not a statistically significant effect, as evidenced by Wald chi-square < 3.84
```

In each of the four groups of cars, the regression with mass and footprint as separate parameters attributes, as it should, almost the same fatality increase to downsizing as the regression with mass as the only size-mass parameter (where the 100-pound mass reduction implicitly incorporates, on the average, a 0.65 square foot reduction of footprint as well).

OVERALL EFFECT OF DOWNSIZING

Parameters in the regressions:	Mass + Footprint	Mass Only (with Implicit Size Reduction
With all 2-door and 4-door cars	766	778
Excluding muscle cars	730	744
Excluding muscle and sporty cars	759	777
4-door cars only	804	813

2.3 Analyses of NHTSA's 2003 database by methods resembling DRI's

DRI's 2003 report states that "The accident and fatality risk model used in [DRI's] analysis was based on the models described in Chapters 3 and 4 of [NHTSA's 1997 report[381]], but suitably extended to assess the effects of vehicle mass and size parameters on the vehicle crashworthiness, compatibility, and crash avoidance components of overall fatality risk."[382]

Chapters 3 and 4 of NHTSA's 1997 report estimate the relationship between mass-size and fatality rates per vehicle registration year, for MY 1985-1993 cars in CY 1989-1993 by splitting the analysis into two regression steps. First, in Chapter 3, the fatality rate per 1,000 induced-exposure crashes was analyzed for a database compiled from 11 State crash files – i.e., using only the fatal-crash data, as well as the induced-exposure data from those 11 States. The analyses are disaggregate logistic regressions, with independent variables including mass-size parameters (usually just curb weight, expressed as a simple, linear parameter, sometimes supplemented or replaced by track width and/or wheelbase), driver age and gender (expressed by the four variables FEMALE, YOUNGDRV, OLDMAN, and OLDWOMAN[383]), road type, and other factors. The dependent variable is whether the crash involvement was a fatality or an induced-exposure case. The induced-exposure crashes are not weighted by registration years or by any factor that would inflate them to national numbers: the estimation is internal to the data from these 11 States.

Chapter 4 is a regression of the rate of induced exposure crashes per 1,000 vehicle registration years in those same 11 States, by mass-size, driver age and gender, road type and other factors. Of course, the registration years in the Polk file do not have age, gender, or road type. Instead, the data are aggregated by make, model, and State (and other variables). For each make-model-State-… combination, a crash rate per 1,000 registration years is computed. The average driver age, proportion of females, proportion of rural roads, etc. among the induced-exposure cases for that combination serve as the values of the independent variables. The analysis is a weighted log-linear regression of the crash rates.

The effect of a reducing car mass or size on fatalities per million years is the sum of the coefficients for that mass or size parameter in the two regressions. It may be called a "two-step" approach because it involves two separate regression steps – i.e., the procedure in Chapter 3 and the procedure in Chapter 4.

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[381] Kahane (1997), pp. 37-88.
[382] Van Auken and Zellner (2003), p. 19.
[383] Kahane (1997), p. 38.

DRI in their 2003-2005 analyses modified these procedures by:

- Always using curb weight, track width, and wheelbase as the mass/size parameters.

- Refining the basic logistic regressions of Chapter 3 to "simultaneous two-stage logistic regressions" that generate (in one regression step) separate coefficients for a "crashworthiness/compatibility" effect and part of the "crash-avoidance" effect – but these two coefficients are expected to sum to the single coefficient produced by the basic regression.[384]

The method (as originally developed in Chapters 3 and 4, or as modified by DRI) appears to be theoretically unbiased. Ultimately, it estimates the relationship of mass/size parameters with societal fatality rates per million car years, just like NHTSA's 2003 analysis. However, already in its 1997 report, NHTSA stopped using the method of Chapters 3 and 4 of that report because:

- It is limited to the fatality data from just the States whose nonfatal crash files were available. It would be more precise (and thus preferable) to use fatality data from all States.

- Splitting the analysis into two regression steps is an unnecessary complication if a way can be found to do it in a single step.

Chapters 5 and 6 of NHTSA's 1997 report, which generated the principal findings of that report, found a way to use fatality data from all the States, at the cost of an even more cumbersome series of regression steps. The method of NHTSA's 2003 report used fatality data from all the States in a single regression step.

Nevertheless, the method of Chapters 3 and 4 could provide adequate if not precise estimates of the mass-size-safety relationship if mass-size is expressed by a single parameter, such as just curb weight. Problems arise with multiple parameters, such as curb weight, track width, and wheelbase. This was already known in 1997. In fact, on p. 45 of the 1997 report, there is a regression (Run No. C4) of first-event rollovers per 1,000 induced-exposure crashes by mass, track width, and wheelbase. It attributed a large benefit to reducing mass, offset by large fatality increases for reducing track width or wheelbase. On the next page it says:

> "[Could] a…case be made by putting all three parameters in the same regression? The problem, of course, is that they are highly intercorrelated: among these 1985-93 passenger cars, the correlation coefficients are .86 for curb weight with track width, .89 for curb weight with wheelbase and .79 for track width with wheelbase. When they are entered simultaneously (C4), it leads to typical "wrong signs"…: the "effect" for curb weight is a very large 11.1 percent per 100 pounds, in the wrong direction, while the effects for track width and wheelbase, while in the right direction, are double the values in [the regressions where track width or wheelbase is the only parameter]. "[385]

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[384] Van Auken and Zellner (2003), pp. 24-26 and Appendix D; Van Auken and Zellner (2005a).

[385] Kahane (1997), p. 46.

In other words, NHTSA in its 1997 report believed these regression coefficients were inaccurate as a consequence of the near multicollinearity of the variables.[386] At that time, it was not vital to separate the effects of mass and size, because the objective was to study the effect of downsizing, a concurrent reduction of mass and size. Thenceforth in the 1997 and 2003 reports, NHTSA did not again attempt to estimate the effect of mass and size parameters in the same regression.

DRI, starting in 2003, tackled a different analytic objective, namely to study the effect of reducing mass without reducing size. For that purpose it is essential to separate the effect of mass from other size parameters in the same regression. DRI's analysis method included regressions that incorporated some features of the approach in Chapter 3 of NHTSA's 1997 report. In their analyses of rollovers, collisions with fixed objects, and collisions with other cars, these regressions produced coefficients directionally similar to the analysis in NHTSA's 1997 report, described above, namely, an association of lower mass with lower fatality risk if track width and wheelbase are maintained.[387] DRI did not conclude that the magnitude and direction of those coefficients were consequences of the near multicollinearity of the parameters.

This report attempts to present evidence to the contrary, at least when certain features of DRI's analysis (or the approach in Chapters 3 and 4 of NHTSA's 1997 report) are applied to NHTSA's 2003 database:

- The preceding section showed that benefits for mass reduction are not inevitable from analyses with multiple parameters. The database and method of NHTSA's 2003 report show an increase in fatalities when mass is reduced while maintaining footprint, in fact approximately equal to or perhaps even slightly stronger than the effect of reducing footprint – even when 2-door cars are included in the analysis.

- Now it will try to show that the database was not the issue: when the method of Chapters 3 and 4 of the 1997 report is applied to the 2003 database, the results are similar to DRI's.

- The next section will present analyses that show fatality risk generally increases in the 2003 database, and rarely decreases, for lighter relative to heavier cars of the same footprint. These analyses tend to support the conclusion that mass and footprint have effects in the same direction, and of similar magnitude.

This section does not try to replicate DRI's analysis. Instead, it starts from NHTSA's 2003 method (Table 2-3) and then replaces certain features, one-by-one, with corresponding techniques in Chapters 3 and 4 of NHTSA's 1997 report – until the revised analysis begins producing outcomes like DRI's (namely that mass reduction is beneficial). As will be seen, that happens as soon as the two-step approach of Chapters 3 and 4 is applied. It does not even need other features of the 1997 or DRI reports, such as simple linear curb weight, the 1997

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[386] The increase in magnitude of all three coefficients and the change in the sign of the curb-weight coefficient is the third symptom of multicollinearity described by Greene (1993), pp. 266-268; moreover, the standard error of the coefficients is twice as large when two or more mass or size parameters are in the regression as when there is only one – Greene's second symptom of multicollinearity.

[387] Van Auken and Zellner (2005a), Table 12.

formulation of the age/gender variables,[388] or DRI's simultaneous two-stage regression in place of the basic logistic regression of Chapter 3.

This section will try to explain why those methods, when applied to NHTSA's 2003 database, produce results a lot like DRI's, but it does not claim that DRI obtained their results from their database for exactly those reasons – NHTSA did not review or analyze DRI's database.[389] More generally, splitting the analysis into two regression steps, while theoretically unbiased (because it ultimately estimates the same things as the one-step analysis), increases the chance of coefficients in the lighter ↔ fatalities direction for mass because the effect of mass is essentially split between the two regressions, and it is not strong enough in either regression to assure coefficients in the lighter ↔ more fatalities direction.

Limiting the analysis to six States: The first salient feature of Chapters 3 and 4 in the 1997 report, as discussed above, is that the fatal, induced-exposure, and registration data were limited to 11 States. The DRI analyses were further limited to seven States: Florida, Illinois, Maryland, Missouri, New Mexico, North Carolina, and Ohio. NHTSA's 2003 study included all of these except New Mexico as sources of induced-exposure crashes, but New Mexico only accounted for 2.5 percent of the fatal involvements and 1.8 percent of the induced-exposure crashes in DRI's database.[390] The first step is to drop from the 2003 database the induced-exposure crashes from Pennsylvania and Utah and use only the data from the six States also in DRI's database. More importantly, it also drops all the fatal crashes and vehicle-registration data outside those six States. It will analyze the fatal crashes per registration year in just those six States.

For the moment, however, the basic single-step regression approach of the 2003 report continues, modified only by limiting it to the six States. That is accomplished by deleting the fatal and induced-exposure crashes from any other States. Instead of weighting each induced-exposure crash by its fair share of the nation's vehicle registration years, weight it by its fair share of <u>just that State's</u> vehicle registration years. The independent variables in this regression, and throughout this section, will be the same as in the 2003 report (except where specified).[391]

Table 2-6 estimates the coefficients for curb weight, track width, and wheelbase from the six States and applies those coefficients to the CY 1999 national baseline fatalities to compute national estimates. Compare them to Table 2-3.

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[388] But similar results are obtained when curb weight <u>is</u> entered as a simple, linear variable, as will be discussed below; likewise, when the age/gender variables are formulated as in the 1997 report.

[389] For example, NHTSA does not know the VIF scores for curb weight, track width, and wheelbase in the DRI database (they are not specified in DRI's reports).

[390] Van Auken and Zellner (2003), pp. 13 and 17.

[391] For example, the driver-age variables are M14_30, M30_50, etc. as in the 2003 report; not OLDMAN, OLDWOMAN, etc. as in the 1997 and DRI reports.

TABLE 2-6: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
ONE-STEP REGRESSION (LIKE TABLE 2-3) BUT LIMITED TO FL IL MD MO NC OH

6.1 BASED ON ALL 2-DOOR CARS AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0262*	-26	0.0140*	14	0.0258*	26	14
	FIXED OBJECT	3,357	0.0269	90	-0.0143	-48	0.0239	80	123
	PED/BIKE/MOTORCYCLE	1,741	0.0549	96	0.0063*	11	-0.0125*	-22	85
	HEAVY TRUCK	1,148	0.0533	61	-0.0013*	-2	0.0035*	4	64
	CAR LT 2950 LBS	934	0.0278*	26	0.0035*	3	0.0107*	10	39
	CAR GE 2950 LBS	1,342	0.0139*	19	0.0018*	2	0.0054*	7	28
	LTV	4,091	0.0244	100	0.0181	74	0.0082*	33	207
----------------				------		------		------	------
CARS LT 2950 LBS				365		55		139	559
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	0.0139*	10	0.0140*	10	0.0258*	18	38
	FIXED OBJECT	2,822	0.0193*	54	-0.0146	-41	0.0239	68	81
	PED/BIKE/MOTORCYCLE	1,349	0.0140*	19	0.0063*	8	-0.0125*	-17	10
	HEAVY TRUCK	822	0.0020*	2	-0.0013*	-1	0.0035*	3	3
	CAR LT 2950 LBS	1,342	0.0049*	7	0.0018*	2	0.0054*	7	16
	CAR GE 2950 LBS	677	0.0098*	7	0.0035*	2	0.0107*	7	16
	LTV	3,157	0.0114*	36	0.0181	57	0.0082*	26	119
----------------				------		------		------	------
CARS GE 2950 LBS				134		38		112	284
				======		======		======	======
				500		93		251	844

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

6.2 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0275*	-27	0.0193*	19	0.0158*	16	8
	FIXED OBJECT	3,357	0.0165*	55	0.0060*	20	0.0042*	14	90
	PED/BIKE/MOTORCYCLE	1,741	0.0519	90	0.0095*	17	-0.0131*	-23	84
	HEAVY TRUCK	1,148	0.0505	58	0.0062*	7	-0.0037*	-4	61
	CAR LT 2950 LBS	934	0.0226*	21	0.0219	20	-0.0073*	-7	35
	CAR GE 2950 LBS	1,342	0.0113*	15	0.0109	15	-0.0036*	-5	25
	LTV	4,091	0.0238	97	0.0194	80	0.0076*	31	208
----------------				------		------		------	------
CARS LT 2950 LBS				310		178		22	510
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	0.0134*	10	0.0193*	14	0.0158*	11	35
	FIXED OBJECT	2,822	0.0117*	33	0.0060*	17	0.0042*	12	62
	PED/BIKE/MOTORCYCLE	1,349	0.0102*	14	0.0095*	13	-0.0131*	-18	9
	HEAVY TRUCK	822	0.0008*	1	0.0062*	5	-0.0037*	-3	3
	CAR LT 2950 LBS	1,342	0.0044*	6	0.0109	15	-0.0036*	-5	16
	CAR GE 2950 LBS	677	0.0088*	6	0.0219	15	-0.0073*	-5	16
	LTV	3,157	0.0103*	33	0.0194	61	0.0076*	24	118
----------------				------		------		------	------
CARS GE 2950 LBS				101		139		17	257
				======		======		======	======
				411		317		39	767

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

TABLE 2-6 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
ONE-STEP REGRESSION (LIKE TABLE 2-3) BUT LIMITED TO FL IL MD MO NC OH

6.3 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0131*	-13	0.0149*	15	0.0191*	19	21
	FIXED OBJECT	3,357	0.0196*	66	0.0103*	35	0.0020*	7	107
	PED/BIKE/MOTORCYCLE	1,741	0.0522	91	0.0128	22	-0.0137*	-24	89
	HEAVY TRUCK	1,148	0.0517	59	0.0087*	10	0.0005*	1	70
	CAR LT 2950 LBS	934	0.0238*	22	0.0252	24	-0.0099*	-9	37
	CAR GE 2950 LBS	1,342	0.0119*	16	0.0126	17	-0.0049*	-7	26
	LTV	4,091	0.0271	111	0.0214	88	0.0099*	40	239
CARS LT 2950 LBS				352		210		27	589
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	0.0087*	6	0.0149*	11	0.0191*	14	30
	FIXED OBJECT	2,822	0.0061*	17	0.0102*	29	0.0020*	6	52
	PED/BIKE/MOTORCYCLE	1,349	0.0062*	8	0.0128	17	-0.0137*	-19	7
	HEAVY TRUCK	822	-0.0082*	-7	0.0087*	7	0.0005*	0	1
	CAR LT 2950 LBS	1,342	0.0038*	5	0.0126	17	-0.0049*	-7	15
	CAR GE 2950 LBS	677	0.0076*	5	0.0252	17	-0.0099*	-7	16
	LTV	3,157	0.0034*	11	0.0214	68	0.0099*	31	110
CARS GE 2950 LBS				46		165		19	231
				398		375		46	819

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

6.4 BASED ON 4-DOOR NON-POLICE CARS ONLY

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	0.0123*	12	0.0196*	20	0.0032*	3	35
	FIXED OBJECT	3,357	0.0248*	83	0.0137*	46	0.0008*	3	132
	PED/BIKE/MOTORCYCLE	1,741	0.0435	76	0.0122*	21	-0.0068*	-12	85
	HEAVY TRUCK	1,148	0.0677	78	0.0015*	2	-0.0067*	-8	72
	CAR LT 2950 LBS	934	0.0188*	18	0.0271	25	-0.0081*	-8	35
	CAR GE 2950 LBS	1,342	0.0094*	13	0.0136	18	-0.0040*	-5	25
	LTV	4,091	0.0328	134	0.0232	95	0.0120*	49	278
CARS LT 2950 LBS				413		227		23	663
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0016*	-1	0.0196*	14	0.0032*	2	15
	FIXED OBJECT	2,822	-0.0054*	-15	0.0137*	39	0.0008*	2	26
	PED/BIKE/MOTORCYCLE	1,349	0.0102*	14	0.0122*	16	-0.0068*	-9	21
	HEAVY TRUCK	822	0.0081*	7	0.0015*	1	-0.0068*	-6	2
	CAR LT 2950 LBS	1,342	-0.0019*	-3	0.0136	18	-0.0040*	-5	10
	CAR GE 2950 LBS	677	-0.0038*	-3	0.0271	18	-0.0081*	-5	10
	LTV	3,157	-0.0076*	-24	0.0232	73	0.0120*	38	87
CARS GE 2950 LBS				-25		180		17	172
				388		407		40	835

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

Merely limiting the data to six States barely changes the big picture, although details change here and there. The overall effect of downsizing ranges from 757 to 835 additional fatalities, slightly more than the range of 694 to 757 in Table 2-3. Table 2-6 attributes a range of 388 to 500 added fatalities to the mass reduction, not much different from the range of 458 to 543 in Table 2-3. Specifically, in the analysis excluding muscle cars but including other 2-door and 4-door cars (Table 2-6.2), the point estimate for reducing mass by 100 pounds is an increase of 411 fatalities, which is well within the 1.96-sigma sampling-error confidence bounds of the corresponding analysis of Table 2-3.2 (260 to 690). Detail changes, which likely reflect the smaller number of fatal-crash cases rather than any systematic shift in the computations, include:

- Fewer coefficients in the lighter ↔ fewer fatalities direction for mass in rollovers (4 out of 8, not all 8 as in Table 2-3)

- Fewer coefficients in the shorter ↔ fewer fatalities direction for wheelbase, resulting in a substantial (251) overall effect for wheelbase when muscle cars are included, and no negative overall effects

- For cars ≥ 2,950 pounds, the effect of mass in collisions with LTVs is smaller than in Table 2-3 and even has the opposite sign in the analysis limited to 4-door cars

- Fewer of the individual regression coefficients are statistically significant

In other words, limiting the data to [these particular] six States is not the issue. Or to put it another way, the 2003 report's method of creating a national database with induced-exposure data from just eight States did not bias the results in the direction of a strong effect for mass.

Two-step regression: From the six-State database used in Table 2-6, it is relatively simple to perform regressions in two steps, similar to Chapters 3 and 4 of the 1997 report. For regressions of fatalities per 1,000 induced-exposure involvements, run the same logistic regressions as in Table 2-6, but instead of weighting each induced-exposure crash by its fair share of the State's vehicle registration years, just give it a weight of 1. It is also appropriate to add a categorical variable for State, to account for State-to-State variations in the reporting thresholds of nonfatal crashes.[392]

For regressions of the number of induced-exposure involvements per registration year, aggregate the data, summing the registration years and the counts of induced-exposure cases by make, model, body type, MY, State, and CY. For each combination, find the average value of the driver-age and other control variables among the induced-exposure cases. These averages will serve as the values of the control variables. Perform a log-linear regression of the crash rate (induced-exposure crashes per vehicle year) by curb weight (2-piece linear), track width, wheelbase, and the other control variables in the 2003 report, plus a categorical variable for State. The regression is weighted by the number of registration years in each data point.[393]

Table 2-7 takes the sums of the coefficients from the two regressions and applies them to the CY 1999 national baseline fatalities to compute national estimates. Compare them to Tables 2-3 and 2-6. The big picture has changed completely. Table 2-7 attributes a benefit ranging from 355 to 449 fewer fatalities per 100 pound reduction of curb weight if track width and wheelbase do not change – approaching the 580 benefit estimated by DRI. Specifically, in the analysis excluding muscle cars (Table 2-7.2), the point estimate for reducing mass by 100 pounds is a reduction of 426 fatalities, which is outside the 1.96-sigma sampling-error confidence bounds of the corresponding analysis of Table 2-3.2 (260 to 690 increase). The benefit of reducing mass is more than offset by penalties for reducing track width and wheelbase, but the net overall effect of downsizing ranges from an increase of 280 to 371 fatalities, substantially less than the 700-800 ranges in Tables 3 and 6.

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[392] Kahane (1997), pp. 20-22, 38, and 43.

[393] *Ibid*., p. 71.

TABLE 2-7: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
TWO-STEP REGRESSION (LIKE CHAPTERS 3 AND 4 OF NHTSA's 1997 REPORT)

7.1 BASED ON ALL 2-DOOR CARS AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0396*	-39	0.0226	22	0.0364	36	19
	FIXED OBJECT	3,357	0.0134*	45	-0.0090*	-30	0.0320	107	122
	PED/BIKE/MOTORCYCLE	1,741	0.0105*	18	0.0243	42	-0.0086*	-15	46
	HEAVY TRUCK	1,148	0.0305*	35	0.0062*	7	0.0080*	9	51
	CAR LT 2950 LBS	934	-0.0334*	-31	0.0222	21	0.0180*	17	6
	CAR GE 2950 LBS	1,342	-0.0167*	-22	0.0111	15	0.0090*	12	5
	LTV	4,091	-0.0054*	-22	0.0291	119	0.0108*	44	141
CARS LT 2950 LBS				-17		196		211	390
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0334*	-24	0.0226	16	0.0364	26	18
	FIXED OBJECT	2,822	-0.0230	-65	-0.0090*	-26	0.0320	90	-0
	PED/BIKE/MOTORCYCLE	1,349	-0.0291	-39	0.0243	33	-0.0086*	-12	-18
	HEAVY TRUCK	822	-0.0365	-30	0.0062*	5	0.0080*	7	-18
	CAR LT 2950 LBS	1,342	-0.0328	-44	0.0111	15	0.0090*	12	-17
	CAR GE 2950 LBS	677	-0.0656	-44	0.0222	15	0.0180*	12	-17
	LTV	3,157	-0.0292	-92	0.0291	92	0.0108*	34	34
CARS GE 2950 LBS				-339		150		170	-19
				-355		346		381	371

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

7.2 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0412*	-41	0.0272	27	0.0258*	26	12
	FIXED OBJECT	3,357	0.0043*	14	0.0098*	33	0.0113*	38	85
	PED/BIKE/MOTORCYCLE	1,741	0.0063*	11	0.0294	51	-0.0114*	-20	42
	HEAVY TRUCK	1,148	0.0268*	31	0.0138*	16	0.0000*	0	47
	CAR LT 2950 LBS	934	-0.0392*	-37	0.0411	38	-0.0026*	-2	-1
	CAR GE 2950 LBS	1,342	-0.0196*	-26	0.0206	28	-0.0013*	-2	-0
	LTV	4,091	-0.0063*	-26	0.0307	125	0.0092*	38	137
CARS LT 2950 LBS				-74		318		77	322
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0324*	-23	0.0272	19	0.0258*	18	15
	FIXED OBJECT	2,822	-0.0270	-76	0.0098*	28	0.0113*	32	-17
	PED/BIKE/MOTORCYCLE	1,349	-0.0323	-44	0.0294	40	-0.0114*	-15	-19
	HEAVY TRUCK	822	-0.0366	-30	0.0138*	11	0.0000*	0	-19
	CAR LT 2950 LBS	1,342	-0.0320	-43	0.0206	28	-0.0013*	-2	-17
	CAR GE 2950 LBS	677	-0.0640	-43	0.0411	28	-0.0026*	-2	-17
	LTV	3,157	-0.0295	-93	0.0307	97	0.0092*	29	33
CARS GE 2950 LBS				-352		250		60	-42
				-426		569		138	280

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

TABLE 2-7 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
TWO-STEP REGRESSION (LIKE CHAPTERS 3 AND 4 OF NHTSA's 1997 REPORT)

7.3 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0293*	-29	0.0233*	23	0.0296*	29	23
	FIXED OBJECT	3,357	0.0058*	19	0.0137	46	0.0095*	32	97
	PED/BIKE/MOTORCYCLE	1,741	0.0054*	9	0.0329	57	-0.0119*	-21	46
	HEAVY TRUCK	1,148	0.0276*	32	0.0162	19	0.0043*	5	55
	CAR LT 2950 LBS	934	-0.0394*	-37	0.0438	41	-0.0044*	-4	-0
	CAR GE 2950 LBS	1,342	-0.0197*	-26	0.0219	29	-0.0022*	-3	-0
	LTV	4,091	-0.0034*	-14	0.0324	133	0.0112*	46	165
CARS LT 2950 LBS				-46		348		84	386
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0377*	-27	0.0233*	17	0.0296*	21	11
	FIXED OBJECT	2,822	-0.0321	-91	0.0137	39	0.0095*	27	-25
	PED/BIKE/MOTORCYCLE	1,349	-0.0362	-49	0.0329	44	-0.0119*	-16	-21
	HEAVY TRUCK	822	-0.0454	-37	0.0162	13	0.0043*	4	-20
	CAR LT 2950 LBS	1,342	-0.0323	-43	0.0219	29	-0.0022*	-3	-17
	CAR GE 2950 LBS	677	-0.0646	-44	0.0438	30	-0.0044*	-3	-17
	LTV	3,157	-0.0357	-113	0.0324	102	0.0112*	35	25
CARS GE 2950 LBS				-403		274		65	-64
				-449		622		149	322

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

7.4 BASED ON 4-DOOR NON-POLICE CARS ONLY

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0098*	-10	0.0302	30	0.0069*	7	27
	FIXED OBJECT	3,357	0.0088*	30	0.0180	60	0.0032*	11	101
	PED/BIKE/MOTORCYCLE	1,741	0.0066*	11	0.0296	52	-0.0115*	-20	43
	HEAVY TRUCK	1,148	0.0444	51	0.0090*	10	-0.0080*	-9	52
	CAR LT 2950 LBS	934	-0.0470*	-44	0.0450	42	-0.0131*	-12	-14
	CAR GE 2950 LBS	1,342	-0.0235*	-32	0.0225	30	-0.0066*	-9	-10
	LTV	4,091	0.0056*	23	0.0338	138	0.0070*	29	190
CARS LT 2950 LBS				30		363		-4	389
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0391*	-28	0.0302	22	0.0069*	5	-1
	FIXED OBJECT	2,822	-0.0366	-103	0.0180	51	0.0032*	9	-43
	PED/BIKE/MOTORCYCLE	1,349	-0.0223*	-30	0.0296	40	-0.0115*	-16	-6
	HEAVY TRUCK	822	-0.0227*	-19	0.0090*	7	-0.0080*	-7	-18
	CAR LT 2950 LBS	1,342	-0.0320	-43	0.0225	30	-0.0066*	-9	-22
	CAR GE 2950 LBS	677	-0.0640	-43	0.0450	30	-0.0131*	-9	-22
	LTV	3,157	-0.0386	-122	0.0338	107	0.0070*	22	7
CARS GE 2950 LBS				-388		287		-4	-105
				-358		650		-8	284

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

A closer look at Table 2-7 reveals:

- The effect of reducing wheelbase by 1.01 inches is not robust at all, ranging from an increase of 381 fatalities (stronger even than the effect of track width) in the regressions including all 2-door and 4-door cars to a reduction of 8 fatalities in the analysis limited to 4-door cars. That mirrors the DRI analyses, where limiting to 4-door cars also made the wheelbase effect non-significant.[394]

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[394] Van Auken and Zellner (2005b), p. 29; the wide swing in the coefficients for wheelbase and track width in response to the inclusion or exclusion of relatively few models of muscle cars suggests the first symptom of multicollinearity cited by Greene (1993), p. 267.

- For cars ≥ 2,950 pounds, every regression for every type of crash attributes a benefit to reducing mass, regardless of whether 2-door cars are included or excluded from the data.

- For cars < 2,950 pounds, mass reduction is beneficial in rollovers, collisions with other cars, and collisions with LTVs.

- Track width is the dominant factor in most of the regressions, even in collisions with LTVs, but it is in the narrower ↔ fewer fatalities direction in the fixed-object analysis that includes muscle cars.

- The overall effect of downsizing in cars ≥ 2,950 pounds is a fatality reduction.

Based on the above, NHTSA believes that the analysis method is the issue, not the database. The method of Chapters 3 and 4 in the 1997 report produces similar results with NHTSA's 2003 database and DRI's databases, attributing a benefit to mass reduction without changing track width or wheelbase. Why is that so? In regression analyses where there are several nearly multicollinear independent variables, the variable with a weak relationship to the dependent variable (in that specific regression, not necessarily overall) is likely to get a sign in the lighter/smaller ↔ fewer fatalities direction. It appears the regression can get a better fit with the dependent variable by giving this unimportant independent variable the opposite sign while intensifying the coefficient for one of the other, more important independent variables. As discussed earlier, curb weight approaches near multicollinearity with track width and wheelbase, as evidenced by VIF scores in the 6-7 range. As Greene said in his textbook, unusual data in just a few of these combinations "can produce wide swings in the parameter estimates."[395]

Thus, for example, in Table 2-3, where wheelbase was usually the variable with the weakest relationship to fatality risk, the regressions often gave wheelbase a weakly negative coefficient while perhaps slightly intensifying the positive coefficients for track width or curb weight and making them less accurate. In rollovers, where mass was less important than wheelbase, mass received the negative coefficient. But the analyses in Table 2-4 used only two mass-size variables – curb weight and footprint – both of which have strong natural relationships to fatality risk. Rarely did either receive a negative coefficient, even though they are quite inter-correlated ($r = .893$).[396] Only in rollovers, where curb weight probably matters little, did it receive a negative coefficient.

The two-step regression approach splits the effect of curb weight between the two regressions. In many types of crashes, and especially for cars ≥ 2,950 pounds, those partial effects are weak enough, relative to some of the other variables, to get coefficients in the lighter ↔ fewer fatalities direction in both regressions even though the full effect got a coefficient in the lighter ↔ more fatalities direction in the single-step regression. Why is that so? It appears that part of the genuine effect of mass is momentarily "lost" when fatality rates are analyzed per 1,000 reported crash involvements or per 1,000 reported induced-exposure involvements, because that effect is "hidden" in the rate of reported involvements per 1,000 registration years. Heavier cars

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[395] Greene (1993), p. 267.

[396] But two caveats stated earlier should be recalled: (1) the mere absence of negative coefficients does not by itself prove that a regression is estimating accurately and (2) analysts may differ in their judgments on whether a coefficient ought to be positive or negative.

have fewer reported crash involvements per registration year. Reported crash rates decrease by about 2 percent reduction per 100-pound increase.[397] Because log-linear effects are additive across the two regression steps, this 2-percent effect is basically "lost" from the analysis of fatalities per 1,000 induced-exposure crashes and, except where the mass effect is much stronger than 2 percent (e.g., cars < 2,950 pounds hitting heavy trucks), that is apparently enough to make the regressions recognize mass as a weak factor and give it the opposite sign while intensifying the effect of track width or wheelbase.

Subsequently, the regression of induced-exposure crashes per registration year aggregates the data by make and model and averages the ages of the drivers over that make and model. This average driver age is also highly correlated with curb weight, because heavier cars have, on the average, older drivers. Specifically, the VIF test on the aggregated database generates a score of 9.2 for curb weight and up to 11.6 for the driver-age/gender variables, substantially higher than the VIF scores for other analyses of this report and approaching a level of near multicollinearity where regression becomes inadvisable.[398] As discussed in NHTSA's 2003 report on pp. 168-171, the aggregate regression attributes the effect of mass to the driver-age variables instead, as evidenced by implausibly large or opposite-sign coefficients for the driver-age variables.[399] In other words, the effect of mass is not transferred to track width or wheelbase, but away from the mass and size parameters entirely. That is probably why, in Table 2-7, the overall effect of downsizing ranges from 280 to 371, rather than the 700-800 range found in all the previous analyses.

In Table 2-7, if mass is entered in the regressions as a simple, linear variable (as in the analyses of DRI and NHTSA's 1997 report) instead of the two-piece-linear variables UNDRWT00 and OVERWT00 (as in NHTSA's 2003 report), the regressions still generate nearly identical coefficients for track width and wheelbase and continue to attribute approximately the same large benefit to mass reduction. This appears to be an intrinsic feature of logistic regression, independent of the data: just as in Table 2-4, expressing mass as a simple or a two-piece linear variable does not affect how the regression allocates between this mass and the other independent variables.[400] Likewise, the coefficients for the mass, track width, and wheelbase do not change much if age and gender are expressed by the parameters YOUNGDRV, OLDMAN, OLDWOMAN, and FEMALE (as in NHTSA's 1997 report and DRI's analyses) rather than M14_30, M30_50, M50_70, M70_96, F14_30, F30_50, F50_70, F70_96, and DRVMALE (as in NHTSA's 2003 report and Table 2-4).

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[397] Kahane (1997), pp. 65-66.

[398] If the age/gender variables from NHTSA's 2003 report are replaced by the parameters YOUNGDRV, OLDMAN, OLDWOMAN, and FEMALE (as in NHTSA's 1997 report and DRI's analyses), VIF for these variables drops below 10, but VIF for curb weight is still 9.1.

[399] Kahane (2003), pp. 168-171; the regression discussed there, from Kahane (1997), p. 74, estimated that VMT increases significantly for each year that drivers are younger than 35 and decreases by 4% for each year that they are older than 50 (and the Step 2 regression for this report had directionally similar results); in fact, analyses of odometer readings in the Crashworthiness Data System showed that mileage does not increase for young drivers and decreases at only half that rate for older drivers.

[400] In its comments to the proposed MY 2012-2016 CAFE/GHG standards (EPA-OAR-HQ-2009-0472-7238.1, pp. 8-10) DRI raised this issue, asking whether the different formulations of the mass variable might be contributing to the difference between NHTSA's and DRI's results.

Influence of the driver-age variables in the second regression: This next analysis is not presented as a “remedy” for Table 2-7, but merely to illustrate how splitting up the effect of mass between the two regressions, plus the data aggregation in the second regression, affect the mass coefficients in both regressions. (It is not a proposal to generally analyze the data without controlling for driver age.) Table 2-8 shows the effect of removing the confounding effect of driver age in the aggregate regressions by simply rerunning them without the driver-age variables (while leaving the first-step regression of fatalities per 1,000 induced-exposure crashes unchanged). The overall effect of downsizing returns to a range of 679 to 764 additional fatalities, reasonably consistent with all the previous results, except for Table 2-7.

TABLE 2-8: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
TWO-STEP REGRESSION (LIKE CHAPTERS 3 AND 4 OF NHTSA’s 1997 REPORT), BUT WITHOUT DRIVER-AGE VARIABLES ON THE 2^{ND} STEP

8.1 BASED ON ALL 2-DOOR CARS AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0260*	-26	0.0210	21	0.0334	33	28
	FIXED OBJECT	3,357	0.0270	91	-0.0106	-36	0.0291	98	153
	PED/BIKE/MOTORCYCLE	1,741	0.0241*	42	0.0227	39	-0.0115*	-20	61
	HEAVY TRUCK	1,148	0.0441	51	0.0046*	5	0.0051*	6	62
	CAR LT 2950 LBS	934	-0.0062*	-6	0.0190	18	0.0121*	11	23
	CAR GE 2950 LBS	1,342	-0.0031*	-4	0.0095	13	0.0061*	8	17
	LTV	4,091	0.0082*	34	0.0275	112	0.0079*	32	178
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CARS LT 2950 LBS				181		173		168	522
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0063*	-5	0.0210	15	0.0334	24	34
	FIXED OBJECT	2,822	0.0041*	12	-0.0106	-30	0.0291	82	64
	PED/BIKE/MOTORCYCLE	1,349	-0.0020*	-3	0.0227	31	-0.0115*	-16	12
	HEAVY TRUCK	822	-0.0094*	-8	0.0046*	4	0.0051*	4	0
	CAR LT 2950 LBS	1,342	-0.0057*	-8	0.0095	13	0.0061*	8	13
	CAR GE 2950 LBS	677	-0.0114*	-8	0.0190	13	0.0121*	8	13
	LTV	3,157	-0.0021*	-7	0.0275	87	0.0079*	25	105
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CARS GE 2950 LBS				-25		132		136	242
				======		======		======	======
				156		305		304	764

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

TABLE 2-8 (Continued): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
TWO-STEP REGRESSION (LIKE CHAPTERS 3 AND 4 OF NHTSA’s 1997 REPORT), BUT WITHOUT DRIVER-AGE VARIABLES ON THE 2^{ND} STEP

8.2 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0275*	-27	0.0262	26	0.0221*	22	21
	FIXED OBJECT	3,357	0.0180*	60	0.0087*	29	0.0077*	26	116
	PED/BIKE/MOTORCYCLE	1,741	0.0200*	35	0.0284	49	-0.0150*	-26	58
	HEAVY TRUCK	1,148	0.0405	46	0.0128*	15	-0.0036*	-4	57
	CAR LT 2950 LBS	934	-0.0118*	-11	0.0391	37	-0.0099*	-9	16
	CAR GE 2950 LBS	1,342	-0.0059*	-8	0.0196	26	-0.0049*	-7	12
	LTV	4,091	0.0074*	30	0.0296	121	0.0056*	23	174
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CARS LT 2950 LBS				126		303		24	453
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0046*	-3	0.0262	19	0.0221*	16	31
	FIXED OBJECT	2,822	0.0008*	2	0.0087*	25	0.0077*	22	49
	PED/BIKE/MOTORCYCLE	1,349	-0.0045*	-6	0.0284	38	-0.0150*	-20	12
	HEAVY TRUCK	822	-0.0088*	-7	0.0128*	10	-0.0036*	-3	0
	CAR LT 2950 LBS	1,342	-0.0042*	-6	0.0196	26	-0.0049*	-7	14
	CAR GE 2950 LBS	677	-0.0084*	-6	0.0391	26	-0.0099*	-7	14
	LTV	3,157	-0.0017*	-5	0.0296	94	0.0056*	18	106
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CARS GE 2950 LBS				-31		238		18	226
				======		======		======	======
				95		542		43	679

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

8.3 BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0151*	-15	0.0224*	22	0.0262*	26	33
	FIXED OBJECT	3,357	0.0200*	67	0.0129	43	0.0061*	20	131
	PED/BIKE/MOTORCYCLE	1,741	0.0196*	34	0.0320	56	-0.0154*	-27	63
	HEAVY TRUCK	1,148	0.0418	48	0.0153*	18	0.0009*	1	67
	CAR LT 2950 LBS	934	-0.0110*	-10	0.0420	39	-0.0113*	-11	18
	CAR GE 2950 LBS	1,342	-0.0055*	-7	0.0210	28	-0.0057*	-8	13
	LTV	4,091	0.0108*	44	0.0315	129	0.0078*	32	205
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CARS LT 2950 LBS				161		335		34	530
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0108*	-8	0.0224*	16	0.0262*	19	27
	FIXED OBJECT	2,822	-0.0052*	-15	0.0129	36	0.0061*	17	39
	PED/BIKE/MOTORCYCLE	1,349	-0.0093*	-13	0.0320	43	-0.0154*	-21	10
	HEAVY TRUCK	822	-0.0185*	-15	0.0153*	13	0.0009*	1	-2
	CAR LT 2950 LBS	1,342	-0.0054*	-7	0.0210	28	-0.0057*	-8	13
	CAR GE 2950 LBS	677	-0.0108*	-7	0.0420	28	-0.0113*	-8	13
	LTV	3,157	-0.0088*	-28	0.0315	100	0.0078*	25	96
----------------				------		------		------	------
CARS GE 2950 LBS				-92		264		25	197
				======		======		======	======
				68		599		59	727

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

TABLE 2-8 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .34" OF TRACK WIDTH, OR 1.01" OF WHEELBASE
TWO-STEP REGRESSION (LIKE CHAPTERS 3 AND 4 OF NHTSA's 1997 REPORT), BUT WITHOUT DRIVER-AGE VARIABLES ON THE 2^{ND} STEP

8.4 BASED ON 4-DOOR NON-POLICE CARS ONLY

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .34" TRACK WIDTH RED	FATL INCR	EFFECT OF 1.01" WHEEL BASE RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	0.0046*	5	0.0286	28	0.0054*	5	38
	FIXED OBJECT	3,357	0.0232*	78	0.0164	55	0.0017*	6	139
	PED/BIKE/MOTORCYCLE	1,741	0.0210*	37	0.0280	49	-0.0130*	-23	63
	HEAVY TRUCK	1,148	0.0588	68	0.0073*	8	-0.0095*	-11	65
	CAR LT 2950 LBS	934	-0.0182*	-17	0.0417	39	-0.0162*	-15	7
	CAR GE 2950 LBS	1,342	-0.0091*	-12	0.0208	28	-0.0081*	-11	5
	LTV	4,091	0.0200*	82	0.0321	131	0.0055*	22	236
----------------				------		------		------	------
CARS LT 2950 LBS				239		339		-26	552
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0150*	-11	0.0286	20	0.0054*	4	14
	FIXED OBJECT	2,822	-0.0125*	-35	0.0164	46	0.0017*	5	16
	PED/BIKE/MOTORCYCLE	1,349	0.0018*	2	0.0280	38	-0.0130*	-18	23
	HEAVY TRUCK	822	0.0014*	1	0.0073*	6	-0.0095*	-8	-1
	CAR LT 2950 LBS	1,342	-0.0079*	-11	0.0208	28	-0.0081*	-11	7
	CAR GE 2950 LBS	677	-0.0158*	-11	0.0417	28	-0.0162*	-11	7
	LTV	3,157	-0.0145*	-46	0.0321	101	0.0055*	17	73
----------------				------		------		------	------
CARS GE 2950 LBS				-109		268		-21	137
				======		======		======	======
				130		607		-47	689

*Not a statistically significant effect, as evidenced by the sum of the coefficients from the two regression steps having smaller absolute value than 1.96 root-sum-of-squares of the standard errors

Essentially, Table 2-8 "restores" approximately .02 to each of the mass coefficients, changing the overall effect of mass reduction from a strong benefit to a modest penalty. However, in many cases that is not enough to offset the opposite-sign coefficients introduced in the first step of the regression analysis, leaving many opposite-sign net effects, especially for cars ≥ 2,950 pounds. In the analysis excluding muscle cars (Table 2-8.2), the point estimate for reducing mass by 100 pounds is an increase of 95 fatalities, but it is still below the 1.96-sigma sampling-error confidence bounds of the corresponding analysis of Table 2-3.2 (260 to 690). The effects for track width and wheelbase changed little from Table 2-7, because track width and wheelbase have little relationship with the number of induced-exposure crashes per registration year.

2.4 The effect of curb weight within deciles of footprint in NHTSA's 2003 database and the effect of footprint within deciles of curb weight

The preceding section may help explain why some analysis methods attribute a benefit to mass reduction when footprint is maintained and others, working with the same 2003 database, do not. Regardless of which analysis looks better conceptually, the bottom-line question is, "Which result is more accurate?" If reducing mass while maintaining footprint really saves lives, there should be, among cohorts of cars with similar footprint, a rather consistent trend to lower fatality rates with lower car mass. One way to explore this is to split up the database into deciles of footprint. Within a decile, all the cars have similar footprint, typically within a square foot. Compute the simple fatality rate per million registration years for each "car group" in that decile and check if these rates have positive or negative correlation with curb weight.[401] If correlations are usually positive, mass reduction while maintaining footprint is beneficial. If the correlations are usually negative, mass reduction while maintaining footprint is harmful. If the correlations are about half positive and half negative, then mass reduction while maintaining footprint is safety-neutral. This is a method that does not involve any multivariate regression or any induced-exposure data (being based on simple fatality rates per million registration years, which are known with certainty from FARS and Polk data). This analysis is not intended as a substitute for regression: it does not estimate an effect and it also does not control for other confounding factors such as driver age and gender – it does not isolate the effect of mass alone. But it may be helpful in identifying, when there are two important and inter-correlated variables such as mass and footprint and there is a concern that a regression might estimate inaccurately, the general directional trend in the data when one of these variables is held constant and the other varies.

Specifically, NHTSA's 2003 database of MY 1991-1999 cars in CY 1995-2000 comprises 215 car groups (including both 2-door and 4-door cars). Consider only the groups that accumulated 500,000 or more vehicle registration years in CY 1995-2000, of which there are 94.[402] These 94 car groups are ordered by footprint and split into 10 cohorts containing approximately equal numbers of car groups. Table 2-9 enumerates the ten deciles of footprint and specifies the range of footprint and curb weight in each decile:

TABLE 2-9: TEN DECILES OF FOOTPRINT FOR MY 1991-1999 CAR GROUPS WITH 500,000 OR MORE VEHICLE REGISTRATION YEARS IN CY 1995-2000

Footprint Deciles	Range of Footprint (Square Feet)	Range of Curb Weight (Pounds)
1st	33.02 to 37.39	1655 to 2321
2nd	37.62 to 38.85	2093 to 2676
3rd	38.86 to 39.78	2197 to 3085
4th	39.91 to 40.73	2319 to 3329

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[401] A "car group" consists of one or more models built on the same platform (e.g., all Toyota Camrys produced in a 5-MY run from one redesign to the next, plus their corporate cousins Lexus ES). All cars of the same car group have identical footprint and just minor variations in curb weight.

[402] A threshold of 500,000 registration years is also used in Wenzel, T. (2009). *Analysis of the Relationship Between Vehicle Weight/Size and Safety and Implications for Federal Fuel Economy Regulation*. Draft report. Berkeley, CA: Lawrence Berkeley National Laboratories, Department of Energy.

5th	40.82 to 41.46	2408 to 3068
6th	41.50 to 42.80	2308 to 3307
7th	42.81 to 44.01	2787 to 3391
8th	44.03 to 45.00	2846 to 3639
9th	45.15 to 47.50	2977 to 3799
10th	47.79 to 51.64	3415 to 4460

Within the middle deciles, all footprints are in a range of about one square foot, while curb weights vary by 600 to 1000 pounds. Fatality rates are computed for the six types of crashes, as shown below in Table 2-10, in each decile. The correlation coefficient of curb weight with a particular fatality rate is computed in each decile two ways: (a) weighting each of the 9 or 10 high-sales car groups in that decile equally or (b) weighting them by the number of registration years. Thus, 60 correlation coefficients are computed by method (a) and 60 by (b).

A correlation coefficient is a decimal number anywhere between -1 and 1; the chance that a coefficient is exactly zero is infinitesimal. The analysis is basically a nonparametric test: out of 60 coefficients, how many are greater than zero and how many are less than zero? (For this test it does not matter if a coefficient is significantly greater or less than zero, just if it is greater or less than zero.) If these 60 coefficients were fully independent observations, it would be possible to say outright that 37 or more positives is significantly more than 30 and 23 or fewer is significantly less than 30. However, the observations are not quite fully independent. They are independent from one decile to the next (because each vehicle case is in only one of the deciles) but they are not entirely independent from one crash type to another (because fatality rates in different crash types are based on the same denominator of induced-exposure data, although different numerators of fatal-crash data). Under the circumstances, 39 or 40 may well be significantly more than half, but it is not certain.

Table 2-10 shows the number of deciles in which the correlation coefficient is <u>less than zero</u> – *i.e.*, lower curb weight, given the same footprint, is associated with <u>increased</u> fatality risk.

TABLE 2-10: HOLDING FOOTPRINT NEARLY CONSTANT

NUMBER OF FOOTPRINT DECILES WHERE CURB WEIGHT HAS NEGATIVE CORRELATION WITH THE FATAL-CRASH RATE

(Simple fatal-crash rates per million registration years,
car groups with 500,000+ registration years, MY 1991-1999 in CY 1995-2000)

Crash Type	Unweighted Correlation	Registration-Weighted Correlation
First-event rollovers	6	5
Collisions with fixed objects	4	2
Collisions with ped/bike/MC	8	7
Collisions with heavy trucks	8	5
Collisions with other passenger cars	6	5
Collisions with LTVs	7	6
Total	39	30

With the unweighted data points, 39 of 60 correlations are negative. This is consistent with the theory that mass reduction while holding footprint nearly constant is harmful to safety. More often than not, lighter cars have higher fatality risk than heavier cars of more or less the same footprint.

When the data points are weighted by registrations, exactly half of the correlations are negative. This is consistent with a hypothesis that mass reduction while maintaining footprint is safety-neutral. Neither result supports the conclusion that mass reduction is beneficial.

Specifically, first-event rollovers and collisions with other passenger cars are two crash types where DRI found a large benefit for reducing mass while maintaining track width and wheelbase and so did the two-step regression analysis of NHTSA’s 2003 database (Table 2-7). Table 2-10 suggests that is unlikely, at least for the 2003 database, because for each of those crash types, curb weight had negative correlation with fatality risk in 6 of 10 deciles (unweighted) or 5 of 10 deciles (weighted). Table 2-10 suggests mass reduction while maintaining footprint is more or less safety-neutral in rollovers and collisions with other cars (when the fatalities in both cars are taken into account).

The converse analysis, namely, testing the correlation of fatality rates with footprint across ten deciles of curb weight, helps put these results in perspective. Table 2-11 lists the ten deciles of curb weight, with the range of curb weight and footprint in each decile:

TABLE 2-11: TEN DECILES OF CURB WEIGHT FOR MY 1991-1999 CAR GROUPS WITH 500,000 OR MORE VEHICLE REGISTRATION YEARS IN CY 1995-2000

Curb Weight Deciles	Range of Curb Weight (Pounds)	Range of Footprint (Square Feet)
1st	1655 to 2206	33.02 to 39.16
2nd	2245 to 2352	34.63 to 41.50
3rd	2375 to 2606	37.97 to 41.46
4th	2655 to 2794	38.67 to 43.56
5th	2796 to 2902	39.53 to 44.10
6th	2903 to 3048	39.91 to 45.15
7th	3068 to 3282	39.64 to 44.90
8th	3299 to 3401	40.08 to 46.70
9th	3402 to 3727	44.08 to 48.65
10th	3799 to 4460	46.94 to 51.64

Within the middle deciles, curb weights are typically in a range of 100 to 200 pounds (as compared to 600 to 1000 in the preceding analysis), while footprints vary by 4 to 7 square feet (as compared to less than a square foot in the preceding analysis). Table 2-12 shows the number of deciles in which the correlation coefficient is less than zero – i.e., lower footprint, given the same curb weight, is associated with increased fatality risk.

With the unweighted data points, 39 of 60 correlations are negative, exactly the same as in Table 2-10. That suggests curb weight and footprint have more or less similar independent effects in the same direction (mass reduction ↔ fatality increase) and (footprint reduction ↔ fatality increase). The weighted correlations show a strong effect for footprint, in contrast to the safety-neutral effect of curb weight in Table 2-10. The footprint effect is very clear in rollovers, but it is also strong in all the other types of crashes except collisions with pedestrians. The weighted correlations suggest that a reduction in footprint will result in a fatality increase.

TABLE 2-12: HOLDING CURB WEIGHT NEARLY CONSTANT

NUMBER OF CURB-WEIGHT DECILES WHERE FOOTPRINT HAS NEGATIVE CORRELATION WITH THE FATAL-CRASH RATE

(Simple fatal-crash rates per million registration years,
car groups with 500,000+ registration years, MY 1991-1999 in CY 1995-2000)

Crash Type	Unweighted Correlation	Registration-Weighted Correlation
First-event rollovers	9	8
Collisions with fixed objects	7	7
Collisions with ped/bike/MC	3	4
Collisions with heavy trucks	6	8
Collisions with other passenger cars	7	8
Collisions with LTVs	7	9
Total	39	44

Tables 10 and 12 are based on the simple fatality rates per million registration years. They do not attempt to adjust the rates for driver age and gender or other factors. They are one way to look at the trends in the actual fatality rates. Another possible analysis is to split the 2003 database into deciles of footprint and to run the regression model of the 2003 report separately for each decile, with curb weight as the single mass-size attribute. How often does curb weight get a negative coefficient (reduction ↔ fatality increase)? Or, conversely, split it into deciles of curb weight and run regressions with footprint as the single mass-size attribute. This analysis will not provide much information about the basic trends in the data, but it will show if the regressions using multiple mass-size parameters produce results consistent with single-parameter regressions for cohorts where the other parameter is nearly constant – i.e., provide an indication if the regression is handling multiple parameters well.

The analysis uses the same deciles of footprint and curb weight as in Tables 10 and 12, but now includes all car groups, not just those with 500,000 or more registration years. Muscle cars are excluded because their inclusion diminished the effect of footprint (see Tables 3 and 4). In the analyses of footprint deciles, curb weight is a single linear variable, so as to produce a single coefficient. Table 2-13 shows the number of deciles in which the regression coefficient for curb weight is negative. Except for rollovers, curb weight reduction is associated with increased risk in the majority of the footprint deciles, and the effect is strong in collisions with pedestrians, heavy trucks, and LTVs; even in rollovers, the effect is close to neutral. This is consistent with the findings in Table 2-4, the regressions that included curb weight and footprint.

TABLE 2-13: HOLDING FOOTPRINT NEARLY CONSTANT

NUMBER OF FOOTPRINT DECILES WHERE CURB WEIGHT REDUCTION IS ASSOCIATED WITH A HIGHER FATAL-CRASH RATE
(Logistic regressions of fatal-crash rates per million registration years adjusting for driver age, gender, and other factors, MY 1991-1999 in CY 1995-2000, excluding muscle cars)

First-event rollovers	4
Collisions with fixed objects	6
Collisions with ped/bike/MC	8
Collisions with heavy trucks	8
Collisions with other passenger cars	6
Collisions with LTVs	8
Total	40

Conversely, Table 2-14 shows the number of curb-weight deciles in which the regression coefficient for footprint is negative. The effect of footprint is strong in rollovers, but in the other types of crashes it is close to neutral. On the whole, the number of analyses where mass reduction while controlling for footprint increased risk (40) was slightly higher but basically similar to the number where footprint reduction while controlling for curb weight increased risk (34). That, too, is consistent with the fairly equal allocation in Table 2-4 of the mass-safety effect to curb weight and footprint.

TABLE 2-14: HOLDING CURB WEIGHT NEARLY CONSTANT

NUMBER OF CURB-WEIGHT DECILES WHERE FOOTPRINT REDUCTION IS ASSOCIATED WITH A HIGHER FATAL-CRASH RATE
(Logistic regressions of fatal-crash rates per million registration years adjusting for driver age, gender, and other factors, MY 1991-1999 in CY 1995-2000, excluding muscle cars)

First-event rollovers	8
Collisions with fixed objects	6
Collisions with ped/bike/MC	4
Collisions with heavy trucks	4
Collisions with other passenger cars	6
Collisions with LTVs	6
Total	34

In summary, these analyses are consistent with the results of Table 2-4, the analysis of curb weight and footprint using the database and regression method of NHTSA’s 2003 report – namely, that curb weight and footprint have historical relationships with fatality risk of similar magnitude and direction, and that, in MY 1991-1999, lighter cars had higher fatality risk than heavier cars of the same footprint. Because the registration-weighted analysis in Table 2-10 showed an exact 30-30 split of the coefficients for curb weight, the results could also be consistent with a hypothesis that curb weight was safety-neutral for cars of the same footprint. But they do not support the conclusion that lower mass with the same footprint is beneficial to safety, because not a single analysis found fewer than 30 negative coefficients for curb weight.

The analyses also support the conclusion that reductions in footprint while keeping mass constant are harmful to safety.

2.5 Implications for future mass-reduction technologies: recommended effects for the upper-estimate and lower-estimate scenarios

Two alternative scenarios will be defined for the effect of mass reduction while maintaining footprint in passenger cars and applied in the Volpe model to predict potential safety impacts of mass reduction in MY 2012-2016. One scenario is based directly on regression coefficients generated by the analyses in Table 2-4. While the analyses estimate the cross-sectional trends in MY 1991-1999 cars, this section of the report will present reasons that the effect of mass reductions in future vehicles is likely to be smaller. The scenario based directly on the regression results should be considered an "upper-estimate" scenario. A corresponding "lower-estimate" scenario will be defined in this section; in it, many of the regression coefficients will be replaced by other (usually smaller) numbers, based on additional analyses and judgment on what is the likely effect of mass *per se* and what trends in the historical data could be avoided by mass-reduction technologies such as materials substitution. The author believes the two scenarios offer a plausible range of point estimates for the effect of mass reduction while maintaining footprint, but they should not be construed as upper and lower bounds. Furthermore, being point estimates, they are themselves subject to uncertainties, such as, for example, the sampling errors associated with the regression results (which will be estimated in Section 4 of this report). The scenarios apply only to passenger cars; corresponding scenarios for LTVs are developed in Section 3.4.

Upper-estimate scenario: The results in Table 2-4, where the analysis method of NHTSA's 2003 report is applied to the database from that report (MY 1991-1999 cars in CY 1995-2000), but with 2-door cars included in the analysis and footprint as well as curb weight included among the independent variables appear to estimate the relationship of mass and footprint to fatal-crash risk across the range of MY 1991-1999 cars. The two middle analyses in that table appear to be slightly more accurate than the analysis that included muscle cars (because the high track width and fatality rate of those cars nudged the results) or the one limited to 4-door cars. The average of these two middle analyses could be considered a "best estimate" for the trend in MY 1991-1999 cars. Table 2-15 recapitulates the two analyses for the reader's convenience and, in its last sub-table, averages each of the effects across the two analyses.

TABLE 2-15: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .65 SQ FT OF FOOTPRINT

BASED ON 2-DOOR CARS (EXCLUDING MUSCLE CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0171*	-17	0.0606	60	43
	FIXED OBJECT	3,357	0.0040*	13	0.0154	52	65
	PED/BIKE/MOTORCYCLE	1,741	0.0324	56	-0.0023*	-4	52
	HEAVY TRUCK	1,148	0.0411	47	0.0101*	12	59
	CAR LT 2950 LBS	934	0.0220	21	0.0134*	13	33
	CAR GE 2950 LBS	1,342	0.0110	15	0.0067*	9	24
	LTV	4,091	0.0384	157	0.0096	39	196
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CARS LT 2950 LBS				292		180	473
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0118*	-8	0.0606	43	35
	FIXED OBJECT	2,822	0.0132	37	0.0154	43	81
	PED/BIKE/MOTORCYCLE	1,349	-0.0048*	-6	-0.0023*	-3	-10
	HEAVY TRUCK	822	0.0097*	8	0.0101*	8	16
	CAR LT 2950 LBS	1,342	0.0094*	13	0.0067*	9	22
	CAR GE 2950 LBS	677	0.0188*	13	0.0134*	9	22
	LTV	3,157	0.0195	62	0.0096	30	92
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CARS GE 2950 LBS				117		140	257
				======		======	======
				410		321	730

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

BASED ON 2-DOOR CARS (EXCLUDING MUSCLE AND SPORTY CARS) AND 4-DOOR NON-POLICE CARS

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0146*	-15	0.0608	61	46
	FIXED OBJECT	3,357	0.0088*	30	0.0170	57	86
	PED/BIKE/MOTORCYCLE	1,741	0.0322	56	-0.0003*	-1	55
	HEAVY TRUCK	1,148	0.0384	44	0.0127	15	59
	CAR LT 2950 LBS	934	0.0174*	16	0.0202	19	35
	CAR GE 2950 LBS	1,342	0.0087*	12	0.0101	14	25
	LTV	4,091	0.0406	166	0.0111	45	211
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CARS LT 2950 LBS				309		209	518
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0148*	-11	0.0608	44	33
	FIXED OBJECT	2,822	0.0085*	24	0.0170	48	72
	PED/BIKE/MOTORCYCLE	1,349	-0.0072*	-10	-0.0003*	-0	-10
	HEAVY TRUCK	822	0.0071*	6	0.0127	10	16
	CAR LT 2950 LBS	1,342	0.0053*	7	0.0101	14	21
	CAR GE 2950 LBS	677	0.0106*	7	0.0202	14	21
	LTV	3,157	0.0169	53	0.0111	35	88
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CARS GE 2950 LBS				77		163	241
				======		======	======
				386		372	759

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

TABLE 2-15 (Concluded): ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .65 SQ FT OF FOOTPRINT

AVERAGE OF TWO PRECEDING ANALYSES

CAR WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .65 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
CARS LT 2950 LBS	1ST EVENT ROLLOVER	995	-0.0159**	-16	0.0607	61	45
	FIXED OBJECT	3,357	0.0064**	22	0.0162	55	76
	PED/BIKE/MOTORCYCLE	1,741	0.0323	56	-0.0013**	-3	54
	HEAVY TRUCK	1,148	0.0398	46	0.0114*	14	59
	CAR LT 2950 LBS	934	0.0197*	18	0.0168*	16	34
	CAR GE 2950 LBS	1,342	0.0099*	14	0.0084*	12	25
	LTV	4,091	0.0395	162	0.0104	42	204
----------------				------		------	------
CARS LT 2950 LBS				301		195	496
CARS GE 2950 LBS	1ST EVENT ROLLOVER	715	-0.0133**	-10	0.0607	44	34
	FIXED OBJECT	2,822	0.0109*	31	0.0162	46	77
	PED/BIKE/MOTORCYCLE	1,349	-0.0060**	-8	-0.0013**	-2	-10
	HEAVY TRUCK	822	0.0084**	7	0.0114*	9	16
	CAR LT 2950 LBS	1,342	0.0074**	10	0.0084*	12	22
	CAR GE 2950 LBS	677	0.0147**	10	0.0168*	12	22
	LTV	3,157	0.0182	58	0.0104	33	90
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CARS GE 2950 LBS				97		152	249
				======		======	======
				398		347	745

*Effect was not statistically significant effect in one of the two preceding sub-tables
**Effect was not statistically significant effect in either of the two preceding sub-tables

The average overall effect of downsizing – i.e., reducing mass by 100 pounds and footprint by 0.65 square feet – is an increase of 745 fatalities (average of 730 and 759), as shown in the last section of Table 2-15. The average effect of just reducing mass by 100 pounds without changing footprint is an increase of 398 fatalities (average of 410 and 386).[403] Overall, that is 53 percent of the effect of downsizing. However, mass accounts for a larger proportion of the effect of downsizing in cars < 2,950 pounds (301 of the 496 additional fatalities) than it does in cars ≥ 2,950 pounds (97 of the 249 additional fatalities).

The upper-estimate scenario estimates the historical difference in societal fatality rates of cars of different curb weights but the same footprint. It may be construed to estimate the possible effect of mass reduction without any particular regard for safety (other than not to reduce footprint).

Discussion of possible effects of future mass-reduction technologies: A key question is whether the MY 1991-1999 cross-sectional relationships between mass and societal fatality risk are likely to be accurate for predicting the effects of future mass reduction. A review of the reasons that lighter cars had higher fatality risk in 1991-1999 and the likely near-future technologies for mass reduction suggests that the effect of mass reduction could likely be substantially lower than the upper-estimate scenario.

The discussion that follows is confined to the past and future societal effects of mass reduction – i.e., the combined effect on fatalities in the reduced-mass vehicles and their collision partners. It does not take into account a tangible and an intangible harmful effect that mass reduction in passenger cars will have on the individuals who actually buy these cars or ride in them.

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[403] 1.96-sigma confidence bounds from approximately 183 to 613, assuming the average point estimate (398) has approximately the same sampling error as the point estimate in Table 2-4.2a (410).

The tangible effect is that the occupants of the reduced-mass MY 2012-2016 cars may experience more fatalities in collisions with (unchanged) pre-2012 cars and LTVs than they would have if their mass had not been reduced. It is an effect of mass *per se* that fatality risk is, on the average, higher for the occupants of the lighter vehicle in a 2-vehicle crash and will increase further as the mass mismatch becomes greater. But it is not a societal cost because it will be offset by fewer fatalities in the unchanged pre-2012 vehicles that are the collision partners. The elevated risk may continue, gradually diminishing over time, until all pre-2012 vehicles are retired and cease being collision partners. Specifically, a regression of the case-car fatality rate per million registration years in collisions with other cars attributes a 6.26 percent increase per 100-pound reduction in cars < 2,950 pounds, a 4.46 percent increase per 100-pound reduction in cars ≥ 2,950 pounds, and only a 2.43 percent increase per 0.65 square foot reduction of footprint. Similarly, the case-car fatality rate per million registration years in collisions with LTVs increases by 5.41 percent per 100-pound reduction in cars < 2,950 pounds, by 3.51 percent per 100-pound reduction in cars ≥ 2,950 pounds, and only by 2.15 percent per 0.65 square foot reduction of footprint.[404] In other words, mass is the dominant factor, even in the cars ≥ 2,950 pounds – i.e., fatalities will increase for the occupants of these cars if are reduced in mass, even if footprint is maintained. (However, if there were to be additional mass reduction in MY 2017 and later vehicles, it would, by the same logic, save lives in the MY 2012-2016 vehicles, offsetting the above increase.)

The intangible effect is opportunity cost. If safety-conscious mass-reduction technologies could be applied to build cars of unchanged mass and higher footprint, rather than lower mass and unchanged footprint, the former would likely be even safer than the latter.

Section 2.1 of this report presented a list of hypotheses for residual associations of lower mass with higher societal fatality risk, even after controlling for footprint, in cross-sectional analyses of MY 1991-1999 cars – i.e., a tendency of lighter cars to have higher fatal-crash risk than heavier ones with the same footprint, even after controlling for driver age and other factors. These hypotheses will now be restated and examined one-by-one as to their relevance to predicting the effects of near-future mass reduction.

- True societal effects of mass *per se*: A heavy car may be able to knock down a medium-size tree and continue moving forward, whereas a light car would have come to a complete stop – and likewise for collisions with other partially moveable objects such as unoccupied parked vehicles, deformable poles, or large animals. Partyka's analysis showed this is a factor of some importance.[405] A heavy car will transfer momentum to a medium-size truck or an LTV with GVWR ≥ 10,000 pounds (not regulated by CAFE) more than a light car, reducing its own ΔV and the fatality risk of its own occupants (but the fatality risk in the truck is so low that its slight increase in ΔV will not offset the benefit for the car's occupants).
    - These are basically advantages of mass *per se* helping a car reduce its own ΔV by transferring momentum to something else. These advantages will be lost if mass is reduced, no matter what way it is reduced. (Perhaps an increase in structural

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[404] Both of these regressions are based on 2-door non-muscle cars and 4-door non-police cars.

[405] Partyka (1995).

    rigidity might to a limited extent compensate for a loss of mass in some configurations by increasing deformation to the struck object.)

- Car-LTV collisions: When relatively light cars (< 3,000 pounds) hit average LTVs (curb weight ≥ 4,000 pounds) or when relatively heavy cars (weight 3,000 to 4,000 pounds) hit relatively heavy LTVs (weight ≥ 4,500 pounds), there are substantially more fatalities in the cars than in the LTVs. A further reduction in the mass of the cars will increase societal fatality risk, because the increase in the cars' occupant fatalities would exceed the reduction of occupant fatalities in the partner LTVs.

    - This, too, is an advantage of mass *per se* helping a car reduce its own ΔV by transferring momentum to something else (the LTV). The advantage will be lost if mass of the car is reduced, no matter what way it is reduced, but mass of the LTV stays the same. (But it can potentially be offset by societal benefits in these crashes if mass is reduced in the heavier LTVs, as will be shown in Section 3 of this report.)

- Structural strength: In MY 1991-1999, when there was little use of some high-strength materials that are now becoming more customary in vehicles, less mass for the same footprint may have meant a structurally weaker vehicle, and less safe for that reason.

    - This need not be an issue if future mass reduction is accomplished exclusively by substituting lighter materials of greater strength (per unit mass) or by removing mass from non-structural components.

- Factors that are fundamentally size-related but not correlated with footprint: Because these "size" features are not particularly correlated with a vehicle's footprint (and were actually more correlated with mass than footprint in MY 1991-1999), the CAFE incentive to maintain footprint does not inoculate against potentially harmful changes in these attributes. Prime examples: structure on the front and side, beyond the wheels (overhang) that adds protective crush space to the vehicle; a sill high enough to make a car less vulnerable in side impacts; a hood long enough to protect pedestrians from most head impacts with rigid structures.

    - This, too, need not be an issue if future mass reduction does not change the profile of the vehicle. For example, materials substitution would not change a vehicle's profile. But reducing the overhang on the front or side of a car would change the profile, even though it does not affect footprint.

- Possible driver-vehicle interface factors: As discussed in the Section 2.1 of this report, the historical, empirical data consistently show higher crash rates for light, small cars than for heavier, larger cars. In MY 1991-1999, drivers of lighter cars were significantly more likely to be the culpable party in a 2-vehicle collision, even after controlling for the driver's age/gender and the car's footprint – i.e., light cars were not driven as well as heavier cars. Section 2.1 did not resolve how much of that, if any was due to "self-selection" (poor drivers being more likely to choose lighter vehicles) and how much, if any was due to "driver-vehicle interface" (certain aspects of lightness and/or smallness in a car giving a driver a perception of greater maneuverability that ultimately results in driving with less of a safety margin). However, there was no obvious empirical evidence of self-selection in the MY 1991-1999 cars: after controlling for the driver's age/gender and urban/rural, there was no increase in antisocial driving behavior (such as DWI, drugs, speeding, or driving without a license) as car mass decreases.

- Of course, if these phenomena were merely a transient feature of past cars or a consequence of self-selection, they would not make future mass reduction add risk. But even if the lightness of a car can and does contribute to driving with less of a safety margin, there may still be ways to reduce mass with minimal added risk. Intuitively, mass reduction that does not perceptibly change the size, appearance, and performance of a car – that does not make it "feel light" or "easier to steer" – would not change driving patterns.[406] Furthermore, if mass reduction could create a perception of decreased maneuverability – e.g., by making the engine less powerful – it might even make drivers less inclined to push the safety margin.

It seems quite possible, then, that the fatality increase associated with future mass reduction could be smaller, perhaps much smaller than the upper-estimate scenario based on the MY 1991-1999 database. Conceptually, mass reduction carefully accomplished entirely by materials substitution that does not perceptibly change the external appearance or ride of a vehicle and that maintains its structural strength (without making it excessively rigid) could confine the added risk as close as possible to the effect of mass *per se* – namely, in collisions with partially moveable objects, medium-heavy trucks, and LTVs.[407]

Lower-estimate scenario – preliminary estimates of the effect of mass *per se*: Information from the regression analysis of the 2003 database combined with certain assumptions and inferences can be used to develop a "lower-estimate scenario" where the effect of future mass reduction would be limited to the effect of mass *per se*, in three of the six types of crashes: collisions with "fixed" (but actually breakable or partially moveable) objects, with medium-heavy trucks, and with LTVs. As discussed above, the net societal effect of mass *per se* is likely to be negligible in first-event rollovers, in collisions with pedestrians, and in car-to-car collisions – and the lower-estimate scenario sets the effect of mass reduction to zero in those three types of crashes.

The derivation of the effect of mass *per se* in fixed-object and heavy-truck collisions actually uses regression results for two other crash types: car-to-car and car-to-LTV. These are the two types of crashes where a passenger car is the "case" vehicle and the fatalities are to a substantial extent divided between the case car and the other vehicle. (In first-event rollovers and collisions with fixed objects or heavy trucks, the fatalities are almost all in the case vehicle; in collisions with pedestrians, bicyclists, or motorcyclists, they are rarely in the case vehicle.) In both types of crashes, it is possible to perform a regression on the societal fatality rate (involving occupants

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[406] The discussion is not intended to preclude potential improvements in vehicle performance that might be associated with mass reduction – such as improvements in stopping distance or steering response – if these are not offset by changes in driver behavior.

[407] Assuming the mass of the LTVs remains unchanged; Section 3 estimates the reduction in societal fatality risk for mass reduction in the LTVs.

of both vehicles) or on the occupant fatality rate in the case vehicle alone. The latter produces a higher coefficient for mass, because it does not take into account that reducing mass in the case vehicle saves lives in the [unchanged] other vehicle – and this increment of risk in the case vehicle, due to its increased ΔV relative to what the other vehicle experiences is the essence of the effect of mass *per se*. The working assumption will be that the <u>difference</u> between the mass coefficients in the two regressions (societal risk and case-vehicle risk) estimates the component of the mass coefficient that is the effect of mass *per se*.

Here are the coefficients for mass, after controlling for footprint, driver age/gender, and the other control variables used with the 2003 database. These numbers are the averages of the coefficients from the regressions including 4-door cars and all 2-door cars except muscle cars and the regressions including 4-door cars and all 2-door cars except muscle and sporty cars. The numbers for the societal fatality risk are copied directly from the last sub-table of Table 2-15. The numbers for own-vehicle risk are derived from identical regressions, except with fatalities in the case vehicle used to compute the dependent variable:

		EFFECT OF 100-POUND MASS REDUCTION (REGRESSION COEFFICIENT)		
CRASH TYPE	CAR WEIGHT GROUP	SOCIETAL	IN OWN CAR	Δ
HIT ANOTHER CAR	CARS LT 2950 LBS	0.0099	0.0615	0.0516
	CARS GE 2950 LBS	0.0074	0.0420	0.0346
	AVERAGE			0.0431
HIT LTV	CARS LT 2950 LBS	0.0395	0.0543	0.0148
	CARS GE 2950 LBS	0.0182	0.0338	0.0156
	AVERAGE			0.0152

The <u>difference</u> in the mass coefficients for societal risk and case-vehicle risk averages 4.31 percent per 100-pound reduction in the car-to-car collisions and 1.52 percent in the car-to-LTV collisions. The first number (4.31), while probably accurate for car-to-car collisions, no doubt overstates the likely effect of mass *per se* in collisions with fixed objects or medium-size trucks – because when the two vehicles are of similar mass (two cars), the proportional change in ΔV for reducing the lighter vehicle by 100 pounds is greater than when the two collision partners are of quite dissimilar mass (a car and a medium-size truck). The second number (1.52) no doubt understates the effect of mass *per se* in car-LTV collisions because in those collisions even the societal mass effect (which is much higher than in car-car) contains a component of mass *per se*.[408] The average of the two numbers, 2.92 percent will be used in the computations.

Table 2-15 shows 6,179 baseline fatalities in collisions of cars with fixed objects (i.e., 3,357 in the cars < 2,950 pounds plus 2,822 in the cars ≥ 2,950 pounds). An estimated 1,591 of them were frontal impacts into trees or poles.[409] Partyka found that a heavy car could knock down or substantially damage the tree or pole, while a light car could not, in 25 percent of impacts with

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[408] The regressions model the effect of reducing cars by 100 pounds while LTVs remains unchanged. Because the majority of fatalities are in the cars, the absolute increase in the car-occupant fatalities will exceed the decrease in the LTV occupant fatalities – resulting in an increase of societal risk that reflect mass *per se*. That societal increase can only be counterbalanced by taking more mass out of the LTVs than out of the cars.

[409] When the distribution of fixed-object fatalities in CY 2006 fatalities by object struck and principal impact point is applied to the baseline number.

fixed objects.[410] It is assumed that mass *per se* could potentially help the car occupants in these 398 (25% of 1,591) fatalities, but not in the other frontal collisions with trees or poles.

Furthermore, 319 of the 6,179 baseline fatalities were collisions with unoccupied parked cars, large animals, or non-fixed objects. It is assumed that mass *per se* has at least the potential to help the car occupants in all of those cases.

Thus, additional mass *per se* in the car might have helped the occupants of the car (and, conversely, a reduction of mass might have increased risk) in 398 + 319 = 717 of the 6,179 baseline fatalities in collisions with fixed objects. A 100-pound reduction in mass *per se* might have increased those 717 fatalities by 2.92 percent, which would amount to a .34 percent increase in the 6,179 baseline fatalities.

Table 2-15 shows 1,970 baseline fatalities in collisions of cars with heavy trucks. In an estimated 357 of these fatalities, the "heavy" truck was an LTV (pickup or van) with GVWR > 10,000 pounds (but curb weight usually in the 5,000-6,000 pound range), a single-unit truck with GVWR < 26,000 pounds, or a bus. Here, additional mass in the car has at least the potential to reduce risk for its occupants by measurably lowering the car's ΔV. But the other 1,613 are collisions with tractor-trailers or bobtail tractors, which outweigh cars to the point that adding mass in the car would only trivially lower its ΔV. A 100-pound reduction in mass *per se* in the passenger cars might have increased those 357 fatalities by 2.92 percent, which would amount to a .53 percent increase in the 1,970 baseline fatalities.

The regression analysis attributes a 3.95 percent fatality increase in collisions with LTVs per 100-pound mass reduction in cars < 2,950 pounds (last sub-table of Table 2-15, controlling for footprint). The increase includes effects of mass *per se* as well as other factors in the historical data, such as the trend toward higher crash-involvement rates in lighter and smaller cars. The regression analysis also attributed a 0.99 percent fatality increase in car-to-car collisions; however, the preceding discussion concluded that little or none of the 0.99 percent increase was attributable to mass *per se* and, in the lower-estimate scenario, it set the effect of mass reduction in car-to-car collisions to zero. Assuming a similar effect of factors other than mass *per se* in car-to-car and car-to-LTV collisions and deducting 0.99 from 3.95 percentage points yields an estimated 2.96 percent increase attributable to mass *per se* in car-to-LTV collisions when cars < 2,950 pounds are reduced by 100 pounds and the LTVs remain unchanged. The corresponding effect in cars ≥ 2,950 pounds is a 1.82 – 0.74 = 1.08 percent increase.

Table 2-16 summarizes the recommended effects for mass reduction after controlling for footprint in the two scenarios for passenger cars:

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[410] Partyka (1995); the analysis of the Crashworthiness Data System included nonfatal as well as fatal crashes (in order to provide enough cases for analysis); thus, the 25% figure may not be accurate for fatal crashes.

TABLE 2-16: SOCIETAL EFFECTS OF 100-POUND MASS REDUCTION WHILE MAINTAINING FOOTPRINT, PASSENGER CARS

	Fatality Increase per 100-Pound Reduction (%)	
Crash Type	Upper-Estimate Scenario (Actual Regression Results)	Lower-Estimate Scenario
CARS WEIGHING LESS THAN 2,950 POUNDS		
First-event rollover	-1.59	0
Fixed object	.64	.34
Pedestrian/bike/motorcycle	3.23	0
Heavy truck	3.98	.53
Car < 2,950 pounds	1.97	0
Car ≥ 2,950 pounds	.99	0
LTV	3.95	2.96
CARS WEIGHING 2,950 POUNDS OR MORE		
First-event rollover	-1.33	0
Fixed object	1.09	.34
Pedestrian/bike/motorcycle	-.60	0
Heavy truck	.84	.53
Car < 2,950 pounds	.74	0
Car ≥ 2,950 pounds	1.47	0
LTV	1.82	1.08

3. Analyses of LTVs

3.1 Differences between the analyses of LTVs and passenger cars

NHTSA’s 2003 and 1997 reports and DRI’s studies include regression analyses of LTVs that essentially parallel the regressions for passenger cars. LTVs (light trucks and vans) include all pickup trucks, SUVs, minivans, and full-size vans with GVWR less than 10,000 pounds. Likewise, this report will now present statistical analyses of societal fatality risk in MY 1991-1999 LTVs, by mass and footprint, using the database from NHTSA’s 2003 report. There are, however, some important differences between LTVs and passenger cars that impinge on the analyses.

There are, of course, also important similarities. Given a collision between two vehicles, regardless whether they are cars or LTVs, removing mass from one of them would tend to increase the risk for its occupants but decrease risk for the occupants of the other vehicle. A large footprint should be protective because it tends to enhance directional stability (preventing loss of control), static stability (preventing rollover), and crush space for the occupant’s ride-down (reducing injury severity).

Hypothetical relationships between mass and fatality risk in cross-sectional analyses of LTVs: An important empirical difference between LTVs and cars is that LTVs were, on the average, substantially heavier: 920 pounds heavier in MY 1991-1999, and that difference has grown. When LTVs above the median curb weight (3,870 pounds in MY 1991-1999) collide with another vehicle, it is usually a vehicle lighter than them, such as a car or a light LTV. The occupant's fatality risk is quite low in the heavy LTV relative to the other vehicle. Thus, if the heavy LTV were reduced in mass, the fatality risk for its own occupants only increases by a small amount (in absolute terms), whereas the fatality risk in the other vehicle decreases by a larger amount. This will contribute to a net societal benefit in collisions with cars or with other LTVs, as the heavy LTVs become lighter. In fact, if the LTV is heavy enough, that societal benefit of mass reduction will tend to supersede any harm (for the LTV's own occupants) associated with size or mass reductions. As a consequence, there is some "crossover weight" above which mass reduction, even without controlling for footprint, is beneficial (estimated to be circa 5,085 pounds in NHTSA's 2003 report[411]). Intuitively, controlling for footprint is likely to lower the crossover weight substantially.

Section 2.1 reviewed a number of factors that could contribute to a relationship between mass reduction and increased fatality risk in passenger cars, even after controlling for footprint and including risk to the occupants of the other vehicle. Which of these factors might also apply to analyses of LTVs?

- True societal effects of mass *per se*: a heavy LTV, similar to a heavy car may be able to knock down a medium-size tree and continue moving forward, whereas a lighter LTV might have come to a complete stop – and likewise for collisions with other partially moveable objects. Similarly, in a collision with a truck with GVWR somewhat higher than 10,000 pounds (not yet regulated by CAFE), a heavy LTV will transfer more of its momentum to the truck than a light LTV, reducing the heavy LTV's ΔV and the fatality risk of its own occupants.

- Structural strength: In MY 1991-1999 LTVs, as in cars, less mass for the same footprint may have meant a structurally weaker vehicle, and less safe in many crashes.

- In MY 1991-1999 passenger cars, three factors were fundamentally size-related but were more correlated with the car's mass than with its footprint, with the consequence that associated fatality increases in the smaller/lighter cars were attributed primarily to mass, not footprint. Only the first two of these factors also likely apply to LTVs:

    - Structure on the front and side of an LTV, beyond the wheels (overhang) that adds protective crush space.

    - The generally lower sills of smaller LTVs make them more vulnerable in side impacts than large LTVs.

    - On the other hand, the historic association of lighter cars with higher pedestrian-fatality rates would not appear to carry over to LTVs. Unlike heavy cars, heavy LTVs do not have long, low, relatively pedestrian-friendly hoods.

- Possible driver-vehicle interface factors: Whereas small, light cars historically (1976-2009) had higher collision-involvement rates (with or without injury) than larger, heavier

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[411] Kahane (2003), pp. 163-166.

> cars, the trend is not nearly so strong, at least recently, for light versus heavy LTVs.[412] Likewise, the FARS and GES analyses discussed in Section 2.1, which showed that drivers of lighter cars are more likely to be the culpable party in a 2-vehicle collision – even after controlling for footprint, the driver's age, gender, urbanization, and region of the country – do not produce corresponding results for LTVs. Specifically, in FARS and GES, the log-odds of being the culpable party in a 2-vehicle collision (other than front-to-rear collisions) does not change significantly as LTVs get 100 pounds lighter, after controlling for driver age/gender and footprint, in MY 1991-1999 LTVs < 3,870 pounds. For LTVs ≥ 3,870 pounds, the results from FARS and GES are in opposite directions.[413] The issue of "lighter cars historically being less well driven," which played a role in the statistical analysis of passenger cars, does not appear to have a counterpart in the analysis of LTVs.

Other differences between LTVs and cars: One potential problem in the analyses of passenger cars was the strong natural and historical relationship between mass and size – e.g., a correlation of .893 of mass with footprint. At first glance, there is less linkage of mass with size among LTVs – e.g., only a .742 correlation of mass with footprint. But the relationships of mass with size parameters are quite confounded with the specific type of LTV. Among passenger cars, there were a few "niche" vehicles such as muscle cars (with wide track, short wheelbase and high mass), but for the most part a continuum from small-and-light to large-and-heavy with some model-to-model variations in the relationship of mass to size that were not obviously related in some way to a third factor (such as market class). LTVs, much more than cars, are an assortment of niche vehicles. For example, SUVs introduced before the late 1990s typically had high mass relative to their short wheelbase and footprint; they also had exceptionally high rates of fatal rollovers, partly due to high centers of gravity (cg); because cg height is not a variable in the regression models, the models are likely to attribute the high risk to a combination of high mass and small footprint.[414] Minivans typically have low mass relative to their footprint and some of the lowest fatality rates among vehicles; their low risk may, however, partly be a consequence of the way they are driven.[415] Heavy-duty pickup trucks used extensively for work tend to have more mass, for the same footprint, as basic full-sized pickup trucks that are more often used for personal transportation.

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[412] In 2009, the Highway Loss Data Institute (HLDI) reported a strong trend toward higher overall collision losses per claim year for light versus heavy 4-door cars, but little or no corresponding trend for pickups and SUVs (Auto Insurance Loss Facts, September 2009, http://www.iihs.org/research/hldi/fact_sheets/CollisionLoss_0909.pdf).

[413] As in Section 2.1, the FARS analysis for LTVs is based on CY 1991-2008 data, with the same definitions of "culpability" and exclusion of collisions with cars or LTVs in which only one of the drivers died. In these 20,681 collisions of MY 1991-1999 "case" LTVs with other vehicles, with culpability as the dependent variable and mass, footprint, driver age/gender, and vehicle age as independent variables, the estimated effects were a non-significant 1.0% increase in the log-odds of culpability per 100-pound mass reduction in LTVs < 3,870 pounds, a significant 1.7% increase for LTVs ≥ 3,870 pounds, and a significant 1.0% increase per square-foot reduction of footprint. The effects in weighted CY 1995-2000 GES (primarily nonfatal crashes) were a non-significant 0.3% decrease in the log-odds of culpability per 100-pound mass reduction in LTVs < 3,870 pounds, a significant 1.6% decrease for LTVs ≥ 3,870 pounds, and close to zero effect for footprint (in unweighted GES, these effects were a 0.2% decrease, a 1.0% decrease, and close to zero, respectively – all non-significant).

[414] Future analyses might consider adding cg height as an independent variable, if that can be accomplished without exacerbating near multicollinearity.

[415] Kahane (2003), pp. 210-213.

Because of these interactions, the variance inflation factor in the LTV database is about the same as for passenger cars, namely in a range of 3.6 to 5.7, notwithstanding the lower correlation of mass with footprint.[416] Just as in the analyses for cars, the VIF exceeds 2.5 (a level of near multicollinearity at which inaccurate estimation is a concern, but not inevitable) yet falls short of 10 (a level of near multicollinearity that virtually precludes accurate estimation).

Another difference between LTVs and cars is that annual mileage for LTVs varies by the type, size, and mass of the LTV, whereas cars of different sizes have fairly similar annual mileage. It is necessary to analyze fatality rates per billion miles rather than per million registration years, as described in NHTSA's 2003 report.[417]

3.2 Regression by mass and footprint with NHTSA's 2003 database and method

Curb weight was the only attribute of vehicle mass or size in NHTSA's 2003 weight-safety report. Table 3-1, reproduced from p. ix of that report, shows the analysis associates an increase of 305 fatalities with a mass reduction of 100 pounds that includes implicit, accompanying size reductions (downsizing), applied to the baseline 1999 on-road fleet of LTVs. For example, in CY 1999, LTVs weighing less than 3,870 pounds were involved in first-event-rollover crashes resulting in 1,319 baseline fatalities. When curb weight is the only size parameter in the analysis, the regression associates a 3.15 percent increase in fatality risk with a 100-pound mass reduction (which under these circumstances implicitly includes commensurate reductions in footprint – or in track width and wheelbase), amounting to 42 additional fatalities.

The numbers are societal effects: the baseline and the increase for the multi-vehicle collision types include the fatalities in the other vehicle as well as in the case vehicle. In LTVs weighing less than 3,870 pounds, the fatality increases in the various crash types add up to 234. In LTVs weighing 3,870 pounds or more, the fatality increases add up to 71. The sum for both LTV weight groups and all crash types is an increase of 305 fatalities, in the baseline year 1999. The 1.96-sigma confidence bounds for the sampling error are 305 ± 220.1; the confidence interval ranges from 85 to 525.[418]

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[416] For curb weight, footprint, and the dummy variables SUV, BIGVAN, and MINIVAN, the VIF is 5.7 for footprint and 4.5 for curb weight; for curb weight, wheelbase, track width, and these dummy variables, the VIF is 4.8 for curb weight, 3.9 for wheelbase, and 3.6 for track width.

[417] Kahane (2003), pp. 26-31.

[418] Sampling error is computed as in Kahane (2003), p. 108, footnote 51; p. 160, footnote 34; and p. 161, footnote 35, but including only the two components: (1) Basic sampling error in the regression coefficients for vehicle mass, accumulated on a root-sum-of-squares basis across crash types (but additive across small and large LTVs and across the two LTV-to-LTV results). (2) Additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc. It contributes a .0036 coefficient of variation to the entire estimate for the lighter LTVs and a .0058 coefficient of variation to the entire estimate for the heavier LTVs; these contributions are additive.

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TABLE 3-1: MODEL FROM NHTSA 2003 REPORT (ALL LTVs, CURB WEIGHT ONLY PARAMETER)

                                            BASELINE   EFFECT OF   FATALITY
LTV WEIGHT GROUP     CRASH TYPE            FATALITIES  100 LB RED  INCREASE

LTVs LT 3870 LBS    1ST EVENT ROLLOVER       1,319      0.0315        42
                    FIXED OBJECT             1,687      0.0402        68
                    PED/BIKE/MOTORCYCLE      1,148      0.0124        14
                    HEAVY TRUCK                584      0.0591        35
                    CAR                      2,062      0.0113        23
                    LTV LT 3870 LBS            247      0.0698        17
                    LTV GE 3870 LBS          1,010      0.0349        35
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LTVs LT 3870 LBS                                                     234

LTVs GE 3870 LBS    1ST EVENT ROLLOVER       2,183      0.0256        56
                    FIXED OBJECT             2,639      0.0306        81
                    PED/BIKE/MOTORCYCLE      2,043      0.0013*        3
                    HEAVY TRUCK                860      0.0062*        5
                    CAR                      5,186     -0.0068       -35
                    LTV LT 3870 LBS          1,010     -0.0150       -15
                    LTV GE 3870 LBS            784     -0.0300       -24
----------------                                                  ------
LTVs GE 3870 LBS                                                      71
                                                                  ======
                                                                     305

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84
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The main patterns in Table 3-1 are:

- The absolute fatality increase associated with downsizing is about three times as large in LTVs < 3,870 pounds as in the LTVs ≥ 3,870 pounds.

- The mass-size-safety effects are in the lighter/smaller ↔ more fatalities direction in each type of crash, except collisions of LTVs ≥ 3,870 pounds with cars and with other LTVs, where it is statistically significant[419] and in the opposite direction: here the fatality increase in the case LTV is more than offset by a reduction in the other vehicle.

- In absolute terms, the largest fatality increases are in collisions with fixed objects.

- In relative terms, the strongest percentage increase is in collisions with heavy trucks, for case LTVs < 3,870 pounds.

The strong observed effects in rollovers and collisions with fixed objects likely reflect the reduction of size rather than mass and may diminish when footprint is entered as a separate variable. By the same token, the negative coefficients for heavy LTVs colliding with cars or LTVs may become even more negative after controlling for footprint.

Adding footprint to the analysis: The results in Table 3-1 are not useful for assessing the effects of mass reduction that maintains footprint. That issue may be addressed by adding footprint as an independent variable to the regressions. As stated above, the VIFs among the

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[419] As evidenced by Wald $\chi^2 > 3.84$ for the logistic regression's coefficient for curb weight.

independent variables are then in a range of 3.6 to 5.7, a level of near multicollinearity at which inaccurate estimation is a concern, but not inevitable.

Table 3-2 estimates the effects of reducing mass by 100 pounds or footprint by 0.975 square feet (the historic average footprint reduction per 100-pound mass reduction in LTVs[420]) in MY 1991-1999 LTVs in CY 1995-2005, including the fatality increase or decrease if the percentage change is applied to CY 1999 baseline fatalities. The regression analyses in Table 3-2 are <u>identical</u> to those in NHTSA's 2003 report (Table 3-1), except that footprint has been added as an independent variable.

TABLE 3-2: ANNUAL FATALITY INCREASE PER 100 LB REDUCTION OF CURB WEIGHT, .975 SQ FT OF FOOTPRINT

LTV WEIGHT GROUP	CRASH TYPE	BASELINE FATALITIES	EFFECT OF 100 LB REDUCTION	FATL INCR	EFFECT OF .975 SQ FT FOOTPRINT RED	FATL INCR	TOTAL FATL INCR
LTVs LT 3870 LBS	1ST EVENT ROLLOVER	1,319	-0.0461	-61	0.0692	91	30
	FIXED OBJECT	1,687	0.0008*	1	0.0309	52	53
	PED/BIKE/MOTORCYCLE	1,148	0.0051*	6	0.0056*	6	12
	HEAVY TRUCK	584	0.0443	26	0.0113	7	33
	CAR	2,062	-0.0017*	-4	0.0099	20	16
	LTV LT 3870 LBS	247	0.0600	15	0.0074*	2	17
	LTV GE 3870 LBS	1,010	0.0300	30	0.0037*	4	34
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LTVs LT 3870 LBS				14		182	195
LTVs GE 3870 LBS	1ST EVENT ROLLOVER	2,183	-0.0494	-108	0.0692	151	43
	FIXED OBJECT	2,639	-0.0055*	-15	0.0309	82	67
	PED/BIKE/MOTORCYCLE	2,043	-0.0048*	-10	0.0056*	11	1
	HEAVY TRUCK	860	-0.0067*	-6	0.0113	10	4
	CAR	5,186	-0.0178	-92	0.0099	51	-41
	LTV LT 3870 LBS	1,010	-0.0192	-19	0.0037*	4	-15
	LTV GE 3870 LBS	784	-0.0384	-30	0.0074*	6	-24
----------------				------		------	------
LTVs GE 3870 LBS				-280		315	35
				======		======	======
				-266		497	230

*Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

The combined, overall effect of downsizing is fairly similar in Table 3-2 (230 increase – the grand-total fatality increase at the lower right) and Table 3-1 (305 increase). Moreover, in both tables, the increase is much larger in LTVs < 3,870 pounds than in the LTVs ≥ 3,870 pounds. The difference, of course, is that Table 3-1 attributes the entire effect to curb weight (the only parameter in the analysis, implicitly including the size reductions that historically accompanied mass reduction) whereas Table 3-2 allocates the effects between curb weight and footprint.

The effect of reducing mass by 100 pounds while holding footprint constant is a substantial societal <u>reduction</u> of 266 fatalities, with 1.96-sigma sampling-error confidence bounds ranging from a reduction of 37 to a reduction of 495.

Conversely, the effect of reducing footprint by 0.975 square feet while holding mass constant ranges is an increase of 497 fatalities, with 1.96-sigma sampling-error confidence bounds ranging from an increase of 276 to an increase of 718.

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[420] Estimated by a regression of footprint by curb weight in NHTSA's MY 1991-1999 database of LTVs.

For LTVs ≥ 3,870 pounds, <u>every</u> regression has mass coefficients in the lighter ↔ fewer fatalities direction, although the coefficients for fixed-object, pedestrian, and heavy-truck collisions are not statistically significant. The only regressions with statistically significant mass coefficients in the lighter ↔ more fatalities direction are for LTVs < 3,870 pounds when they collide with heavy trucks or with other LTVs. Footprint always has an effect in the smaller ↔ more fatalities direction, although it is not statistically significant in LTV-to-pedestrian and LTV-to-LTV collisions.

Table 3-2 may be compared to the last sub-table of Table 2-15, the principal regression result for passenger cars. Mass reduction by 100 pounds in passenger cars while holding footprint constant is associated with a societal increase of 398 fatalities, but in LTVs, a reduction of 266 fatalities. Based on these regressions, a uniform mass reduction of 100 pounds for all vehicles might result in an increase of 132 fatalities (but that is not a statistically significant increase).[421] But a larger mass reduction in the heavier LTVs could generate benefits offsetting the increases in the other groups and result in a neutral or net-beneficial effect. In contrast, footprint reductions by one square foot while holding mass constant are associated with quite similar fatality increases, 534 in cars and 510 in LTVs, respectively.[422]

While the regression results in Table 3-2, in combination with the corresponding results for cars could be considered one basis for estimating the overall effect of mass reduction, questions can and probably should be raised about the accuracy of some of the regressions, especially considering that the VIFs in the 3.6 to 5.7 range among the independent variables suggest a potential concern with multicollinearity.

The regressions of LTV-to-car and LTV-to-LTV collisions appear to be accurate. Footprint has relatively limited but important effects in the smaller ↔ more fatalities direction, and after controlling for footprint, mass reductions in the heavier LTVs have noticeably larger societal benefits than they did in Table 3-1. These regressions reveal the benefits of the mass reductions for the occupants of the other vehicles. In the lighter LTVs, mass reduction has little net effect in collisions with cars – plausible, given that the mass of the average light LTV is about the same as the mass of the average car; mass reduction in the lighter LTVs is harmful when they collide with heavy LTVs.

The analysis of rollovers evokes questions. It produces strong mass coefficients in the lighter ↔ fewer fatalities direction and an even stronger coefficients for footprint in the opposite direction. At first glance, these results resemble Table 2-7 (the analysis of passenger cars by a two-step regression procedure) and suggest inaccurate estimation due to near multicollinearity. But that conclusion would be premature without additional inspection of the data, such as by a decile analysis, as will be performed in the next section.

The analysis of collisions with fixed objects attributed almost the entire effect to footprint and near zero to curb weight. While it is not surprising that footprint has more effect than mass – the

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[421] The 398 increase had standard deviation 110 and the 266 reduction, 117; the confidence bounds for the difference are ± $1.96(110^2+117^2)^{.5}$ = ±315 – i.e., they could range from a reduction of 183 to an increase of 447.

[422] Table 2-15 estimates the effect of reducing footprint by .65 square feet, but Table 3-2 by .975 square feet; 347/.65 = 534 and 497/.975 = 510.

same was true of passenger cars (see Table 2-15) – it might be questioned if the effect of mass is indeed so small.

The regression for collisions with heavy trucks produced a strong coefficient (.0443) in the lighter ↔ more fatalities direction for light LTVs, but a non-significant coefficient in the opposite direction for the heavier LTVs. That might be an inconsistency, for presumably the effect ought to be in the same direction when either of these vehicles strikes an even heavier truck.

A limitation of the 2003 database and report is that the mass of the "other" vehicle is unknown. It generates a single coefficient for LTVs < 3,870 pounds colliding with other LTVs – regardless of the mass of the other LTV. The strong coefficient in the lighter ↔ more fatalities direction makes sense when the other vehicle is a heavy LTV, but less so when it is also a light LTV; conversely, for heavy "case" LTVs, the strong coefficient in the lighter ↔ fewer fatalities direction makes sense when the other vehicle is a light LTV, but less so when it is also a heavy LTV. (The same limitation was present in the analysis of passenger cars, but it did not become an issue because the coefficients in the car-to-car analyses were generally small.)

The next section presents additional analyses to address some of these questions and in some cases proposes alternative estimates for the effects of mass reductions.

3.3 Decile analyses and additional regressions

If reducing mass while maintaining footprint really saves lives, there should be, among cohorts of LTVs with similar footprint, a rather consistent trend to lower fatality rates with lower mass. One way to explore this, as in Section 2.4, is to split up the database into deciles of footprint. Within a decile, all the LTVs have similar footprint, typically within a square foot or two. Compute the simple fatality rate per billion miles for each "LTV group" in that decile and check if these rates have positive or negative correlation with curb weight.[423] If correlations are usually positive, mass reduction while maintaining footprint is beneficial. If the correlations are usually negative, mass reduction while maintaining footprint is harmful. If the correlations are about half positive and half negative, then mass reduction while maintaining footprint is safety-neutral. As discussed in Section 2.4, this analysis is not a precise tool because it does not control for other confounding factors such as driver age and gender or the specific type of LTV – it does not isolate the effect of mass. But it may be helpful in identifying the general directional trend in the data when footprint is held constant and curb weight varies.

Specifically, NHTSA's 2003 database of MY 1991-1999 LTVs in CY 1995-2000 comprises 145 LTV groups. Consider only the groups that accumulated 5,000,000,000 or more VMT[424] in CY 1995-2000, of which there are 89. These 89 LTV groups are ordered by footprint and split into 10 cohorts containing approximately equal numbers of LTV groups. Table 3-3 enumerates the ten deciles of footprint and specifies the range of footprint and curb weight in each decile:

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[423] A "LTV group" consists of one or more models built on the same platform (e.g., all Dodge Grand Caravans produced from one redesign to the next, plus their corporate cousins Chrysler Town & Country and Plymouth Grand Voyager). All LTVs of the same LTV group have identical track width and wheelbase (or wheelbase-range in the case of some pickup trucks).

[424] Estimation of VMT is described in Kahane (2003), pp. 26-31.

TABLE 3-3: TEN DECILES OF FOOTPRINT FOR MY 1991-1999 LTV GROUPS WITH 5,000,000,000 OR MORE VMT IN CY 1995-2000

Footprint Deciles	Range of Footprint (Square Feet)	Range of Curb Weight (Pounds)
1st	33.08 to 40.20	2350 to 3949
2nd	40.35 to 41.93	2744 to 3939
3rd	42.95 to 44.11	3106 to 4000
4th	44.91 to 46.69	3124 to 4273
5th	46.73 to 48.70	3114 to 4864
6th	49.26 to 50.63	3439 to 4758
7th	50.69 to 53.39	3675 to 5138
8th	53.56 to 59.38	3629 to 5162
9th	59.77 to 65.27	4265 to 5045
10th	65.74 to 78.28	4364 to 5791

Within the middle deciles, all footprints are in a narrow range, while curb weights vary considerably. Fatality rates are computed for the six types of crashes for each LTV group in each decile. The correlation coefficient of curb weight with a particular fatality rate is computed in each decile two ways: (a) weighting each of the 8 or 9 high-sales car groups in that decile equally or (b) weighting them by VMT. Thus, 60 correlation coefficients are computed by method (a) and 60 by (b). The analysis is a nonparametric test: out of 60 coefficients, how many are greater than zero and how many are less than zero? If these 60 coefficients were fully independent observations, it would be possible to say outright that 37 or more positives is significantly more than 30 and 23 or fewer is significantly less than 30. However, as explained in Section 2.4, the observations are not quite fully independent. Table 3-4 shows the number of deciles in which the correlation coefficient is less than zero – i.e., lower curb weight, given the same footprint, is associated with increased fatality risk.

TABLE 3-4: ALL LTVs – HOLDING FOOTPRINT NEARLY CONSTANT

NUMBER OF FOOTPRINT DECILES WHERE CURB WEIGHT HAS NEGATIVE CORRELATION WITH THE FATAL-CRASH RATE
(Fatal-crash rates per billion VMT,
LTV groups with 5 billion+ VMT, MY 1991-1999 in CY 1995-2000)

Crash Type	Unweighted Correlation	VMT-Weighted Correlation
First-event rollovers	2	1
Collisions with fixed objects	7	8
Collisions with ped/bike/MC	6	7
Collisions with heavy trucks	10	9
Collisions with other passenger cars	4	4
Collisions with LTVs	8	9
Total	37	38

Conversely, if the LTV groups are subdivided into deciles of curb weight (as described in Section 2.4), Table 3-5 shows the numbers of deciles in which the correlation of the fatal-crash rate with footprint is negative:

TABLE 3-5: ALL LTVs – HOLDING CURB WEIGHT NEARLY CONSTANT

NUMBER OF FOOTPRINT DECILES WHERE FOOTPRINT HAS NEGATIVE CORRELATION WITH THE FATAL-CRASH RATE
(Fatal-crash rates per billion VMT,
LTV groups with 5 billion+ VMT, MY 1991-1999 in CY 1995-2000)

Crash Type	Unweighted Correlation	VMT-Weighted Correlation
First-event rollovers	9	9
Collisions with fixed objects	7	6
Collisions with ped/bike/MC	6	6
Collisions with heavy trucks	3	4
Collisions with other passenger cars	5	6
Collisions with LTVs	3	4
Total	33	35

The decile analyses for rollovers are consistent with the regression in Table 3-2. There does appear to be a tendency for fatal crashes per billion VMT to decrease with curb weight reduction (as evidenced by the 2 and 1 in Table 3-4) but increase with footprint reduction (as evidenced by the 9s in Table 3-5). Likewise, in collisions with pedestrians, the 6 and 7 in Table 3-4 are consistent with the absence of a statistically significant effect for mass in the regression.

However, in the other four crash types, the decile analyses could suggest a stronger association of lower mass ↔ more fatalities than the regressions. In collisions with fixed objects, the regression attributed almost the entire effect to footprint and almost nothing to mass, but Tables 3-4 and 3-5 hint at similar results for mass and footprint. In collisions with heavy trucks, the regression only showed a significant effect for mass in the lighter LTVs, but the 10 and 9 in Table 3-4 suggest a widespread effect. In collisions with cars and with other LTVs, likewise, Table 3-4 shows somewhat more negative correlations than might be expected from the regression coefficients. The decile analyses, however, need to be viewed with a degree of caution because they do not control for other confounding variables such as driver age or LTV type.

One factor that may be driving both the regression and decile analysis of rollovers in the MY 1991-1999 database is the presence of mid-size SUVs of typical 1990s design with exceptionally high rates of fatal rollover crashes.[425] These vehicles were unstable in part due to a high center of gravity relative to other vehicles (including SUVs of later design). But cg height is not a variable in the analyses, which may instead be focusing on the relatively low footprint and high mass of those SUVs and generally attributing a high rollover risk to that combination, without regard to how the mass is distributed within the vehicle.

Table 3-6 shows how the decile analysis changes if a list of 14 LTV groups that are typical 1990s SUVs with high cg are deleted from the 89 groups originally in the analysis:

TABLE 3-6: EXCLUDING HIGH-cg SUVs –
HOLDING FOOTPRINT NEARLY CONSTANT

NUMBER OF FOOTPRINT DECILES WHERE CURB WEIGHT
HAS NEGATIVE CORRELATION WITH THE FATAL-CRASH RATE
(Fatal-crash rates per billion VMT,
LTV groups with 5 billion+ VMT, MY 1991-1999 in CY 1995-2000)

Crash Type	Unweighted Correlation	VMT-Weighted Correlation
First-event rollovers	6	7
Collisions with fixed objects	9	8
Collisions with ped/bike/MC	8	7
Collisions with heavy trucks	8	9
Collisions with other passenger cars	7	6
Collisions with LTVs	8	7
Total	46	44

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[425] See, for example, Kahane (2003), pp. 188-190.

Curb weight has negative correlation with rollover fatality risk in 6 or 7 deciles in Table 3-6, as compared to 2 or 1 in Table 3-4. Table 3-6 suggests there is little relationship between rollover risk and curb weight or perhaps even a trend of lower mass ↔ more fatalities after controlling for footprint.

Table 3-6 also shows many correlations in the lower mass ↔ more fatalities direction in collisions with fixed objects and results similar to Table 3-4 for the other crash types. Overall, 46 of 60 correlations are negative with the unweighted data points and 44 with the weighted data points. More often than not, lighter LTVs have higher fatality risk than heavier LTVs of similar footprint.

Additional regressions: The decile analyses suggest that additional regressions on selected subsets of NHTSA's 2003 database might be useful for checking the results for the full database (Table 3-2). One subset would exclude the high-cg, mid-size SUVs, but include all other LTVs as in Table 3-6. It might also be desirable to analyze just pickup trucks, since "they are a more continuous spectrum of vehicles and drivers than other types of trucks: heavy and light pickup trucks look quite a bit alike, except the heavier ones are longer, wider, higher and more rigid. As pickup trucks get heavier, the database used in this report shows that rural mileage increases, as does the average age of the drivers and the percentage of male drivers, but all these increases are at a gradual, steady rate."[426]

Another tool for possibly strengthening the reliability of regression coefficients in the first four types of crashes is to model curb weight as a simple linear variable rather than a two-piece linear variable. The rationale is that the relationship between mass and fatality risk, after controlling for footprint, may well be in the same direction for the lighter and heavier LTVs – and modeling weight as a single, linear variable should generate a statistically more precise coefficient, namely the overall average effect across the two weight groups. In collisions with cars and with other LTVs however, the societal effect of mass reduction is expected to be a substantial benefit in the heavy LTVs but not in the light LTVs, so it is crucial to continue estimating separate mass effects for the two weight groups.

Table 3-7 shows the regression coefficients for curb weight, while controlling for footprint and all the other factors in the regressions of Table 3-2, for each type of crash and subset of the database:

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[426] Kahane (2003), p. 114.

TABLE 3-7: REGRESSION COEFFICIENTS FOR CURB WEIGHT
BY CRASH TYPE, WEIGHT RANGE, AND LTV SUBSET

(Societal fatality rates per billion VMT, controlling for footprint,
driver age/gender, and other factors, MY 1991-1999 in CY 1995-2000)

	Fatality Increase per 100-Pound Reduction (%)		
Crash Type (Weight Range)	All LTVs	Excluding High-cg LTVs	Pickup Trucks Only
First-event rollover (all LTV weights)	-4.82	-3.61	+2.84
Collision with:			
Fixed object (all LTV weights)	-.29*	-.48*	-1.75
Pedestrian/bike/motorcycle (all LTV weights)	-.14*	-.05*	-.05*
Heavy truck (all LTV weights)	+1.38	+1.12*	+1.44*
Passenger car (LTVs < 3,870 pounds)	-.17*	+.84	+1.18
Passenger car (LTVs ≥ 3,870 pounds)	-1.78	-.2.24	-2.31
Another LTV (LTVs < 3,870 pounds)	+3.00	+3.72	+2.72
Another LTV (LTVs ≥ 3,870 pounds)	-1.92	-2.71	-3.35

* Not a statistically significant effect, as evidenced by Wald chi-square < 3.84

3.4 Recommended effects for the upper-estimate and lower-estimate scenarios

Three alternative scenarios will be defined for the effect of mass reduction while maintaining footprint in LTVs and applied in the Volpe model to predict the potential safety impact of mass reduction in MY 2012-2016. One scenario uses the actual regression coefficients generated by the analyses in Table 3-2. The other two scenarios will replace some of these coefficients, based on the findings of the decile analyses, the additional regressions documented in Table 3-7, and judgment on what is the likely effect of mass *per se* to produce “upper-estimate” and “lower-estimate” effects corresponding to those for passenger cars. (There were only two scenarios for passenger cars, because the “upper-estimate” effects were the actual coefficients from the regression analysis.) The author believes the three scenarios offer a plausible range of point estimates for the effect of mass reduction while maintaining footprint, but they should not be construed as upper and lower bounds. Furthermore, being point estimates, they are themselves subject to uncertainties, such as, for example, the sampling errors associated with the regression results.[427] The scenarios apply only to LTVs; corresponding scenarios for passenger cars are developed in Section 2.5.

The coefficients for rollovers are the least consistent results in Table 3-7. The regression for all LTVs associates a strong 4.82 percent fatality reduction with a 100-pound mass reduction; it is consistent with the decile analysis, as shown in Table 3-4. But the presence of high-cg, mid-size SUVs, with their high mass, small footprint, and high rollover rates may be driving the results. Excluding these SUVs, the decile analysis in Table 3-6 suggests a likely neutral result, but the regression still associates a 3.61 percent fatality reduction with a 100-pound mass reduction, not that much weaker than the result for all LTVs. However, the regression for pickup trucks alone attributes a statistically significant 2.84 percent fatality increase per 100-pound mass reduction. For unknown reasons – e.g., near multicollinearity or the specific types of vehicles in the analysis – the regression analyses do not point to a single result or even in a single direction. While regression analyses for subsets are not intended as substitutes for the main result based on the full database, they can shed light on the stability of the main result. For example, with passenger cars, results for each type of crash were quite similar regardless of whether 2-door cars were fully included, partially included, or excluded from the analysis. This is not true of LTVs in rollovers, although Table 3-7 shows it is true in other crash types. Given the neutral results of the decile analysis in Table 3-6 and the corresponding near-zero effects for passenger cars (see Table 2-15), the recommendation for now is not to assume any effect of mass after controlling for footprint. Both the upper- and lower-estimate scenarios will assume a zero effect for mass in rollovers. This is one area, however, where new analyses of more recent data should be conducted in the future, especially considering the introduction of “crossover” SUVs and other changes in the vehicle fleet after MY 1999.

The regression analysis in Table 3-2 did not attribute significant effects to mass, after controlling for footprint, in collisions with fixed objects. The discussion in Section 3.2 questioned if the effect was indeed so small, given that additional mass ought to be helpful in knocking down trees or displacing other objects; the decile analyses in Tables 3-4 and 3-6 likewise suggest a possible effect in the lower mass ↔ more fatalities direction. But the additional regressions in Table 3-7 do not show an effect in that direction; in fact, the analysis of pickup trucks even shows a modest but significant effect in the opposite direction. Based on the near-zero, non-significant effects for all LTVs, it is recommended to set the effect to zero in the lower-estimate scenario for fixed-object crashes. The upper estimate is the effect of mass *per se*, estimated as for passenger cars in Section 2.5. It is the benefit of additional mass for knocking down trees or displacing other objects. For LTVs, the effect is an estimated 0.35 percent fatality increase per 100-pound mass reduction.[428]

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[427] For a uniform 100-pound reduction in all LTVs, the discussion after Table 3-2 indicates a 1.96-sigma sampling error of ±229 fatalities; sampling error would, of course, vary if mass reduction is not uniform or a different amount.

[428] In LTVs, 25% of frontal impacts with poles or trees plus all collisions with unoccupied parked cars, large animals, or non-fixed objects add up to 514 of the 4,326 baseline fatalities in collisions with fixed objects (see Section 2.5 for the corresponding analysis of passenger cars). A 100-pound reduction in mass *per se* might have increased those 514 fatalities by 2.92%, which would amount to a .35% increase in the 4,326 baseline fatalities. The Partyka (1995) study, which is the basis for the estimate that additional mass is helpful in 25% of the impacts, only found a significant effect in passenger cars (and included nonfatal crashes); the LTV sample in the Crashworthiness Data System was insufficient for statistically meaningful results; the 25% figure is assumed to apply to LTVs as well as cars.

Each of the regressions in Table 3-7 showed close to zero effect for LTV mass after controlling for footprint in collisions with pedestrians, bicyclists, or motorcyclists. Both the upper and lower estimates will assume a zero effect for mass in those crashes.

With curb weight expressed as a simple linear variable, Table 3-7 shows that the regression for all LTVs attributes a statistically significant 1.38 percent fatality increase in collisions with heavy trucks per 100-pound reduction in the LTVs. The regressions excluding high-cg SUVs or limited to pickup trucks produce quite similar (although non-significant) coefficients: 1.12 and 1.44. The upper estimate will use the 1.38 coefficient from the all-LTV regression. The lower estimate will be limited to the benefit of mass *per se*, as computed for passenger cars in Section 2.5. It is the benefit of additional mass in the LTV enabling it to transfer momentum to medium-heavy trucks with GVWR somewhat over 10,000 pounds. It amounts to an estimated 0.53 percent fatality increase per 100-pound mass reduction in the LTVs.

In collisions of LTVs with passenger cars, the regression in Table 3-2 attributed a non-significant 0.17 percent societal fatality reduction when LTVs < 3,870 pounds are reduced by 100 pounds and a strong, significant 1.78 percent reduction when LTVs ≥ 3,870 pounds are reduced by 100 pounds. For the LTVs < 3,870 pounds, the additional regressions show small but significant effects in the opposite direction, namely a 0.84 percent fatality increase when high-cg SUVs are excluded and a 1.18 percent increase for pickup trucks only. Given the lack of directional agreement among the three regressions and the near-zero effect in the all-LTV regression, the upper- and lower-estimate scenarios will assume a zero societal effect for mass-reduction in the LTVs < 3,870 pounds. For the LTVs ≥ 3,870 pounds, the effects in the additional regressions, a 2.24 percent reduction and a 2.31 percent reduction, are consistent with the 1.78 percent in the all-LTV regression. The coefficient from Table 3-2, a 1.78 percent fatality reduction per 100-pound reduction in the LTVs ≥ 3,870 pounds, will be used in all three scenarios.

Table 3-7 shows that the three datasets produced fairly consistent coefficients in the regressions of LTV-to-LTV crashes: societal fatality increases of 3.00, 3.72, and 2.72 percent per 100-pound reduction in the LTVs < 3,870 pounds and fatality reductions of 1.92, 2.71, and 3.35 percent in the LTVs ≥ 3,870 pounds. The coefficients from the all-LTV regression, 3.00 and -1.92, will be used in all three scenarios. However, the model in NHTSA’s 2003 report is formulated in a way that these coefficients are to be applied regardless of the mass of the “other” LTV.[429] Intuitively, when a light LTV collides with a heavy LTV, a mass reduction in the light LTV would tend to increase the likelihood of a crash fatality while mass reduction in the heavy LTV would tend to decrease it – consistent with the estimated coefficients. But when both LTVs are approximately of the same mass, a mass reduction in one or in both of the LTVs is not likely to have much effect on crash fatality risk (because the added harm in the LTV whose mass is reduced is more or less offset by the benefit in the other LTV). Therefore, in the upper- and lower-estimate scenarios, the regression coefficients are used only for the crashes between an LTV < 3,870 pounds and an LTV ≥ 3,870 pounds, but are set to zero for collisions between two LTVs < 3,870 pounds or two LTVs ≥ 3,870 pounds.

Table 3-8 summarizes the recommended effects for mass reduction after controlling for footprint in the three scenarios for LTVs:

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[429] Kahane (2003), p. 102.

TABLE 3-8: SOCIETAL EFFECTS OF 100-POUND MASS REDUCTION WHILE MAINTAINING FOOTPRINT, LTVs

	Fatality Increase per 100-Pound Reduction (%)		
Crash Type	Actual Regression Results	Upper-Estimate Scenario	Lower-Estimate Scenario
LTVs WEIGHING LESS THAN 3,870 POUNDS			
First-event rollover	-4.61	0	0
Fixed object	.08	.35	0
Pedestrian/bike/motorcycle	.51	0	0
Heavy truck	4.43	1.38	.53
Car	-.17	0	0
LTV < 3,870 pounds	6.00	0	0
LTV ≥ 3,870 pounds	3.00	3.00	3.00
LTVs WEIGHING 3,870 POUNDS OR MORE			
First-event rollover	-4.94	0	0
Fixed object	-.55	.35	0
Pedestrian/bike/motorcycle	-.48	0	0
Heavy truck	-.67	1.38	.53
Car	-1.78	-1.78	-1.78
LTV < 3,870 pounds	-1.92	-1.92	-.192
LTV ≥ 3,870 pounds	-3.84	0	0

4. Parameters for the Volpe Model

The Volpe model requires four numbers in order to predict the safety effects, if any, of the foreseeable mass reductions in MY 2012-2016 cars and LTVs over the lifetime of those vehicles. The four numbers are the overall percentage increases or decreases, per 100-pound mass reduction while holding footprint constant, in crash fatalities involving:

- Passenger cars weighing less than 2,950 pounds
- Passenger cars weighing 2,950 pounds or more
- LTVs weighing less than 3,870 pounds
- LTVs weighing 3,870 pounds or more

Tables 4-1 through 4-4 compute the respective overall percentages. Moreover, they compute them under three alternative scenarios:

- Based on the actual regression coefficients from the historical, statistical analyses in Tables 2-15 (cars) and 3-2 (LTVs)
- An "upper-estimate scenario" and a "lower-estimate scenario" in which some of the regression coefficients are replaced by numbers based on additional analyses and judgments of the likely effect of mass *per se* in future mass reductions

For passenger cars, the result based on the actual regression coefficients is also the “upper-estimate scenario,” as explained in Section 2.5.

Table 4-1, for example, computes the overall percentages for a 100-pound mass reduction in cars < 2,950 pounds, while maintaining footprint. There were 995 annual baseline fatalities in first-event rollovers. The actual regression coefficient was a 1.59 percent fatality reduction per 100-pound mass reduction. That is an estimated saving of .0159 x 995 = 15.8 lives. However, fatalities are estimated to increase in the other types of crashes. The fatality changes add up to an increase of 300.9 over the six types of crashes. This is 2.21 percent of the 13,608 total baseline fatalities. In the lower-estimate scenario, the fatality changes add up to an increase of just 138.6, which is 1.02 percent of the 13,608 baseline fatalities.

TABLE 4-1

PASSENGER CARS WEIGHING LESS THAN 2,950 POUNDS FATALITY INCREASE PER 100-POUND MASS REDUCTION, NO CHANGE IN FOOTPRINT

		Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
Crash Type	Annual Baseline[430] Crash Fatalities	Actual Regression Result Scenario		Upper-Estimate Scenario[431]		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	995	-1.59	-15.8	-1.59	-15.8	0	0
Fixed object	3,357	.64	21.5	.64	21.5	.34	11.4
Ped/bike/motorcycle	1,741	3.23	56.2	3.23	56.2	0	0
Heavy truck	1,148	3.98	45.7	3.98	45.7	.53	6.1
Car < 2,950 pounds	934	1.97	18.7	1.97	18.7	0	0
Car ≥ 2,950 pounds	1,342	.99	13.3	.99	13.3	0	0
LTV	4,091	3.95	161.6	3.95	161.6	2.96	121.1
Overall	13,608	2.21	300.9	2.21	300.9	1.02	138.6

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[430] The baseline fatalities are computed from CY 1999 data (total fatalities) and the fatality distribution of MY 1996-1999 vehicles in CY 1996-2000. However, all regressions are based on MY 1991-1999 case vehicles in CY 1996-1999; see Kahane (2003), pp. 104-106.

[431] For passenger cars, the upper-estimate scenario is the actual-regression-result scenario.

TABLE 4-2

PASSENGER CARS WEIGHING 2,950 POUNDS OR MORE FATALITY INCREASE PER 100-POUND MASS REDUCTION, NO CHANGE IN FOOTPRINT

		Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
Crash Type	Annual Baseline[432] Crash Fatalities	Actual Regression Result Scenario		Upper-Estimate Scenario[433]		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	715	-1.33	-9.5	-1.33	-9.5	0	0
Fixed object	2,822	1.09	30.8	1.09	30.8	.34	9.6
Ped/bike/motorcycle	1,349	-.60	-8.1	-.60	-8.1	0	0
Heavy truck	822	.84	6.9	.84	6.9	.53	4.4
Car < 2,950 pounds	1,342	.74	9.9	.74	9.9	0	0
Car ≥ 2,950 pounds	677	1.47	10.0	1.47	10.0	0	0
LTV	3,157	1.82	57.5	1.82	57.5	1.08	34.1
Overall	10,844	.90	97.5	.90	97.5	.44	48.1

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[432] The baseline fatalities are computed from CY 1999 data (total fatalities) and the fatality distribution of MY 1996-1999 vehicles in CY 1996-2000. However, all regressions are based on MY 1991-1999 case vehicles in CY 1996-1999; see Kahane (2003), pp. 104-106.

[433] For passenger cars, the upper-estimate scenario is the actual-regression-result scenario.

TABLE 4-3

LTVs WEIGHING LESS THAN 3,870 POUNDS
FATALITY INCREASE PER 100-POUND MASS REDUCTION,
NO CHANGE IN FOOTPRINT

		Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
Crash Type	Annual Baseline[434] Crash Fatalities	Actual Regression Result Scenario		Upper-Estimate Scenario		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	1,319	-4.61	-60.8	0	0	0	0
Fixed object	1,687	.08	1.3	.35	5.9	0	0
Ped/bike/motorcycle	1,148	.51	5.9	0	0	0	0
Heavy truck	584	4.43	25.9	1.38	8.1	.53	3.1
Car	2,062	-.17	-3.5	0	0	0	0
LTV < 3,870 pounds[435]	247	6.00	14.8	0	0	0	0
LTV ≥ 3,870 pounds	1,010	3.00	30.3	3.00	30.3	3.00	30.3
Overall	8,057	.17	13.9	.55	44.3	.41	

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[434] The baseline fatalities are computed from CY 1999 data (total fatalities) and the fatality distribution of MY 1996-1999 vehicles in CY 1996-2000. However, all regressions are based on MY 1991-1999 case vehicles in CY 1996-1999; see Kahane (2003), pp. 104-106.

[435] Assumes both LTVs in the collision were reduced by 100 pounds.

TABLE 4-4

LTVs WEIGHING 3,870 POUNDS OR MORE FATALITY INCREASE PER 100-POUND MASS REDUCTION, NO CHANGE IN FOOTPRINT

		Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
Crash Type	Annual Baseline[436] Crash Fatalities	Actual Regression Result Scenario		Upper-Estimate Scenario		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	2,183	-4.94	-107.8	0	0	0	0
Fixed object	2,639	-.55	-14.5	.35	9.2	0	0
Ped/bike/motorcycle	2,043	-.48	-9.8	0	0	0	0
Heavy truck	860	-.67	-5.8	1.38	11.9	.53	4.6
Car	5,186	-1.78	-92.3	-1.78	-92.3	-1.78	-92.3
LTV < 3,870 pounds[437]	1,010	-1.92	-19.4	-1.92	-19.4	-1.92	-19.4
LTV ≥ 3,870 pounds	784	-3.84	-30.1	0	0	0	0
Overall	14,705	-1.90	-279.7	-.62	-90.6	-.73	-107.1

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[436] The baseline fatalities are computed from CY 1999 data (total fatalities) and the fatality distribution of MY 1996-1999 vehicles in CY 1996-2000. However, all regressions are based on MY 1991-1999 case vehicles in CY 1996-1999; see Kahane (2003), pp. 104-106.

[437] Assumes both LTVs in the collision were reduced by 100 pounds.

Table 4-5 summarizes the parameters that go into the Volpe model under the three scenarios: the percentage increases or decreases in crash fatalities per 100-pound mass reduction while holding footprint constant:

TABLE 4-5: SOCIETAL EFFECTS OF 100-POUND MASS REDUCTION WHILE MAINTAINING FOOTPRINT

	Fatality Increase per 100-Pound Reduction (%)		
	Actual Regression Result Scenario	Upper-Estimate Scenario[438]	Lower-Estimate Scenario
Cars < 2,950 pounds	2.21	2.21	1.02
Cars ≥ 2,950 pounds	.90	.90	.44
LTVs < 3,870 pounds	.17	.55	.41
LTVs ≥ 3,870 pounds	-1.90	-.62	-.73

In all three scenarios, the estimated effects of a 100-pound mass reduction while maintaining footprint are an increase in cars < 2,950 pounds, substantially smaller increases in cars ≥ 2,950 pounds and LTVs < 3,870 pounds, and a societal benefit for LTVs ≥ 3,870 pounds (because it reduces fatality risk to occupants of cars and lighter LTVs they collide with).

Table 4-5 estimates the effects of reducing each vehicle by exactly 100 pounds. However, the actual mass reduction will vary by make and model. The aggregate effect on fatalities can only be estimated by using the Volpe model or some other forecast of the mass reductions by make and model. It should be noted, however, that a 100-pound reduction would be 5 percent of the mass of a 2000-pound car but only 2 percent of a 5000-pound LTV. Thus, a forecast that mass will decrease by an equal or greater percentage in the heavier vehicles than in the lightest cars would be proportionately more influenced by the benefit for the heavy LTVs than by the increases in the other groups; it is likely to result in an estimated net benefit under one or more of the scenarios.

It should also be noted that the three scenarios are point estimates and are subject to uncertainties, such as the sampling errors associated with the regression results. In the scenario based on actual regression results, the sampling errors can be estimated by the method of NHTSA's 2003 report.[439] For cars < 2,950 pounds, the 1.96-sigma sampling error is ±0.91 percentage points; likewise for cars ≥ 2,950 pounds. For LTVs < 3,870 pounds, the 1.96-sigma sampling error is ±0.82 percentage points, but for LTVs ≥ 3,870 pounds it is ±1.18 percentage points. In other words, the fatality increase in the cars < 2,950 pounds and the societal fatality reduction attributed to mass reduction in the LTVs ≥ 3,870 pounds are statistically significant; the effects in the heavier cars and lighter LTVs are not. Because the other two scenarios are not

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[438] For passenger cars, the upper-estimate scenario is the actual-regression-result scenario.

[439] Sampling error is computed as in Kahane (2003), p. 108, footnote 51; p. 160, footnote 34; and p. 161, footnote 35, but including only the two components: (1) Basic sampling error in the regression coefficients for vehicle mass, accumulated on a root-sum-of-squares basis across crash types (but additive across small and large LTVs and across the two LTV-to-LTV results). (2) Additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc.

based directly on a statistical analysis, sampling error cannot be estimated the same way; however, the sampling errors associated with the scenario based on actual regression results perhaps indicates the general level of statistical noise in the estimates.

(Kahane March 24, 2010 report ends here.)

Calculation of MY 2012-2016 safety impact

NHTSA estimates that weight reductions of 1.5 percent can be achieved during redesigns occurring prior to MY 2014, and that weight reductions of 5-10 percent can be achieved in redesigns occurring in MY 2014 or later. For purposes of analyzing CAFE standards, NHTSA has further assumed that weight reductions would be limited to 5 percent for small vehicles (*e.g.*, subcompact passenger cars), and that reductions of 10 percent would only be applied to the larger vehicle types (*e.g.*, large light trucks).

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 (2010), 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 during the rulemaking time frame. 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 (2010) 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.[440] 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). 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

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[440] 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)

place in passenger car and light truck safety between the 2007 baseline on-road fleet used for this particular analysis and year 2020.

As discussed above, after controlling for footprint, Table IX-15 shows the rates for the regression results, the upper estimate and the lower estimate.

Table IX-15
Percent increase in fatalities per 100 pound weight reduction

	Base Fatalities per Billion Miles	Regression Results (%)	Upper Estimate (%)	Lower Estimate (%)
PC < 2,950	12.60	2.21	2.21	1.02
PC > 2,950	10.35	0.90	0.90	0.44
LT < 3,870	15.08	0.17	0.55	0.41
LT > 3,870	15.23	-1.90	-0.62	-0.73

After applying these percentage increases to the estimated weight reductions per vehicle size by model year assumed in the Volpe model, Table IX-16 shows the results of NHTSA's safety analysis separately for each model year[441]. 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. In general, a 5 percent reduction in weight was assumed for light vehicles and a 10 percent reduction in weight was assumed for heavier light trucks. Thus for example, if 5 percent is taken out of a car weighing 2,500 lbs. (125 lbs.) and 10 percent is taken out of an LTV weighing 5,000 lbs. (500 lbs.) the impact on a weight basis (which is used in the regression) could be 4 times more for the heavy LTVs than for passenger cars. 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 results, the straight regression results would estimate a savings in lives in MY 2014-2016, the upper estimate shows a small increase in fatalities over the lifetime of all 5 model years, and the lower estimate shows a slight increase in fatalities for the first two model years and then a larger decrease in fatalities for MY 2014-2016.

Additionally, the societal impacts of increasing fatalities can be monetized using NHTSA's estimated comprehensive cost per life of $6.1 million. This consists of a value of a statistical life

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[441] 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 2010 analysis continues with the definitions used in the Kahane 2003 analysis. Thus, there are different definitions between Table IX-15 (which uses the old definitions) and Tables IX-16 and IX-17 (which use the new definitions).

of $5.8 million plus external economic costs associated with fatalities such as medical care, insurance administration costs and legal costs.[442] 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.[443] If weight impacts non-fatal injuries roughly proportional to its impact on fatalities, then total costs would be roughly 2.3 times the value of fatalities alone, or around $14 million per fatality. The potential societal costs for fatalities and injuries combined are shown in Table IX-17.

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[442] Blincoe et al, The Economic Impact of Motor Vehicle Crashes 2000, May 2002, DOT HS 809 446. 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.

[443] Based on data in Blincoe et al updated for inflation and reflecting the Department's current VSL of $5.8 million.

Table IX-16a
Comparison of the Calculated Weight Safety-Related Fatality Impacts of the Preferred Alternative over the Lifetime of the Vehicles Produced in each Model Year
(Increase in Fatalities Compared to the Calendar Year 2007 Fatality Level)
Regression Results

	Baseline MY 2011 standards continued for lifetime of vehicles				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	0	0	0	0	0
Light trucks	(18)	(19)	(36)	(33)	(41)
Combined	(17)	(18)	(36)	(33)	(41)
	Preferred alternative				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	6	11	34	67	96
Light trucks	(23)	(27)	(164)	(305)	(437)
Combined	(18)	(16)	(129)	(238)	(342)
	Difference between preferred alternative and baseline continued				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	5	11	34	67	95
Light trucks	(6)	(8)	(128)	(272)	(397)
Combined	(0)	2	(94)	(206)	(301)

Table IX-16b
Comparison of the Calculated Weight Safety-Related Fatality Impacts of the Preferred Alternative over the Lifetime of the Vehicles Produced in each Model Year
(Increase in Fatalities Compared to the Calendar Year 2007 Fatality Level)
Upper Estimate

	Baseline MY 2011 standards continued for lifetime of vehicles				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	0	0	0	0	0
Light trucks	(5)	(5)	(11)	(10)	(13)
Combined	(5)	(5)	(11)	(10)	(13)
	Preferred alternative				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	11	17	57	100	134
Light trucks	(7)	(8)	(42)	(87)	(125)
Combined	4	9	15	14	9
	Difference between preferred alternative and baseline continued				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	11	17	57	100	134
Light trucks	(2)	(3)	(31)	(77)	(112)
Combined	9	14	26	24	22

Table IX-16c
Comparison of the Calculated Weight Safety-Related Fatality Impacts of the Preferred Alternatives over the Lifetime of the Vehicles Produced in each Model Year
(Increase in Fatalities Compared to the Calendar Year 2007 Fatality Level)
Lower Estimate

	Baseline MY 2011 standards continued for lifetime of vehicles				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	0	0	0	0	0
Light trucks	(6)	(7)	(13)	(12)	(15)
Combined	(6)	(7)	(13)	(12)	(15)
	Preferred alternative				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	4	7	25	43	61
Light trucks	(8)	(10)	(55)	(108)	(156)
Combined	(4)	(3)	(30)	(65)	(95)
	Difference between preferred alternative and baseline continued				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Passenger cars	4	7	25	43	61
Light trucks	(2)	(3)	(41)	(96)	(140)
Combined	2	4	(17)	(53)	(80)

Table IX-16d
Comparison of the Calculated Weight Safety-Related Fatality Impacts of the Preferred Alternatives over the Lifetime of the Vehicles Produced in each Model Year
Combined Passenger Cars and Light Trucks

	Difference between preferred alternative and baseline continued				
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**
Regression results	0	2	(94)	(206)	(301)
Upper estimate	9	14	26	24	22
Lower estimate	2	4	(17)	(53)	(80)

Table IX-17a
Calculated Weight Safety Impacts on Societal Costs for the Preferred Alternative over the Lifetime of the Vehicles Produced in each Model Year
Estimated Fatalities and Assumed Injuries
Regression Results
($ millions)

Undiscounted	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Passenger Cars	74	152	479	936	1,336	2,977
Light Trucks	(79)	(117)	(1,790)	(3,814)	(5,555)	(11,355)
Combined	(5)	35	(1,311)	(2,877)	(4,219)	(8,378)
Discounted 3%						
Passenger Cars	62	126	398	778	1,109	2,472
Light Trucks	(64)	(94)	(1,436)	(3,059)	(4,456)	(9,109)
Combined	(2)	32	(1,038)	(2,282)	(3,347)	(6,637)
Discounted 7%						
Passenger Cars	50	102	321	627	895	1,994
Light Trucks	(50)	(74)	(1,128)	(2,404)	(3,501)	(7,157)
Combined	(0)	28	(807)	(1,776)	(2,606)	(5,162)

Discount factors		
	3%	7%
Pass. Car	0.8304	0.67
LT	0.8022	0.6303

Table IX-17b
Calculated Weight Safety Impacts on Societal Costs for the Preferred Alternative over the Lifetime of the Vehicles Produced in each Model Year
Estimated Fatalities and Assumed Injuries
Upper Estimate
($ millions)

Undiscounted	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Passenger Cars	151	233	792	1,405	1,875	4,457
Light Trucks	(24)	(36)	(429)	(1,071)	(1,569)	(3,130)
Combined	128	197	363	334	306	1,327
Discounted 3%						
Passenger Cars	126	193	658	1,167	1,557	3,701
Light Trucks	(19)	(29)	(344)	(859)	(1,259)	(2,511)
Combined	107	164	314	307	298	1,190
Discounted 7%						
Passenger Cars	101	156	531	941	1,256	2,986
Light Trucks	(15)	(23)	(270)	(675)	(989)	(1,973)
Combined	86	133	260	266	267	1,013

Discount factors		
	3%	7%
Pass. Car	0.8304	0.67
LT	0.8022	0.6303

Table IX-17c
Calculated Weight Safety Impacts on Societal Costs for the Preferred Alternative over the Lifetime of the Vehicles Produced in each Model Year
Estimated Fatalities and Assumed Injuries
Lower Estimate
($ millions)

Undiscounted	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Passenger Cars	59	99	346	598	848	1,950
Light Trucks	(29)	(44)	(580)	(1,345)	(1,965)	(3,962)
Combined	30	55	(234)	(746)	(1,117)	(2,012)
Discounted 3%						
Passenger Cars	49	82	287	497	704	1,619
Light Trucks	(23)	(35)	(465)	(1,079)	(1,576)	(3,178)
Combined	25	47	(178)	(582)	(872)	(1,559)
Discounted 7%						
Passenger Cars	39	66	232	401	568	1,306
Light Trucks	(18)	(28)	(365)	(848)	(1,238)	(2,497)
Combined	21	39	(134)	(447)	(670)	(1,191)

Discount factors		
	3%	7%
Pass. Car	0.8304	0.67
LT	0.8022	0.6303

Table IX-17d
Calculated Weight Safety Impacts on Societal Costs for the Preferred Alternative over the Lifetime of the Vehicles Produced in each Model Year
Estimated Fatalities and Assumed Injuries
Combined Passenger Cars and Light Trucks
($ millions)

	Difference between preferred alternative and baseline continued					
	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**	**Total**
Regression results	(0)	28	(807)	(1,776)	(2,606)	(5,162)
Upper estimate	86	133	260	266	267	1,013
Lower estimate	21	39	(134)	(447)	(670)	(1,191)

Additionally, there will be significant fuel-saving benefits from the preferred alternative, up to 61.0 billion gallons during the lifetime of MYs 2012-2016 vehicles, as well as significant reductions in CO_2 emissions, up to 655 million metric tons during that same time period. Improved fuel economy will also result in a decrease in harmful criteria pollutants, which will decrease premature deaths due to a number of diseases related to environmental pollution. The literature strongly supports the causal relationship between health and exposure to criteria pollutants. However, as with vehicle safety impacts, there is much uncertainty regarding the exact level of health impacts that might be achieved with this rule. A detailed discussion of these impacts is included in NHTSA's FEIS, which documents a selection of health outcomes from improved air quality.[444] NHTSA approximated some PM2.5-related health benefits using screening-level estimates in the form of cases per ton of criteria emissions reduced.[445] Due to analytical limitations, the estimated values do not include comparable benefits related to reductions in other criteria pollutants (such as ozone, NO_2 or SO_2) or toxic air pollutants, nor do they monetize all of the potential health and welfare effects associated with $PM_{2.5}$ or the other criteria pollutants.

As illustrative examples, the number of PM2.5-related premature deaths prevented in calendar year 2016 is estimated to range from 39-99 due to reduced PM2.5 as a result of the MY 2012-

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[444] Chapter 7 of EPA's DRIA also contains information on the health impacts of reducing criteria pollutants.

[445] Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ concentrations and population exposure, as determined by full-scale air quality and exposure modeling. Such detailed modeling was not possible within the timeframe for this proposal, but for the final rule, a national-scale air quality modeling analysis will be performed to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics.

2016 standards while in 2030, we estimate between 217-544 premature deaths prevented. However, by 2030, most, but not all of the on-road fleet will already meet the CAFE requirements established for MY 2016, so some further growth in these impacts is possible. Other PM2.5-related health impacts estimated to occur during this period include 26 in 2016 and 142 by 2030 fewer cases of chronic bronchitis and 37 in 2016 and 198 for 2030 fewer emergency room visits for asthma. These benefits will partially offset any negative safety impacts that may occur from vehicle mass reduction associated with higher CAFE standards. Thus, there are potentially both positive and negative impacts that could result from this rulemaking, and the overall impact on health and safety is uncertain. We have not attempted to quantify other beneficial health impacts that are expected to result from the standards, including the results of a decrease in the rate of global warming, and increased energy security resulting from a lesser dependence on oil imported volatile regions of the world, but they, too, could be significant.

X. NET BENEFITS AND SENSITIVITY ANALYSES

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 fines 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 2011. 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. Table X-2 provides the total benefits at a 3 percent discount rate from a societal perspective for all vehicles produced. Table X-3 shows the total net benefits at a 3 percent discount rate in millions of dollars for the projected fleet of sales for MY 2012 – MY 2016. Table X-4 provides the total benefits at a 7 percent discount rate from a societal perspective for all vehicles produced. Table X-5 shows the total net benefits at a 7 percent discount rate in millions of dollars for the projected fleet of sales for MY 2012 – MY 2016.

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. Total compliance costs for the passenger cars under the Total Cost = Total Benefit alternative are 1.9 times those under the Preferred Alternative. For light trucks, compliance costs are 2.7 times higher under the Total Cost = Total Benefit alternative than under the Preferred Alternative.

In Tables X-2 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 1.55 times those of the Preferred Alternative.

Tables X-3 and X-5 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-3, the combined net benefit for passenger cars and light trucks under all five model years ranges from $80 billion under the 3% Annual Increase alternative to $170 billion under the Total Cost = Total Benefit alternative. Net benefits for the Preferred Alternative (the total under both vehicle types and all model years) are $131 billion at the 3% discount rate.

Table X-1
Incremental Total Cost – Societal Perspective
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$4,148	$5,411	$6,855	$8,221	$9,534	$34,170
3% Annual Increase	$1,622	$2,341	$3,142	$4,047	$5,222	$16,375
4% Annual Increase	$2,148	$3,455	$4,944	$6,561	$8,031	$25,138
5% Annual Increase	$3,074	$5,288	$7,426	$9,410	$11,403	$36,601
6% Annual Increase	$4,504	$7,196	$10,567	$13,546	$16,130	$51,943
7% Annual Increase	$5,263	$8,985	$13,451	$16,627	$19,898	$64,224
Max Net Benefits	$5,217	$8,837	$12,535	$14,930	$17,050	$58,568
TC = TB	$5,674	$9,779	$13,898	$16,673	$19,403	$65,427
Light Trucks						
Preferred Alternative	$1,754	$2,479	$3,657	$4,318	$5,369	$17,578
3% Annual Increase	$8	$463	$1,371	$2,009	$2,719	$6,570
4% Annual Increase	$968	$1,747	$2,975	$3,714	$4,647	$14,051
5% Annual Increase	$2,407	$3,791	$6,103	$6,833	$7,614	$26,749
6% Annual Increase	$2,950	$5,646	$8,157	$9,813	$11,226	$37,793
7% Annual Increase	$3,260	$7,298	$10,020	$12,478	$14,074	$47,130
Max Net Benefits	$4,149	$7,370	$9,698	$11,163	$11,648	$44,028
TC = TB	$4,247	$7,891	$10,464	$12,330	$13,218	$48,149
Passenger Cars & Light Trucks						
Preferred Alternative	$5,903	$7,890	$10,512	$12,539	$14,904	$51,748
3% Annual Increase	$1,630	$2,804	$4,513	$6,057	$7,941	$22,944
4% Annual Increase	$3,116	$5,202	$7,919	$10,275	$12,678	$39,189
5% Annual Increase	$5,482	$9,079	$13,529	$16,243	$19,017	$63,350
6% Annual Increase	$7,455	$12,842	$18,724	$23,359	$27,356	$89,736
7% Annual Increase	$8,524	$16,283	$23,471	$29,104	$33,972	$111,354
Max Net Benefits	$9,366	$16,207	$22,233	$26,092	$28,698	$102,597
TC = TB	$9,921	$17,670	$24,362	$29,003	$32,620	$113,577

Table X-2
Present Value of Lifetime Societal Benefits by Alternative
3 % Discount Rate
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$6,826	$15,155	$21,626	$28,677	$35,200	$107,483
3% Annual Increase	$3,397	$8,374	$12,331	$16,760	$23,122	$63,984
4% Annual Increase	$4,186	$11,006	$17,315	$24,469	$32,309	$89,286
5% Annual Increase	$6,152	$15,404	$24,075	$32,114	$40,905	$118,649
6% Annual Increase	$7,071	$18,062	$28,137	$37,552	$47,754	$138,576
7% Annual Increase	$8,038	$20,627	$32,225	$42,010	$52,606	$155,507
Max Net Benefits	$8,019	$20,896	$31,683	$39,863	$48,228	$148,689
TC = TB	$8,666	$22,374	$33,916	$42,737	$51,659	$159,352
Light Trucks						
Preferred Alternative	$5,110	$10,684	$15,506	$19,364	$24,310	$74,974
3% Annual Increase	$687	$3,920	$7,635	$11,604	$14,940	$38,786
4% Annual Increase	$2,590	$7,361	$12,580	$17,089	$21,830	$61,450
5% Annual Increase	$4,003	$10,407	$17,686	$23,206	$28,324	$83,626
6% Annual Increase	$4,893	$13,933	$22,031	$28,987	$34,727	$104,571
7% Annual Increase	$5,634	$16,326	$25,550	$32,714	$38,229	$118,453
Max Net Benefits	$7,528	$18,302	$25,913	$31,563	$34,835	$118,141
TC = TB	$7,631	$18,954	$27,294	$33,381	$37,262	$124,522
Passenger Cars & Light Trucks						
Preferred Alternative	$11,936	$25,840	$37,132	$48,040	$59,509	$182,457
3% Annual Increase	$4,085	$12,294	$19,966	$28,364	$38,062	$102,770
4% Annual Increase	$6,776	$18,367	$29,895	$41,559	$54,139	$150,735
5% Annual Increase	$10,155	$25,811	$41,760	$55,320	$69,229	$202,275
6% Annual Increase	$11,964	$31,995	$50,168	$66,539	$82,481	$243,147
7% Annual Increase	$13,672	$36,953	$57,776	$74,724	$90,835	$273,960
Max Net Benefits	$15,547	$39,198	$57,596	$71,426	$83,063	$266,830
TC = TB	$16,297	$41,328	$61,209	$76,118	$88,922	$283,874

Table X-3
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
3% Discount Rate
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$2,677	$9,745	$14,770	$20,455	$25,665	$73,313
3% Annual Increase	$1,776	$6,033	$9,188	$12,713	$17,900	$47,609
4% Annual Increase	$2,038	$7,551	$12,371	$17,909	$24,278	$64,147
5% Annual Increase	$3,077	$10,116	$16,649	$22,704	$29,502	$82,048
6% Annual Increase	$2,567	$10,866	$17,570	$24,005	$31,624	$86,633
7% Annual Increase	$2,775	$11,642	$18,775	$25,383	$32,709	$91,283
Max Net Benefits	$2,802	$12,059	$19,148	$24,933	$31,179	$90,121
TC = TB	$2,992	$12,595	$20,017	$26,064	$32,257	$93,925
Light Trucks						
Preferred Alternative	$3,356	$8,205	$11,849	$15,045	$18,940	$57,396
3% Annual Increase	$679	$3,458	$6,264	$9,595	$12,222	$32,217
4% Annual Increase	$1,622	$5,614	$9,605	$13,375	$17,183	$47,399
5% Annual Increase	$1,596	$6,616	$11,582	$16,373	$20,710	$56,877
6% Annual Increase	$1,943	$8,287	$13,874	$19,174	$23,501	$66,779
7% Annual Increase	$2,373	$9,028	$15,531	$20,236	$24,155	$71,324
Max Net Benefits	$3,379	$10,932	$16,215	$20,400	$23,186	$74,112
TC = TB	$3,384	$11,063	$16,830	$21,050	$24,045	$76,373
Passenger Cars & Light Trucks						
Preferred Alternative	$6,033	$17,950	$26,619	$35,501	$44,606	$130,709
3% Annual Increase	$2,455	$9,490	$15,453	$22,307	$30,121	$79,826
4% Annual Increase	$3,660	$13,165	$21,976	$31,284	$41,461	$111,546
5% Annual Increase	$4,673	$16,732	$28,231	$39,076	$50,213	$138,925
6% Annual Increase	$4,509	$19,154	$31,444	$43,180	$55,125	$153,412
7% Annual Increase	$5,148	$20,670	$34,305	$45,619	$56,864	$162,606
Max Net Benefits	$6,181	$22,991	$35,363	$45,333	$54,365	$164,233
TC = TB	$6,377	$23,658	$36,847	$47,114	$56,301	$170,297

Table X-4
Present Value of Lifetime Societal Benefits by Alternative
7 % Discount Rate
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$5,474	$12,255	$17,499	$23,235	$28,567	$87,031
3% Annual Increase	$2,727	$6,778	$9,980	$13,585	$18,774	$51,844
4% Annual Increase	$3,356	$8,904	$14,015	$19,838	$26,241	$72,353
5% Annual Increase	$4,941	$12,472	$19,493	$26,030	$33,185	$96,122
6% Annual Increase	$5,667	$14,612	$22,763	$30,402	$38,735	$112,180
7% Annual Increase	$6,448	$16,692	$26,080	$34,028	$42,669	$125,917
Max Net Benefits	$6,134	$16,378	$25,041	$31,517	$38,120	$117,191
TC = TB	$6,957	$18,112	$27,453	$34,625	$41,897	$129,044
Light Trucks						
Preferred Alternative	$4,015	$8,427	$12,243	$15,302	$19,225	$59,212
3% Annual Increase	$545	$3,099	$6,035	$9,178	$11,823	$30,679
4% Annual Increase	$2,035	$5,802	$9,927	$13,500	$17,260	$48,524
5% Annual Increase	$3,129	$8,189	$13,929	$18,300	$22,365	$65,913
6% Annual Increase	$3,823	$10,966	$17,349	$22,842	$27,385	$82,366
7% Annual Increase	$4,404	$12,838	$20,108	$25,767	$30,132	$93,248
Max Net Benefits	$5,736	$12,761	$18,525	$22,485	$25,290	$84,797
TC = TB	$6,039	$14,926	$21,502	$26,237	$29,295	$97,999
Passenger Cars & Light Trucks						
Preferred Alternative	$9,490	$20,682	$29,742	$38,538	$47,791	$146,243
3% Annual Increase	$3,272	$9,877	$16,014	$22,763	$30,597	$82,523
4% Annual Increase	$5,390	$14,706	$23,942	$33,338	$43,500	$120,877
5% Annual Increase	$8,070	$20,661	$33,422	$44,330	$55,551	$162,035
6% Annual Increase	$9,490	$25,579	$40,111	$53,245	$66,120	$194,545
7% Annual Increase	$10,852	$29,530	$46,187	$59,795	$72,801	$219,165
Max Net Benefits	$11,870	$29,140	$43,566	$54,002	$63,410	$201,988
TC = TB	$12,997	$33,037	$48,955	$60,862	$71,193	$227,044

Table X-5
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
7% Discount Rate
(Millions of 2007 Dollars)

Alternative	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	5-Year Total
Passenger Cars						
Preferred Alternative	$1,326	$6,844	$10,644	$15,014	$19,032	$52,861
3% Annual Increase	$1,106	$4,436	$6,838	$9,537	$13,552	$35,469
4% Annual Increase	$1,208	$5,449	$9,071	$13,277	$18,210	$47,215
5% Annual Increase	$1,867	$7,184	$12,067	$16,620	$21,782	$59,521
6% Annual Increase	$1,163	$7,416	$12,196	$16,856	$22,605	$60,237
7% Annual Increase	$1,185	$7,707	$12,629	$17,401	$22,771	$61,693
Max Net Benefits	$1,170	$7,894	$12,838	$16,969	$21,583	$60,454
TC = TB	$1,283	$8,333	$13,555	$17,952	$22,495	$63,617
Light Trucks						
Preferred Alternative	$2,261	$5,948	$8,586	$10,984	$13,855	$41,635
3% Annual Increase	$537	$2,636	$4,664	$7,169	$9,104	$24,110
4% Annual Increase	$1,067	$4,055	$6,952	$9,786	$12,613	$34,473
5% Annual Increase	$722	$4,398	$7,826	$11,467	$14,751	$39,164
6% Annual Increase	$872	$5,321	$9,192	$13,029	$16,159	$44,573
7% Annual Increase	$1,143	$5,540	$10,088	$13,289	$16,058	$46,119
Max Net Benefits	$1,647	$6,581	$10,195	$12,936	$15,123	$46,482
TC = TB	$1,579	$7,463	$10,988	$13,982	$16,229	$50,241
Passenger Cars & Light Trucks						
Preferred Alternative	$3,587	$12,792	$19,230	$25,998	$32,888	$94,495
3% Annual Increase	$1,642	$7,073	$11,501	$16,706	$22,656	$59,579
4% Annual Increase	$2,274	$9,504	$16,023	$23,064	$30,822	$81,688
5% Annual Increase	$2,589	$11,583	$19,893	$28,087	$36,534	$98,685
6% Annual Increase	$2,035	$12,737	$21,387	$29,885	$38,764	$104,810
7% Annual Increase	$2,328	$13,247	$22,717	$30,690	$38,829	$107,812
Max Net Benefits	$2,818	$14,475	$23,033	$29,904	$36,706	$106,936
TC = TB	$2,863	$15,795	$24,543	$31,933	$38,724	$113,858

Breakdown of costs and benefits for the preferred alternative

Table X-6 provides a breakdown of the costs and benefits for the preferred alternative using a 3 percent and 7 percent discount rate, respectively.

Table X-6
Preferred Alternative
Cost and Benefit Estimates
Passenger Cars and Light Trucks Combined
MY 2012-2016 Combined
($ millions)

	Undiscounted	Discounted 3%	Discounted 7%
Technology Costs	$51,748	$51,748	$51,748
Benefits			
Lifetime Fuel Expenditures	178,880	143,048	112,005
Consumer Surplus from Additional Driving	13,092	10,491	8,233
Refueling Time Value	11,482	9,443	7,608
Petroleum Market Externalities	9,801	7,952	6,322
Congestion Costs	-7,694	-6,264	-4,993
Noise Costs	-151	-122	-97
Crash Costs	-3,681	-,2989	-2,378
CO2	18,314	14,528	14,528
CO	0	0	0
VOC	612	494	391
NOX	722	612	475
PM	3,720	2,974	2,329
SOX	2,820	2,288	1,819
Total	227,967	182,457	146,243
Net Benefits		$130,709	$94,495

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 and future savings are not discounted to present value, since consumers generally only consider and respond to what they pay at the pump. The payback periods are estimated as an average for all manufacturers for the different alternatives. The payback periods for MY 2016 are shown in Table X-7.

Table X-7
Payback Period for MY 2016 Average Vehicles
(in years)

	Passenger Cars	Light Trucks
Preferred Alternative	3.3	2.2
3% Annual Increase	2.7	2.1
4% Annual Increase	3.0	2.5
5% Annual Increase	3.4	3.2
6% Annual Increase	4.2	3.9
7% Annual Increase	4.8	4.6
Max Net Benefits	4.4	4.0
Total Cost = Total Benefit	4.8	4.3

Sensitivity Analyses

The agency has performed several sensitivity analyses to examine important assumptions. 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 2010 Early Release Reference Case estimate for the price of gasoline (see Table VIII-4). In this sensitivity analysis we examine the effect of using the AEO 2009 High Price Case or Low Price Case forecast estimates instead. AEO 2009 cases are used because the AEO 2010 Early Release only provides the Reference Case forecast.

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 percent or 15 percent rebound effect instead.

3) The values of CO_2 benefits and monopsony: The main analysis uses $21.35 per ton discounted at a 3 percent discount rate to quantify the benefits of reducing CO_2 emissions and $0.190 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. These are the 2010 values, which increase over time. These values can be translated into cents per gallon by multiplying by 0.0089,[446] giving the following values:

   ($4.72 per ton CO_2) x 0.0089 = $0.042 per gallon discounted at 5%
   ($21.35 per ton CO_2) x 0.0089 = $0.190 per gallon discounted at 3% (used in the main analysis)
   ($35.06 per ton CO_2) x 0.0089 = $0.312 per gallon discounted at 2.5%
   And a 95th percentile estimate of
   ($64.90 per ton CO_2) x 0.0089 = $0.5776 per gallon discounted at 3%

4) Military security: The main analysis $0 per gallon to quantify the military security benefits of reducing fuel consumption. In the sensitivity analysis, we examine the impact of using a value of 5 cents per gallon instead.

5) Consumer Benefit: The main analysis assumes there is no loss in consumer surplus with 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 consumer surplus – equivalent to the assumption that consumers will only value the calculated benefits they will achieve at 75, or 50 percent, respectively, of their main analysis estimates.

Varying each of the above 6 parameters in isolation results in a variety of economic scenarios. These are listed in Table X-8 below along with the preferred alternative, together with two

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[446] 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. One ton of C = 44/12 tons CO_2 = 3.67 tons CO_2. 1 gallon of gas weighs 2,819 grams, of that 2,433 grams are carbon. $1.00 CO_2 = $3.67 C and $3.67/ton * ton/1000kg * kg/1000g * 2433g/gallon = (3.67 * 2433) / 1000 * 1000 = $0.0089/gallon

additional scenarios that use values from the first 5 parameters that produce the lowest and highest valued benefits.

6) In addition, the agency performed two additional sensitivity analyses. First, in Tables X-11 and X-12, 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 RPE factor results in higher cost estimates for each of the technologies. The ICM methodology does not include profits, while the RPE factor methodology does. 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. Second, in Table X-13, we will separately examine the sensitivity of the benefits of reducing criteria pollutants and vehicle safety to alternate values of statistical life.

Table X-8
Sensitivity Analyses

Name	Fuel Price	Discount Rate	Rebound Effect	SCC	Monopsony Effect	Military Security
Reference	Reference	3%	10%	$20	0¢/ gal	0¢/ gal
High Fuel Price	High	3%	10%	$20	0¢/ gal	0¢/ gal
Low Fuel Price	Low	3%	10%	$20	0¢/ gal	0¢/ gal
5% Rebound Effect	Reference	3%	5%	$20	0¢/ gal	0¢/ gal
15% Rebound Effect	Reference	3%	15%	$20	0¢/ gal	0¢/ gal
$56/ ton CO_2 Value	Reference	3%	10%	$56	0¢/ gal	0¢/ gal
$10/ ton CO_2	Reference	3%	10%	$10	0¢/ gal	0¢/ gal
5¢/ gal Military Security Value	Reference	3%	10%	$20	0¢/ gal	5¢/ gal
Lowest Discounted Benefits	Low	7%	15%	$10	0¢/ gal	0¢/ gal
Highest Discounted Benefits	High	3%	5%	$56	0¢/ gal	5¢/ gal
50% Consumer Benefit	Reference	3%	10%	$20	0¢/ gal	0¢/ gal
75% Consumer Benefit	Reference	3%	10%	$20	0¢/ gal	0¢/ gal

For these cases, sensitivity analyses were performed on the Preferred Alternative only. Table X-9 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 2016 results, since this model year showed the greatest impacts. For benefits, costs, fuel savings, and CO_2 emissions reductions, the table presents totals over the five model years, rather than their values for MY 2016, to reflect the total impact of the standards that would result from the various economic assumptions.

Table X-10 presents the percentage changes from the Preferred Alternative economic assumptions for the items in Table X-9. From these tables, we conclude the following regarding the impact of varying the economic parameters among the considered values:

1) The various economic assumptions have similar effects on the passenger car and light truck standards.
2) Varying the economic assumptions has almost no impact on achieved fuel economy, with none of the scenarios having an effect of more than 0.2 mpg.
3) Varying the economic assumptions has, at most, a small impact on vehicle costs, total costs, fuel saved or emission reductions with none of these effects being larger than 10 percent.
4) The largest change resulting from varying economic parameters is on benefits. Changing the fuel price forecast to the AEO 2009 High Price Case forecast impacts benefits by a combined +44.2%. Other large impacts on benefits occurred with the 7% discount rate (-19.8%), valuing benefits at 75 percent (-22.3%).
5) Even if consumers value the benefits achieved at 50% of the main analysis assumptions, total benefits still exceed costs.
6) Changing all economic parameters simultaneously to the lowest or highest values, among the values considered (not including the value of consumer benefits), changes benefits by at about 56%. However impacts to other quantities, such as cost, are much smaller, resulting in increases or decreases of 7% or less.

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-9
Sensitivity Analyses
(mpg, Per-Vehicle Cost, Total Benefits, Total Cost, Fuel Saved, & CO2 Emissions Reduced)

Economic Assumptions	MY 2016 Achieved mpg	MY 2016 Per-Vehicle Cost	MY 2012-2016 Benefits, Discounted 3%, in Millions of $	MY 2012-2016 Cost (Societal Perspective), in Millions of $	MY 2012-2016 Fuel Saved, in Millions of Gallons	MY 2012-2016 CO2 Emissions Reduced, in mmT
Passenger Cars						
Preferred	37.2	$907	$107,483	$34,170	35,660	380
High Fuel Price	37.4	$960	$154,052	$36,080	34,374	360
Low Fuel Price	37.2	$907	$101,243	$34,170	35,660	380
5% Rebound Effect	37.2	$907	$112,569	$34,170	37,284	398
15% Rebound Effect	37.2	$907	$102,397	$34,170	34,036	362
$4.72/ ton CO2 Value	37.2	$907	$100,964	$34,170	35,660	380
$35.06/ ton CO2 Value	37.2	$907	$112,788	$34,170	35,660	380
$64.90/ ton CO2 Value	37.2	$907	$124,921	$34,170	35,660	380
5¢/ gal Military Security Value	37.2	$907	$108,875	$34,170	35,660	380
Lowest Discounted Benefits	37.0	$858	$46,329	$32,561	33,547	358
Highest Discounted Benefits	37.4	$960	$166,258	$36,080	35,932	377
50% Consumer Benefit	37.2	$907	$59,201	$34,170	35,660	380
75% Consumer Benefit	37.2	$907	$83,342	$34,170	35,660	380
Light Trucks						
Preferred	28.5	$961	$74,974	$17,578	25,350	275
High Fuel Price	28.6	$991	$108,996	$19,069	24,826	261
Low Fuel Price	28.5	$961	$70,544	$17,578	25,350	275
5% Rebound Effect	28.5	$961	$78,065	$17,578	26,543	288
15% Rebound Effect	28.5	$961	$71,882	$17,578	24,158	262
$4.72/ ton CO2 Value	28.5	$961	$70,311	$17,578	25,350	275
$35.06/ ton CO2 Value	28.5	$961	$78,779	$17,578	25,350	275
$64.90/ ton CO2 Value	28.5	$961	$87,408	$17,578	25,350	275
5¢/ gal Military Security Value	28.5	$961	$75,933	$17,578	25,350	275
Lowest Discounted Benefits	28.3	$865	$31,669	$15,391	23,746	257
Highest Discounted Benefits	28.6	$991	$117,253	$19,069	25,989	274
50% Consumer Benefit	28.5	$961	$41,764	$17,578	25,350	275
75% Consumer Benefit	28.5	$961	$58,369	$17,578	25,350	275

Passenger Cars & Light Trucks Combined						
Preferred	33.7	$926	$182,457	$51,748	61,010	655
High Fuel Price	33.8	$970	$263,048	$55,149	59,200	621
Low Fuel Price	33.7	$926	$171,787	$51,748	61,010	655
5% Rebound Effect	33.7	$926	$190,634	$51,748	63,826	686
15% Rebound Effect	33.7	$926	$174,279	$51,748	58,194	624
$4.72/ ton CO2 Value	33.7	$926	$171,276	$51,748	61,010	655
$35.06/ ton CO2 Value	33.7	$926	$191,567	$51,748	61,010	655
$64.90/ ton CO2 Value	33.7	$926	$212,329	$51,748	61,010	655
5¢/ gal Military Security Value	33.7	$926	$184,808	$51,748	61,010	655
Lowest Discounted Benefits	33.5	$861	$77,998	$47,952	57,293	615
Highest Discounted Benefits	33.8	$970	$283,511	$55,149	61,921	651
50% Consumer Benefit	33.7	$926	$100,965	$51,748	61,010	655
75% Consumer Benefit	33.7	$926	$141,711	$51,748	61,010	655

Table X-10
Sensitivity Analyses – Percentage Change from the Reference Case

Economic Assumptions	MY 2016 Achieved mpg	MY 2016 Per-Vehicle Cost	MY 2012-2016 Benefits, Discounted 3%, in Millions of $	MY 2012-2016 Cost (Societal Perspective), in Millions of $	MY 2012-2016 Fuel Saved, in Millions of Gallons	MY 2012-2016 CO2 Emissions Reduced, in mmT
Passenger Cars						
Preferred	Base	Base	Base	Base	Base	Base
High Fuel Price	0.4%	5.8%	43.3%	5.6%	-3.6%	-5.2%
Low Fuel Price	0.0%	0.0%	-5.8%	0.0%	0.0%	0.0%
5% Rebound Effect	0.0%	0.0%	4.7%	0.0%	4.6%	4.7%
15% Rebound Effect	0.0%	0.0%	-4.7%	0.0%	-4.6%	-4.7%
$4.72/ ton CO2 Value	0.0%	0.0%	-6.1%	0.0%	0.0%	0.0%
$35.06/ ton CO2 Value	0.0%	0.0%	4.9%	0.0%	0.0%	0.0%
$64.90/ ton CO2 Value	0.0%	0.0%	16.2%	0.0%	0.0%	0.0%
5¢/ gal Military Security Value	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
Lowest Discounted Benefits	-0.5%	-5.4%	-56.9%	-4.7%	-5.9%	-5.7%
Highest Discounted Benefits	0.4%	5.8%	54.7%	5.6%	0.8%	-0.7%
50% Consumer Benefit	0.0%	0.0%	-44.9%	0.0%	0.0%	0.0%
75% Consumer Benefit	0.0%	0.0%	-22.5%	0.0%	0.0%	0.0%
Light Trucks						
Preferred	Base	Base	Base	Base	Base	Base
High Fuel Price	0.1%	3.1%	45.4%	8.5%	-2.1%	-4.9%
Low Fuel Price	0.0%	0.0%	-5.9%	0.0%	0.0%	0.0%
5% Rebound Effect	0.0%	0.0%	4.1%	0.0%	4.7%	4.8%
15% Rebound Effect	0.0%	0.0%	-4.1%	0.0%	-4.7%	-4.8%
$4.72/ ton CO2 Value	0.0%	0.0%	-6.2%	0.0%	0.0%	0.0%
$35.06/ ton CO2 Value	0.0%	0.0%	5.1%	0.0%	0.0%	0.0%
$64.90/ ton CO2 Value	0.0%	0.0%	16.6%	0.0%	0.0%	0.0%
5¢/ gal Military Security Value	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
Lowest Discounted Benefits	-0.7%	-10.0%	-57.8%	-12.4%	-6.3%	-6.5%
Highest Discounted Benefits	0.1%	3.1%	56.4%	8.5%	2.5%	-0.2%
50% Consumer Benefit	0.0%	0.0%	-44.3%	0.0%	0.0%	0.0%
75% Consumer Benefit	0.0%	0.0%	-22.1%	0.0%	0.0%	0.0%

Passenger Cars & Light Trucks Combined						
Preferred	Base	Base	Base	Base	Base	Base
High Fuel Price	0.3%	4.8%	44.2%	6.6%	-3.0%	-5.1%
Low Fuel Price	0.0%	0.0%	-5.8%	0.0%	0.0%	0.0%
5% Rebound Effect	0.0%	0.0%	4.5%	0.0%	4.6%	4.7%
15% Rebound Effect	0.0%	0.0%	-4.5%	0.0%	-4.6%	-4.7%
$4.72/ ton CO2 Value	0.0%	0.0%	-6.1%	0.0%	0.0%	0.0%
$35.06/ ton CO2 Value	0.0%	0.0%	5.0%	0.0%	0.0%	0.0%
$64.90/ ton CO2 Value	0.0%	0.0%	16.4%	0.0%	0.0%	0.0%
5¢/ gal Military Security Value	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
Lowest Discounted Benefits	-0.6%	-7.0%	-57.3%	-7.3%	-6.1%	-6.0%
Highest Discounted Benefits	0.3%	4.8%	55.4%	6.6%	1.5%	-0.5%
50% Consumer Benefit	0.0%	0.0%	-44.7%	0.0%	0.0%	0.0%
75% Consumer Benefit	0.0%	0.0%	-22.3%	0.0%	0.0%	0.0%

In addition, 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) resulting in an overall price increase multiplier from variable cost of 1.2 to 1.25, with special attention being paid to the preferred alternative and the maximum net benefit alternative. Table X-11 shows the impact on the MY 2016 achieved mpg level for passenger cars and light trucks by changing the cost markup factors used in the Volpe model. The big difference is in mpg for the maximum net benefit alternative. Having a higher cost for technologies limits how many technologies are cost effective. Table X-12 shows the impacts on costs and benefits for the preferred alternative comparing the preferred alternative using the ICM method to the RPE method.

Table X-11
Achieved mpg level
Comparing Different Cost Mark-up Methodologies
(Achieved mpg levels)

	ICM Method (Main analysis)	RPE Method (Sensitivity)	Difference (mpg)
Passenger Car Preferred Alternative	37.21	37.17	0.04
Passenger Car Maximum Net Benefits Alternative	39.77	39.21	0.56
Light Truck Preferred Alternative	28.53	28.36	.17
Light Trucks Maximum Net Benefits Alternative	30.63	30.04	.59

Table X-12
Sensitivity Analyses
(mpg, Per-Vehicle Cost, Total Benefits, Total Cost, Fuel Saved, & CO2 Emissions Reduced)

Economic Assumptions	**MY 2016 Achieved mpg**	**MY 2016 Per-Vehicle Cost**	**MY 2012-2016 Benefits, Discounted 3%, in Millions of $**	**MY 2012-2016 Cost (Societal Perspective), in Millions of $**	**MY 2012-2016 Fuel Saved, in Millions of Gallons**	**MY 2012-2016 CO2 Emissions Reduced, in mmT**
Passenger Cars						
Preferred	37.21	$907	$107,483	$34,170	35,660	380
RPE method	37.17	$1,136	$102,589	$41,804	34,052	363
Light trucks						
Preferred	28.53	$961	$74,974	$17,578	25,350	275
RPE method	28.36	$1,141	$74,510	$20,476	25,210	273

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). Although DOT recently revised its central estimate of VSL to $6.0 million, this figure is denominated in 2008 dollars, and when adjusted to 2007 dollars remains at $5.8 million.

By contrast, EPA uses VSL of $7.6 million (2007 dollars), which is 30% higher than DOT's central estimate, although still within the upper estimate recommended by DOT to recognize uncertainty. The differing VSLs across agencies should be judged as arising from different conclusions regarding the validity of the various studies on VSL, rather than a function of the different at-risk populations that they represent.

Within the CAFE FRIA, 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 basic conclusion is that the safety impacts are highly uncertain, but, even under the upper bound estimate, the rule would still be highly cost-beneficial using the DOT VSL of $5.8 million.

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.).[447] This estimate is $6.3 million in 2000 dollars, which corresponds to $7.6 million when expressed in 2007 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.

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[447] 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).

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-13 summarizes these estimates:

Table X-13
Sensitivity Analysis of Alternate VSLs (millions of 2007 Dollars, MYs 2012-2016)

Assumed VSL (2007 Dollars)	Source	Value of Fatality Impacts[448]	Value of Mortality Benefits from Reduced Emissions of Criteria Air Pollutants
$3.2 million	DOT Lower Estimate	$182 – 2,055	$3,125
$5.8 million	DOT Central Estimate	$317 – 3,581	$5,185
$7.6 million	EPA Estimate	$411 – 4,637	$6,557
$8.4 million	DOT Upper Estimate	$452 – 5,107	$7,194

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 very small. Specifically, benefits from reducing premature mortality account for 90-91% of EPA's estimates of total benefits from reducing criteria emissions, depending on the specific pollutant. DOT's estimate of the VSL is 23% lower than the estimate used by EPA to construct the per-ton benefits of reducing emissions, which means that substituting DOT's estimate of VSL would reduce the per-ton benefits estimates by 21% (23% of 90-91%). Our estimates of the total benefits from reducing emissions of criteria air pollutants would be reduced by this same percentage. Since these represent 3.1-3.3% of total benefits from the standards, making this change would reduce total benefits by 0.7% (21% of 3.0-3.3%).

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 costs = total benefits 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 alternative. Thus, this analysis compares MY 2016 passenger car, light truck and combined mpg levels for different sensitivity analyses (see Table X-14).

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[448] Note that calculations for safety impacts are based on comprehensive costs, which include economic impacts in addition to VSL estimates, such as medical care costs, legal costs, insurance administrative costs, etc. These costs are based on previous NHTSA studies of motor vehicle crash costs, and add $300,000 to each VSL. However, costs associated with nonfatal injuries are not accounted for in this calculation.

Table X-14
Sensitivity Analysis for Maximum Net Benefit and TC=TB

Maximum Net Benefit	**Passenger Car mpg**	**Light Truck mpg**	**Combined mpg**
Reference	40.9	31.1	36.9
High Fuel Price	41.4	31.2	37.2
Low Fuel Price	39.8	30.6	36.1
7% Discount Rate	39.5	30.1	35.7
5% Rebound Effect	39.8	30.6	36.1
15% Rebound Effect	39.8	30.6	36.1
$4.72/ ton CO2 Value	39.8	30.6	36.1
$35.06/ ton CO2 Value	39.8	30.6	36.1
$64.90/ ton CO2 Value	39.8	30.6	36.1
5¢/ gal Military Security Value	39.8	30.6	36.1
Lowest Discounted Benefits	36.8	29.1	33.7
Highest Discounted Benefits	40.3	30.8	36.4
50% Consumer Benefit	38.8	29.7	35.1
75% Consumer Benefit	39.3	30.1	35.5
RPE method	39.2	30.0	35.5
3.1 TC = TB			
Reference	42.3	31.8	38.0
High Fuel Price	42.5	31.8	38.1
Low Fuel Price	40.5	31.1	36.7
7% Discount Rate	40.5	31.1	36.7
5% Rebound Effect	40.5	31.1	36.7
15% Rebound Effect	40.5	31.1	36.7
$4.72/ ton CO2 Value	40.5	31.1	36.7
$35.06/ ton CO2 Value	40.5	31.1	36.7
$64.90/ ton CO2 Value	40.5	31.1	36.7
5¢/ gal Military Security Value	40.5	31.1	36.7
Lowest Discounted Benefits	40.1	30.7	36.3
Highest Discounted Benefits	40.7	31.2	36.9
50% Consumer Benefit	40.5	31.1	36.7
75% Consumer Benefit	40.5	31.1	36.7
RPE method	40.4	30.8	36.5

XI. FLEXIBILITIES IN MEETING THE STANDARD

In this context, CAFE credits refer to flexibilities allowed under the Energy Policy and Conservation Act (EPCA) provisions governing use of Alternative Motor Fuels Act (AMFA) credits, 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 flexibilities when determining the stringency of CAFE standards, NHTSA did not consider these flexibilities when it developed alternatives for this rulemaking.

Under the Energy Independence and Security Act (EISA), AMFA credits are being phased out. The allowable credits are reduced so that by 2020 such credits will no longer be allowed under law. However, AMFA credits are allowed during the years affected by this rulemaking. Manufacturers building dual-fuel vehicles are entitled to a CAFE benefit of up to 1.2 mpg in 2012 to 2014, 1.0 mpg in 2015, and 0.8 mpg in 2016 for each fleet. NHTSA estimates that the impact of the use of AMFA credits could result in an average reduction of almost 1.0 mpg in achieved average fuel economy in model years 2012 through 2016, and a related increase in CO_2 emissions.

Regarding credits other than AMFA credits (*e.g.*, CAFE credits earned through over-compliance, credits transferred between fleets, and credits acquired from other manufacturers), we do not have a sound basis to predict the extent to which manufacturers might use them, particularly since the credit transfer and credit trading programs have been only recently authorized, and credit transfers could involve complex interactions with multi-year planning.[449]

Such questions are similar to, though possibly less tractable than, the behavioral and strategic questions that were entailed in representing manufacturers' ability to "pull ahead" the implementation of some technologies, and that would be involved in attempting to estimate CAFE-induced changes in market shares. Although the Volpe model has been modified to account for multi-year planning effects, substantial concerns remain about how to develop a credible market share model for integration into the modeling system NHTSA has used to analyze the costs and effects of credit transfers and credit trading. The agency continues to consider how a market share model could be integrated into future CAFE analyses.

We believe that some manufacturers are likely to take advantage of these flexibility mechanisms, thereby reducing benefits and costs. Some manufacturers make substantial use of the carry forward and carry back credit flexibilities today. Many manufacturers make dual fuel vehicles today and earn credits. These vehicles are in their MY 2008 and MY 2011 baselines. Other manufacturers regularly exceed CAFE standards applicable to one or both fleets, and allow the corresponding excess CAFE credits to expire. Finally, still other manufacturers regularly pay civil penalties for noncompliance, even when producing dual-fuel vehicles would substantially reduce the magnitude of those penalties.

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[449] For example, if a manufacturer is planning to redesign many vehicles in MY 2013, but few vehicles in MY 2015 when standards will also be significantly more stringent, the benefits (in terms of reducing regulatory burden) of using some flexibilities in MY 2013 (*e.g.*, credit transfers) could be outweighed by the benefits of applying extra technologies in MY 2013 in order to carry them forward to facilitate compliance in MY 2015.

There are vehicle costs to provide the dual fuel capability of using either E85 or gasoline. These costs are incremental to the average vehicle costs of a gasoline vehicle. The additional or redesigned components necessary for E85 capability may include:

- Flexible Fuel Sensor or Oxygen Sensor - Determines the amount of ethanol in the fuel and adjusts the engine operating parameters.
- Fuel System - Plastic Gas Tank, updating components like seals and gaskets to be ethanol capable, increased vapor storage capacity, and some fuel system materials may be changed to stainless steel because ethanol in E-85 is corrosive.
- Low Emission Hardware or Improved Evaporative Emission Systems
- Fuel Injectors and Pressure Regulators
- Valve Seat Materials and Rings
- Fuel Rail Changes to allow for increased fuel pressure
- Cold start enhancement

Combined, the agency estimates that these needed improvements would increase the consumer cost of a vehicle by $100 to $175 (in $2007), even though the manufacturers are charging the same price for a dual-fueled automobile as for a gasoline powered vehicle. The analysis did not include a cost for dual-fueled vehicles because for the most part they are already in the MY 2011 adjusted baseline.

We expect that use of flexibilities would tend to be greater under more stringent standards. As stringency increases, the potential for manufacturers to face greater cost increases, and for some, depending on its level of technological implementation, costs could rise substantially. The economic advantage of employing allowed flexibilities increases and could affect manufacturer behavior in this regard. A critical factor in addressing the fuel and emissions impacts of such flexibilities is that the likely extent of utilization cannot be assumed constant across the alternatives.

To gauge the potential upper end of differences that could result from these provisions, the agency has used the Volpe model to estimate costs and effects if every manufacturer is assumed to take full advantage of the FFV credit provisions throughout MY 2012-2016, under both the baseline (MY 2011) and preferred alternative. The analysis indicates that full use of the provisions could (a) reduce the average achieved fuel economy by 1.1 in MY 2016, and by 0.6-1.1 mpg in earlier model years, (b) reduce technology outlays by about $14 billion (28%) during MY 2012-2016, (c) reduce average price increases by $173-$207 during MY 2012-2016, (d) reduce fuel saved during MY 2012-2016 by 2,377 million gallons (3.9%), and (e) increase by 18.7 mmt. (2.9%) CO_2 emissions avoided during MY 2012-2016.[450,451]

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[450] Estimated differences in costs and prices do not include incremental costs to produce FFVs.

[451] With FFV credits, our analysis includes application of diesel engines at lower volumes than when FFV credits are excluded. Because diesel fuel contains more carbon than gasoline, this difference in diesel application causes a slight reduction in CO_2 emissions.

Table XI-1 shows those potential impacts on passenger cars and light trucks combined. The achieved fuel economy of the fleet and costs are lower if one does not consider the credits from dual-fueled vehicles. We could show many tables supporting these estimates, but we chose just to show some summary highlights.

Table XI-1
Potential Impact of Dual-Fueled Vehicle Credits
Preferred Alternative

	2012	2013	2014	2015	2016	Total
Average Achieved FE (mpg)						
With FFVs	28.7	29.7	30.6	31.5	32.6	
Without FFVs	29.3	30.6	31.7	32.6	33.7	
Difference	(0.6)	(0.9)	(1.1)	(1.1)	(1.1)	
Technology Outlays ($millions)						
With FFVs	3,675	5,123	7,271	9,478	11,921	37,468
Without FFVs	5,903	7,890	10,512	12,539	14,904	51,748
Difference	(2,228)	(2,767)	(3,241)	(3,061)	(2,983)	(14,280)
Price Increases ($)						
With FFVs	261	333	458	589	737	
Without FFVs	434	513	665	782	926	
Difference	(173)	(180)	(207)	(193)	(189)	
Fuel Savings (mil. of gallons)						
With FFVs	4,919	8,236	11,349	15,041	19,092	58,637
Without FFVs	4,201	8,851	12,518	15,950	19,494	61,014
Difference	718	(615)	(1,169)	(909)	(402)	(2,377)
Avoided CO2 (mmt)						
With FFVs	52.8	89.1	123.1	163.4	207.6	636.0
Without FFVs	43.9	94.4	134.3	171.7	210.4	654.7
Difference	8.9	(5.3)	(11.2)	(8.3)	(2.8)	(18.7)

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 2012-2016 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 imbedded 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.[452] 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.[453]

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 20,000 trials under each discount rate scenario. Each complete run is a trial. For each trial, the

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[452] 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.

[453] 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).

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.

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.

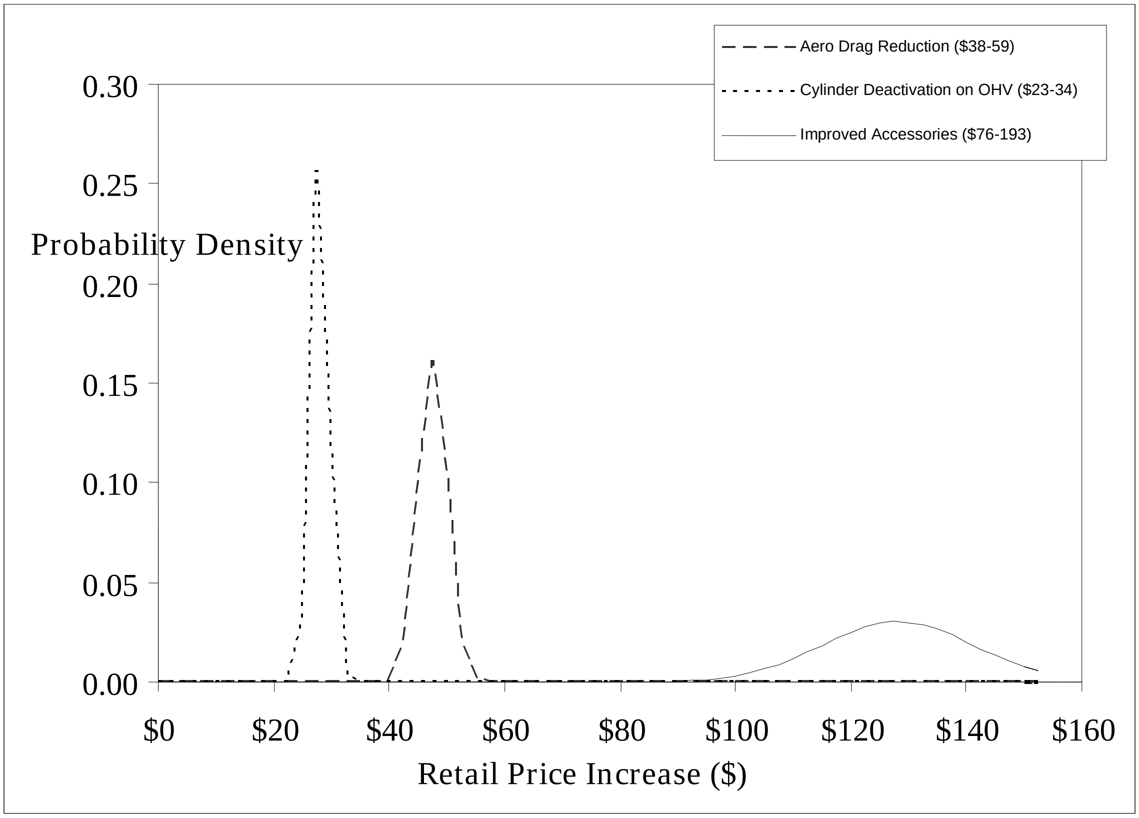
The agency reviewed the inputs and relationships that drive the CAFE model to determine the factors that are the major sources of uncertainty. Six factors were identified as potentially contributing to uncertainty to the estimated impacts of higher CAFE standards, although not all were ultimately selected 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.

Thirty-nine 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 technology complexity ratings that were developed to estimate markup factors were used to distinguish between levels of uncertainty that are expected from technologies that are relatively simple and those that are more uncertain. These ratings were designated as Low, Medium, and High based on the characteristics of each specific technology. This approach assumes that low complexity technologies would tend to have mature costs with well known and understood supply chains, resource availability, and manufacturing techniques, which would imply a more narrow range of potential cost variation compared to high complexity technologies, which would have a broader range of uncertainty. In previous analyses of these technologies (see FRIA for MY 2011), cost variation averaging 31% (based on NAS technology estimates) was assumed to represent 3 standard deviations across all technologies. For this analysis, we are assuming that this average variation represents 2 standard deviations, and applying 1 standard deviation for low complexity technologies, 2 for medium complexity technologies, and 3 standard deviations for high complexity technologies. This results in ranges of 15.5% for low, 31% for medium, and 46.5% for high complexity technologies. The uncertainty model assumes a normal distribution for these cost ranges. Figure XII-1 graphically demonstrates the distributions of a hypothetical sample of three of the technologies.

Figure XII-1
Normal Distributions for 3 Different Technologies



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, thirty-nine 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
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 as much as 40 years in the future and 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 2010 Early Release (AEO). The main analysis is based on the AEO 2010 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 2009 version, the Low Oil Price scenario (LOP) and the High Oil Price scenario (HOP). The 2009 LOP and HOP were employed because AEO Early Releases only contain the Reference Case forecast, so the LOP and HOP for 2010 are not yet available. 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 2009 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 2009 scenarios

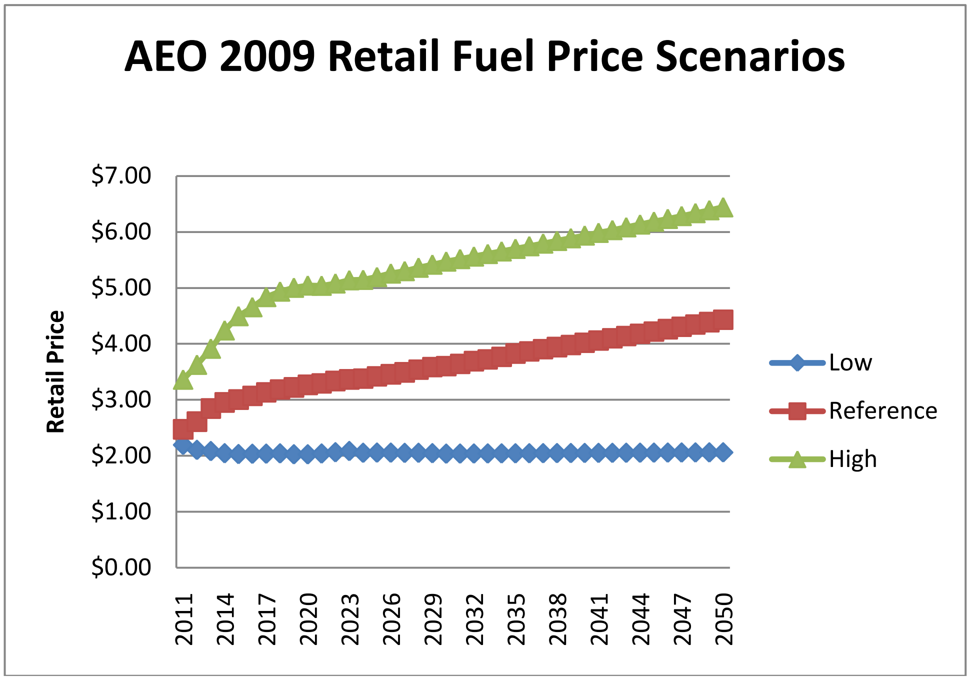
Each of these scenarios was applied as a discrete input (*i.e.*, draws were not made from among the three scenarios separately for each future year). Rather, for each draw, one of the three scenarios was chosen and applied across the full vehicle life for each model year. The probability of selection 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 2007 economics) in Figure XII-2. 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 2009 Gasoline Price Scenarios

Year	Low	Reference	High
2011	$2.194	$2.473	$3.361
2012	$2.103	$2.609	$3.627
2013	$2.082	$2.844	$3.914
2014	$2.044	$2.954	$4.241
2015	$2.028	$3.004	$4.496
2016	$2.033	$3.072	$4.656
2017	$2.035	$3.135	$4.838
2018	$2.041	$3.185	$4.935
2019	$2.025	$3.222	$5.003
2020	$2.024	$3.268	$5.043
2021	$2.038	$3.295	$5.039
2022	$2.061	$3.337	$5.080
2023	$2.083	$3.365	$5.138
2024	$2.051	$3.380	$5.145
2025	$2.055	$3.419	$5.195
2026	$2.054	$3.457	$5.258
2027	$2.049	$3.491	$5.301
2028	$2.051	$3.541	$5.362
2029	$2.044	$3.585	$5.417
2030	$2.036	$3.602	$5.472
2031	$2.037	$3.644	$5.517
2032	$2.038	$3.690	$5.562
2033	$2.039	$3.723	$5.607
2034	$2.040	$3.768	$5.653
2035	$2.042	$3.829	$5.700
2036	$2.043	$3.866	$5.746
2037	$2.044	$3.904	$5.794
2038	$2.045	$3.942	$5.841
2039	$2.046	$3.981	$5.889
2040	$2.047	$4.020	$5.937
2041	$2.049	$4.059	$5.986
2042	$2.050	$4.099	$6.035
2043	$2.051	$4.139	$6.084
2044	$2.052	$4.180	$6.134
2045	$2.053	$4.221	$6.184
2046	$2.055	$4.262	$6.235
2047	$2.056	$4.304	$6.286
2048	$2.057	$4.346	$6.338
2049	$2.058	$4.389	$6.390
2050	$2.059	$4.432	$6.442

Figure XII-2



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.

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.[454] However, consistency with NHTSA's 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

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[454] 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.

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 2012-2016 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. A more complete discussion of price shock is provided in Chapter V, where 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 $0.078 to $0.269, with the actual value most likely to be $0.169 per gallon. For the uncertainty analysis, this central value is used with a normal distribution and a standard deviation of $0.06.

A third imported oil externality is military security. In Chapter VIII, 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 MY 2012-2016 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, and that approximately half of these expenses could be reduced in proportion to a reduction in U.S. oil imports from the region, the estimated savings would range from $0.02 to $0.08 (in 2007 dollars) for each gallon of fuel savings that was reflected in lower U.S. imports of petroleum from the Persian Gulf. 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 $0.05 per gallon, the midpoint of this range. NHTSA employs this estimate in its sensitivity analysis, and examines it further as part of this uncertainty analysis, assuming a 25% probability for this alternate impact.

Table XII-3 lists the range of values that were examined for oil consumption externalities. The expected values were used in the main analysis. Both the value of reducing U.S. demand on the world market price for oil and the value of reduced threat of supply disruptions were derived from a study by Leiby (2008) (see Chapter VIII). For reasons noted in Chapter VIII, military security is not specifically valued in this analysis. A normal distribution was assumed for the range of values for oil consumption externalities with the low and high values assumed to be two standard deviations from the mean, based on the Leiby estimates.

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 $21.35 per metric ton. Additional scenarios could also be examined. The Low SCC value case assumes $4.52/metric ton. The high value case assumes $35.06/metric ton. In addition, a 95th percentile case assuming $64.90/metric ton was examined. 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 0 to 21 percent is used and employed in a slightly skewed Beta distribution which produced a mean of approximately 10.1 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-3 summarizes the economic parameters used in the uncertainty analysis.

Table XII-3
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	6.00
Beta Shape	6.50
Scale	-0.21
Base	0.00
Monopsony Randomization Parameters	
Mean	$ -
Standard Deviation	$ -
Price Shock Randomization Parameters	
Mean	$0.17
Standard Deviation	$0.06
Military Security Randomization Parameters	
Alternative Cost	$0.05
Alternative Cost Probability	25%

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 40,000 trials (20,000 for each discount rate) Figures XII- 3 through XII-12 graphically illustrate the draw results for a sample of the 81 variables (39 technology effectiveness rates, 39 technology costs, the fuel price scenario, oil import externalities, and the rebound effect) that were examined.

Figure XII-3
Monte Carlo Draw Profile, Passenger Car Costs

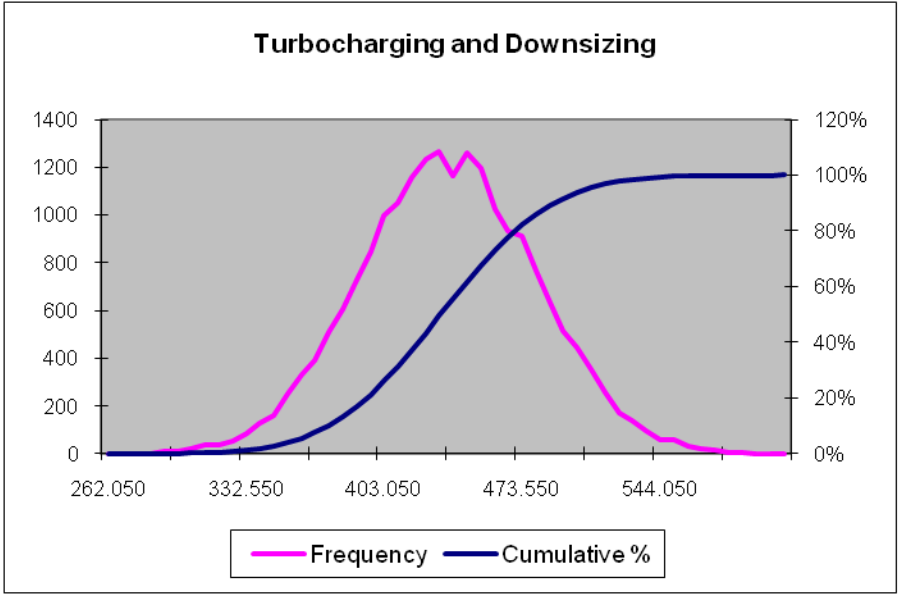

Figure XII-4
Monte Carlo Draw Profile, Passenger Car Effectiveness

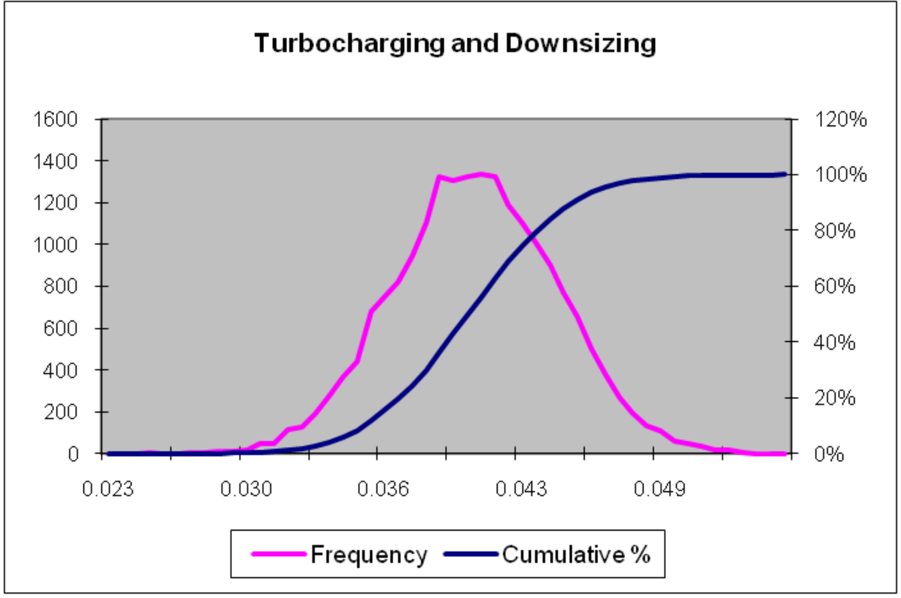

Figure XII-5
Monte Carlo Draw Profile, Passenger Cars, Costs

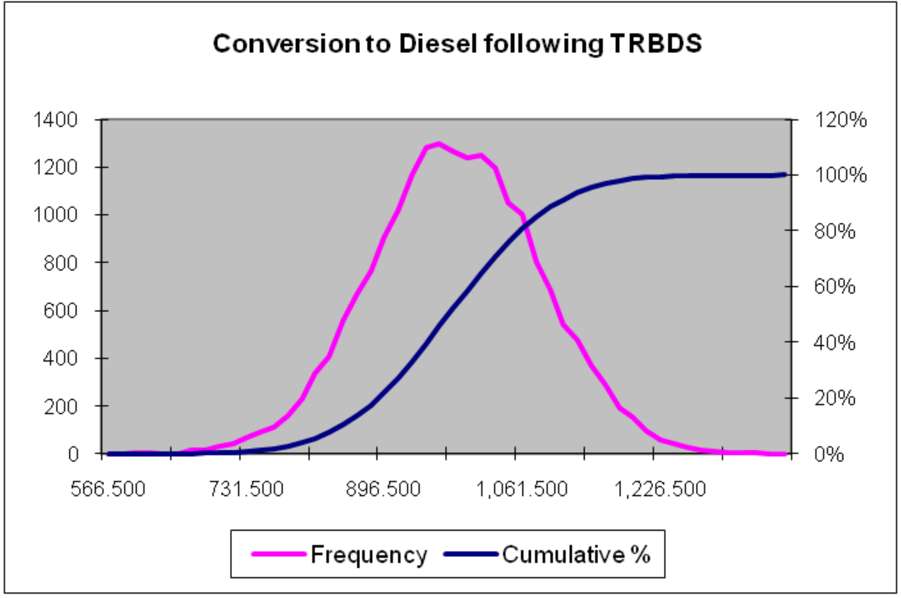

Figure XII-6
Monte Carlo Draw Profile, Passenger Cars, Effectiveness

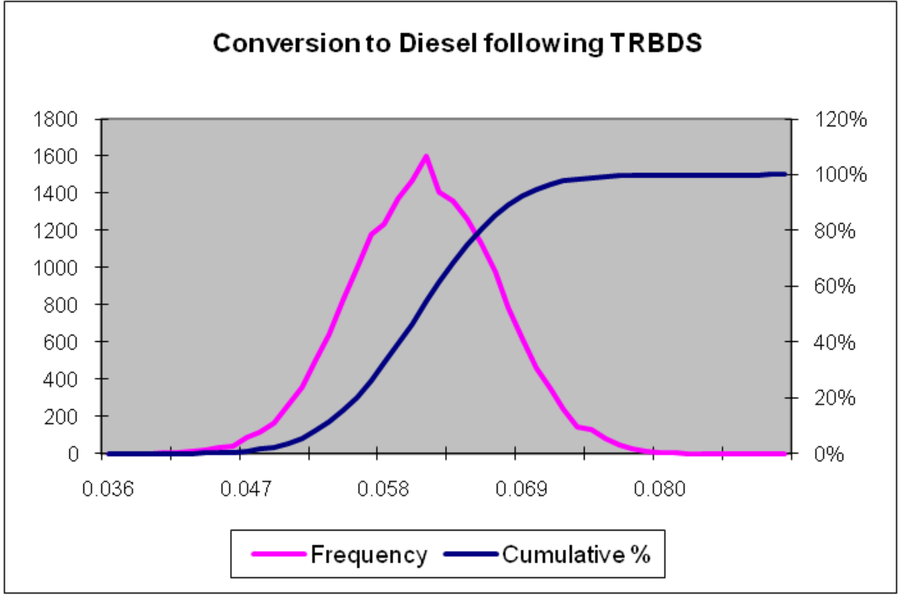

Figure XII-7
Monte Carlo Draw Profile, Passenger Cars, Costs

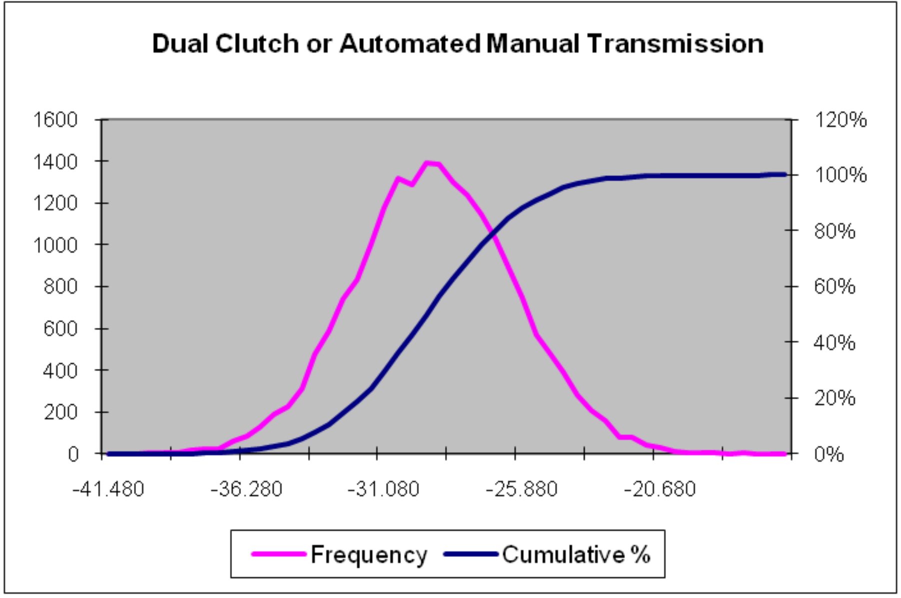

Figure XII-8
Monte Carlo Draw Profile, Passenger Cars, Effectiveness

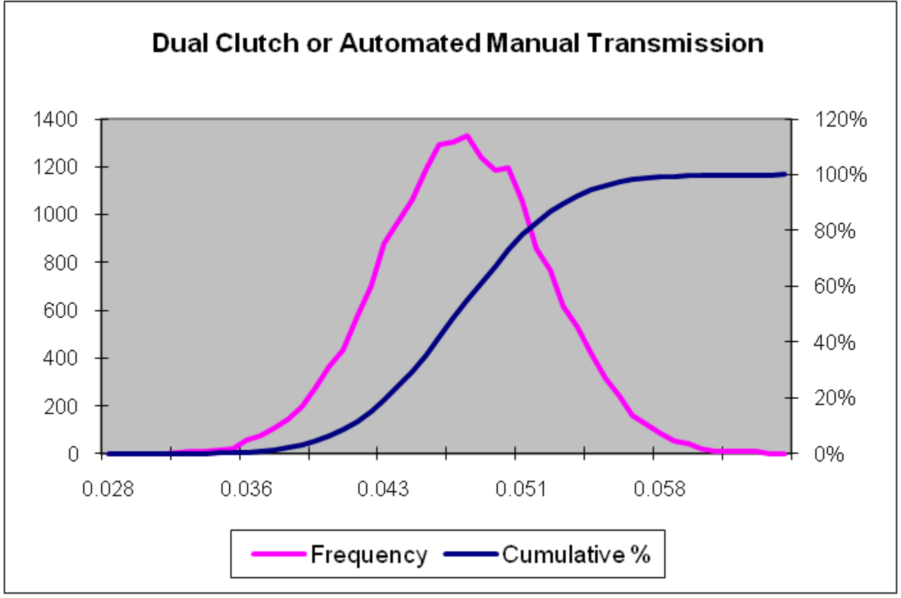

Figure XII-9
Monte Carlo Draw Profile
Pretax Fuel Price Path

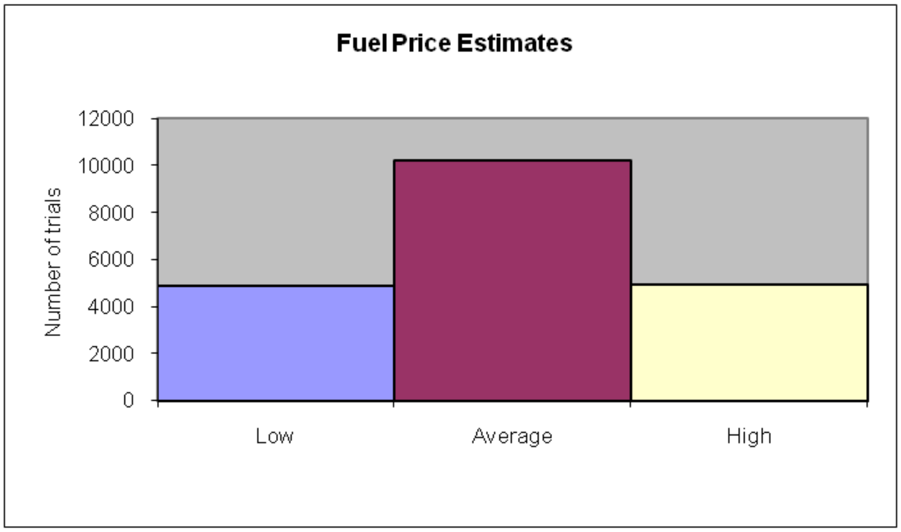

Figure XII-10
Monte Carlo Draw Profile

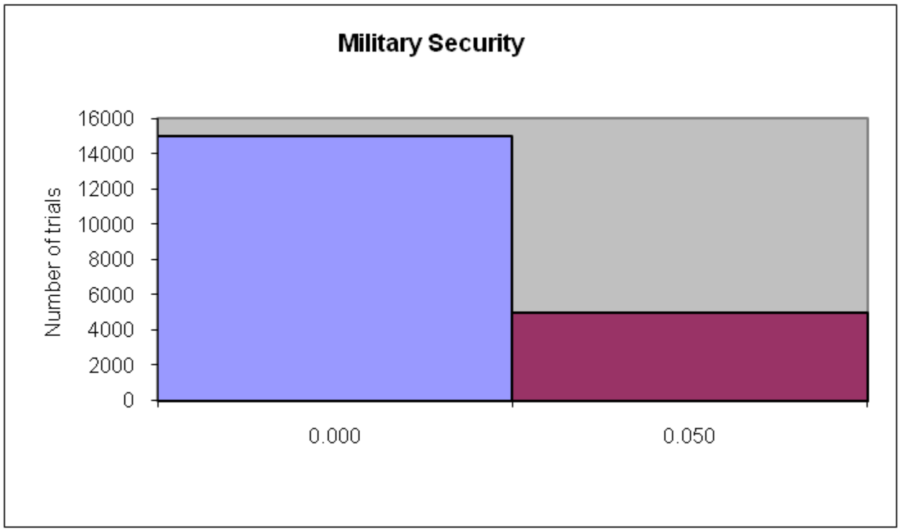

Figure XII-11
Monte Carlo Draw Profile

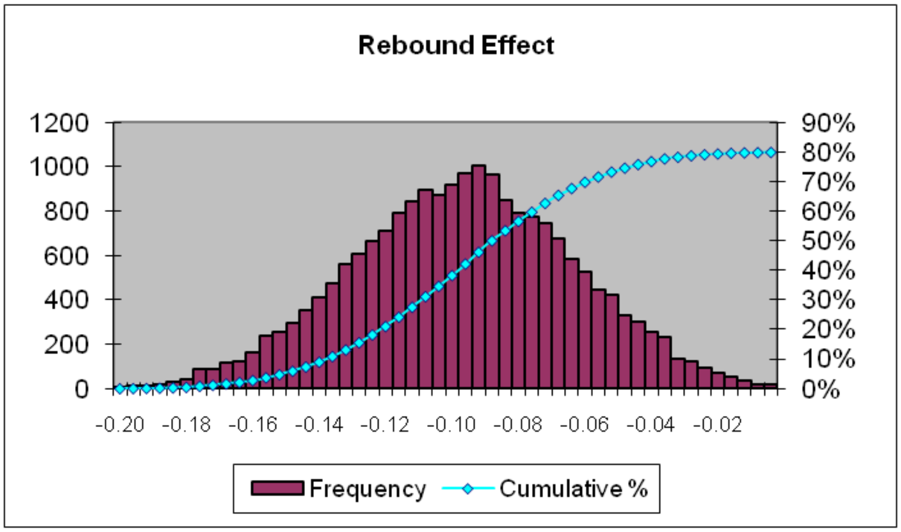

Figure XII-12
Monte Carlo Draw Profile

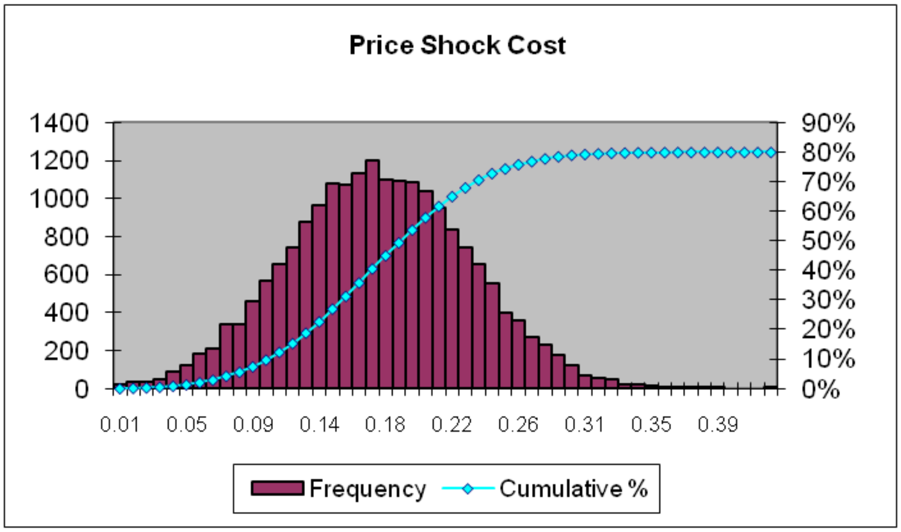

Table XII-3
Monte Carlo Draw Results, Economic Inputs

Economic Inputs	**Minimum**	**Maximum**	**Mean**	**StdDev**
Rebound Effect	-0.2071	-0.0058	-0.1012	0.0336
Military Security Cost	0	0.0500	0.0125	NA
Price Shock Cost	0.00056	0.4166	0.1695	0.0574

Table XII-4 Monte Carlo Draw Results, Passenger Car Technology Costs

Technology	Minimum	Maximum	Mean	StdDev
Low Friction Lubricants	$2.70	$4.21	$3.43	$0.18
Engine Friction Reduction	$9.90	$15.01	$12.57	$0.65
VVT - Coupled Cam Phasing (CCP) on SOHC	$35.88	$53.93	$45.08	$2.31
Discrete Variable Valve Lift (DVVL) on SOHC	$107.66	$165.79	$134.89	$6.93
Cylinder Deactivation on SOHC	$21.87	$34.23	$27.75	$1.43
VVT - Intake Cam Phasing (ICP)	$36.03	$56.60	$45.11	$2.31
VVT - Dual Cam Phasing (DCP)	$30.18	$45.89	$38.31	$1.98
Discrete Variable Valve Lift (DVVL) on DOHC	$106.30	$167.83	$135.05	$7.00
Continuously Variable Valve Lift (CVVL)	$110.64	$430.11	$272.93	$42.48
Cylinder Deactivation on DOHC	$22.47	$33.22	$27.76	$1.44
Cylinder Deactivation on OHV	$22.03	$33.57	$27.96	$1.46
VVT - Coupled Cam Phasing (CCP) on OHV	$32.17	$49.76	$40.85	$2.11
Discrete Variable Valve Lift (DVVL) on OHV	$93.29	$140.91	$117.50	$6.14
Conversion to DOHC with DCP	$215.86	$329.32	$266.14	$13.72
Stoichiometric Gasoline Direct Injection (GDI)	$46.24	$70.10	$58.53	$3.05
Combustion Restart	$67.52	$171.46	$117.52	$12.24
Turbocharging and Downsizing	$255.55	$605.14	$431.95	$45.01
Exhaust Gas Recirculation (EGR) Boost	$83.19	$214.81	$144.39	$14.75
Conversion to Diesel following TRBDS	$561.61	$1,361.58	$973.21	$100.70
Conversion to Diesel following CBRST	$927.72	$2,168.72	$1,548.84	$160.15
6-Speed Manual/Improved Internals	$203.11	$299.79	$250.04	$12.96
Improved Auto. Trans. Controls/Externals	$47.90	$71.87	$60.12	$3.08
Continuously Variable Transmission	$153.58	$361.09	$249.91	$25.57
6/7/8-Speed Auto. Trans with Improved Internals	$94.85	$148.12	$119.38	$6.11
Dual Clutch or Automated Manual Transmission	($41.91)	($16.84)	($29.45)	$3.01
Electric Power Steering	$83.92	$127.15	$106.45	$5.50
Improved Accessories	$74.26	$189.87	$127.58	$13.13
12V Micro-Hybrid	$197.71	$486.70	$326.26	$33.58
Belt mounted Integrated Starter Generator	$165.18	$395.40	$285.53	$29.58
Crank mounted Integrated Starter Generator	$1,495.44	$5,462.30	$3,155.31	$488.49
Power Split Hybrid	$970.47	$4,119.34	$2,604.72	$405.94
2-Mode Hybrid	$1,680.53	$6,684.12	$4,123.51	$640.63
Plug-in Hybrid	$5,566.05	$22,676.11	$14,432.92	$2,233.13
Material Substitution (1.50%)	$1.20	$1.83	$1.48	$0.08
Material Substitution (5% to 10% Cum)	$1.16	$1.76	$1.48	$0.08
Low Rolling Resistance Tires	$4.62	$6.86	$5.72	$0.30
Low Drag Brakes	$49.51	$78.70	$62.90	$3.27
Secondary Axle Disconnect - Ladder Frame	$68.41	$103.85	$86.82	$4.48
Aero Drag Reduction	$37.52	$56.93	$47.62	$2.44

Table XII-5 Monte Carlo Draw Results, Passenger Car Fuel Economy Improvement Rates

Technology	Minimum	Maximum	Mean	StdDev
Low Friction Lubricants	0.003297	0.006774	0.004995	0.000482
Engine Friction Reduction	0.008521	0.021392	0.014992	0.001665
VVT - Coupled Cam Phasing (CCP) on SOHC	0.006288	0.035075	0.020001	0.003321
Discrete Variable Valve Lift (DVVL) on SOHC	0.006296	0.035190	0.019994	0.003324
Cylinder Deactivation on SOHC	0.024234	0.031422	0.027501	0.000835
VVT - Intake Cam Phasing (ICP)	0.008412	0.021828	0.015010	0.001671
VVT - Dual Cam Phasing (DCP)	0.018200	0.033227	0.025002	0.001670
Discrete Variable Valve Lift (DVVL) on DOHC	0.006924	0.034950	0.019980	0.003372
Continuously Variable Valve Lift (CVVL)	0.012571	0.040441	0.025013	0.003328
Cylinder Deactivation on DOHC	0.000004	0.006493	0.002512	0.000828
Cylinder Deactivation on OHV	0.036372	0.058994	0.047018	0.002676
VVT - Coupled Cam Phasing (CCP) on OHV	0.009095	0.015660	0.012514	0.000839
Discrete Variable Valve Lift (DVVL) on OHV	0.001294	0.031847	0.015009	0.003331
Conversion to DOHC with DCP	0.007506	0.028947	0.017508	0.002507
Stoichiometric Gasoline Direct Injection (GDI)	0.018807	0.031099	0.025000	0.001680
Combustion Restart	0.013562	0.031892	0.022523	0.002169
Turbocharging and Downsizing	0.024579	0.054987	0.040107	0.003853
Exhaust Gas Recirculation (EGR) Boost	0.022579	0.051500	0.037481	0.003621
Conversion to Diesel following TRBDS	0.036928	0.088725	0.060763	0.005850
Conversion to Diesel following CBRST	0.082338	0.187326	0.132273	0.012778
6-Speed Manual/Improved Internals	0.003016	0.006991	0.004994	0.000481
Improved Auto. Trans. Controls/Externals	0.013181	0.027517	0.019989	0.001670
Continuously Variable Transmission	0.004942	0.021321	0.013475	0.002168
6/7/8-Speed Auto. Trans with Improved Internals	0.010834	0.039515	0.023982	0.003324
Dual Clutch or Automated Manual Transmission	0.028697	0.064629	0.047186	0.004561
Electric Power Steering	0.008688	0.022226	0.014990	0.001664
Improved Accessories	0.008283	0.021049	0.015003	0.001662
12V Micro-Hybrid	0.016744	0.037837	0.026042	0.002524
Belt mounted Integrated Starter Generator	0.029620	0.070075	0.049013	0.004721
Crank mounted Integrated Starter Generator	0.054397	0.118287	0.087782	0.008466
Power Split Hybrid	0.054487	0.135468	0.093148	0.010177
2-Mode Hybrid	0.023122	0.083804	0.051415	0.007172
Plug-in Hybrid	0.297300	0.655074	0.464704	0.045203
Material Substitution (1.50%)	0.003163	0.007165	0.005254	0.000509
Material Substitution (5% to 10% Cum)	0.023032	0.050878	0.037269	0.003621
Low Rolling Resistance Tires	0.008821	0.021629	0.014999	0.001668
Low Drag Brakes	0.004359	0.011278	0.007508	0.000841
Secondary Axle Disconnect - Ladder Frame	0.009262	0.015969	0.012505	0.000831
Aero Drag Reduction	0.018791	0.030834	0.024981	0.001673

Table XII-6 Monte Carlo Draw Results, Light Truck Technology Costs

Technology	Minimum	Maximum	Mean	StdDev
Low Friction Lubricants	$2.70	$4.21	$3.43	$0.18
Engine Friction Reduction	$9.90	$15.01	$12.57	$0.65
VVT - Coupled Cam Phasing (CCP) on SOHC	$35.88	$53.93	$45.08	$2.31
Discrete Variable Valve Lift (DVVL) on SOHC	$99.43	$153.12	$124.58	$6.40
Cylinder Deactivation on SOHC	$21.87	$34.23	$27.75	$1.43
VVT - Intake Cam Phasing (ICP)	$36.03	$56.60	$45.11	$2.31
VVT - Dual Cam Phasing (DCP)	$32.07	$48.75	$40.70	$2.11
Discrete Variable Valve Lift (DVVL) on DOHC	$98.17	$154.99	$124.73	$6.46
Continuously Variable Valve Lift (CVVL)	$107.99	$419.79	$266.38	$41.46
Cylinder Deactivation on DOHC	$22.47	$33.22	$27.76	$1.44
Cylinder Deactivation on OHV	$20.85	$31.76	$26.46	$1.38
VVT - Coupled Cam Phasing (CCP) on OHV	$20.85	$32.25	$26.48	$1.37
Discrete Variable Valve Lift (DVVL) on OHV	$28.66	$43.29	$36.10	$1.89
Conversion to DOHC with DCP	$201.34	$307.16	$248.23	$12.80
Stoichiometric Gasoline Direct Injection (GDI)	$43.02	$65.22	$54.45	$2.83
Combustion Restart	$67.52	$171.46	$117.52	$12.24
Turbocharging and Downsizing	$325.83	$771.55	$550.73	$57.38
Exhaust Gas Recirculation (EGR) Boost	$83.19	$214.81	$144.39	$14.75
Conversion to Diesel following TRBDS	$654.05	$1,585.69	$1,133.40	$117.27
Conversion to Diesel following CBRST	$1,094.80	$2,559.29	$1,827.77	$188.99
6-Speed Manual/Improved Internals	$203.11	$299.79	$250.04	$12.96
Improved Auto. Trans. Controls/Externals	$47.90	$71.87	$60.12	$3.08
Continuously Variable Transmission	$153.58	$361.09	$249.91	$25.57
6/7/8-Speed Auto. Trans with Improved Internals	$117.02	$182.75	$147.28	$7.54
Dual Clutch or Automated Manual Transmission	($11.18)	($4.49)	($7.86)	$0.80
Electric Power Steering	$83.92	$127.15	$106.45	$5.50
Improved Accessories	$74.26	$189.87	$127.58	$13.13
12V Micro-Hybrid	$218.58	$538.07	$360.70	$37.12
Belt mounted Integrated Starter Generator	$165.18	$395.40	$285.53	$29.58
Crank mounted Integrated Starter Generator	$1,918.40	$7,007.18	$4,047.71	$626.65
Power Split Hybrid	$1,170.26	$4,967.40	$3,140.96	$489.51
2-Mode Hybrid	$2,072.14	$8,241.74	$5,084.42	$789.92
Plug-in Hybrid	$6,326.49	$25,774.17	$16,404.77	$2,538.23
Material Substitution (1.50%)	$1.20	$1.83	$1.48	$0.08
Material Substitution (5% to 10% Cum)	$1.16	$1.76	$1.48	$0.08
Low Rolling Resistance Tires	$4.62	$6.86	$5.72	$0.30
Low Drag Brakes	$49.51	$78.70	$62.90	$3.27
Secondary Axle Disconnect - Ladder Frame	$68.41	$103.85	$86.82	$4.48
Aero Drag Reduction	$37.52	$56.93	$47.62	$2.44

Table XII-7 Monte Carlo Draw Results, Light Truck Fuel Economy Improvement Rates

Technology	Minimum	Maximum	Mean	StdDev
Low Friction Lubricants	0.003297	0.006774	0.004995	0.000482
Engine Friction Reduction	0.008521	0.021392	0.014992	0.001665
VVT - Coupled Cam Phasing (CCP) on SOHC	0.006288	0.035075	0.020001	0.003321
Discrete Variable Valve Lift (DVVL) on SOHC	0.006296	0.035190	0.019994	0.003324
Cylinder Deactivation on SOHC	0.024234	0.031422	0.027501	0.000835
VVT - Intake Cam Phasing (ICP)	0.008412	0.021828	0.015010	0.001671
VVT - Dual Cam Phasing (DCP)	0.018200	0.033227	0.025002	0.001670
Discrete Variable Valve Lift (DVVL) on DOHC	0.006924	0.034950	0.019980	0.003372
Continuously Variable Valve Lift (CVVL)	0.012571	0.040441	0.025013	0.003328
Cylinder Deactivation on DOHC	0.000004	0.006493	0.002512	0.000828
Cylinder Deactivation on OHV	0.036372	0.058994	0.047018	0.002676
VVT - Coupled Cam Phasing (CCP) on OHV	0.009095	0.015660	0.012514	0.000839
Discrete Variable Valve Lift (DVVL) on OHV	0.001294	0.031847	0.015009	0.003331
Conversion to DOHC with DCP	0.007506	0.028947	0.017508	0.002507
Stoichiometric Gasoline Direct Injection (GDI)	0.018807	0.031099	0.025000	0.001680
Combustion Restart	0.013562	0.031892	0.022523	0.002169
Turbocharging and Downsizing	0.014026	0.031379	0.022888	0.002199
Exhaust Gas Recirculation (EGR) Boost	0.022579	0.051500	0.037481	0.003621
Conversion to Diesel following TRBDS	0.036928	0.088725	0.060763	0.005850
Conversion to Diesel following CBRST	0.072653	0.165291	0.116714	0.011275
6-Speed Manual/Improved Internals	0.003016	0.006991	0.004994	0.000481
Improved Auto. Trans. Controls/Externals	0.013181	0.027517	0.019989	0.001670
Continuously Variable Transmission	0.004942	0.021321	0.013475	0.002168
6/7/8-Speed Auto. Trans with Improved Internals	0.010834	0.039515	0.023982	0.003324
Dual Clutch or Automated Manual Transmission	0.020683	0.046581	0.034009	0.003288
Electric Power Steering	0.008688	0.022226	0.014990	0.001664
Improved Accessories	0.008283	0.021049	0.015003	0.001662
12V Micro-Hybrid	0.018441	0.041672	0.028682	0.002780
Belt mounted Integrated Starter Generator	0.028024	0.066299	0.046372	0.004466
Crank mounted Integrated Starter Generator	0.068298	0.148515	0.110214	0.010630
Power Split Hybrid	0.054487	0.135468	0.093148	0.010177
2-Mode Hybrid	0.026160	0.094817	0.058171	0.008115
Plug-in Hybrid	0.297300	0.655074	0.464704	0.045203
Material Substitution (1.50%)	0.003163	0.007165	0.005254	0.000509
Material Substitution (5% to 10% Cum)	0.030551	0.067486	0.049435	0.004803
Low Rolling Resistance Tires	0.008821	0.021629	0.014999	0.001668
Low Drag Brakes	0.004359	0.011278	0.007508	0.000841
Secondary Axle Disconnect - Ladder Frame	0.009262	0.015969	0.012505	0.000831
Aero Drag Reduction	0.018791	0.030834	0.024981	0.001673

Modeling Results – Output

Tables XII-8 and XII-9 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-10 and XII-11 summarize these same results under a 3% discount rate. These results are also illustrated in Figures XII-13 through XII-16 for passenger cars under the Preferred Alternative at 7 percent for MY 2016. Although not shown here, the general shape of the resulting output distributions are similar for the light trucks, 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 one 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 across both the 7 percent (typically the lower range) and 3 percent (typically upper range) discount rates.[455]

<u>Fuel Savings</u>: The analysis indicates that MY 2012 vehicles (both passenger cars and light trucks) will experience between 3,155,853 million and 5,297,310 million gallons of fuel savings over their useful lifespan. MY 2013 vehicles will experience between 7,437,996 million and 10,722,104 million gallons of fuel savings over their useful lifespan. MY 2014 vehicles will experience between 10,354,918 million and 14,434,026 million gallons of fuel savings over their useful lifespan. MY 2015 vehicles will experience between 13,279,284 and 18,082,026 million gallons of fuel savings over their useful lifespan. MY 2016 vehicles will experience between 16,766,243 and 21,718,166 million gallons of fuel savings over their useful lifespan. Over the combined lifespan of the five model years, between 51.4 trillion and 70.3trillion gallons of fuel will be saved.

<u>Total Costs</u>: The analysis indicates that owners of MY 2012 passenger cars and light trucks will pay between $3,838million and $7,968 million in higher vehicle prices to purchase vehicles with improved fuel efficiency. MY 2013 owners will pay between $5,867 million and $10,731 million more. MY 2014 owners will pay between $7,559 million and $13,840 million more. MY 2015 owners will pay between $9,162 million and $16,536 million more. MY 2016 owners will pay between $11,297 million and $19,262 million more. Owners of all five model years vehicles combined will pay between $37.9 billion and $68.2 billion in higher vehicle prices to purchase vehicles with improved fuel efficiency.

<u>Societal Benefits:</u> The analysis indicates that changes to MY 2012 passenger cars and light trucks to meet the proposed CAFE standards will produce overall societal benefits valued between $4,229 million and $22,407 million. MY 2013 vehicles will produce benefits valued between $10,126 million and $47,722 million. MY 2014 vehicles will produce benefits valued between $13,975 million and $66,163 million. MY 2015 vehicles will produce benefits valued

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[455] 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.

between $18,087 million and $83,333 million. MY 2016 vehicles will produce benefits valued between $22,703 million and $101,174 million. Over the combined lifespan of the five model years, societal benefits valued between $69.1 billion and $320.8 billion will be produced.

Net Benefits: The uncertainty analysis indicates that the net impact of the higher CAFE requirements for MY 2012 passenger cars and light trucks will be between a net cost of $2,012 million and a net benefit of $16,138 million. There is at least a 78 percent certainty that changes made to MY 2012 vehicles to achieve the higher CAFE standards will produce a net benefit. The net impact of the higher CAFE requirements for MY 2013 will be a net benefit of between $2,033 million and a net benefit of $38,286 million. There is a 100 percent certainty that changes made to MY 2013 vehicles to achieve the CAFE standards will produce a net benefit. The net impact of the higher CAFE requirements for MY 2014 will be a net benefit of between $3,756 million and a net benefit of $54,448 million. There is a 100 percent certainty that changes made to MY 2014 vehicles to achieve the higher CAFE standards will produce a net benefit. The net impact of the higher CAFE requirements for MY 2015 will be a net benefit of between $6,084 million and $69,461 million. There is 100 percent certainty that changes made to MY 2015 vehicles to achieve the CAFE standards will produce a net benefit. The net impact of the higher CAFE requirements for MY 2016 will be a net benefit of between $8,651 million and $84,920 million. There is 100 percent certainty that changes made to MY 2016 vehicles to achieve the CAFE standards will produce a net benefit. Over all five model years, the higher CAFE standards will produce net benefits ranging from $18.5 billion to $263.3 billion. There is at least a 78 percent certainty that higher CAFE standards will produce a net societal benefit in each of the model years covered by this final rule. In most years, this probability is 100%.

Table XII-8
UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS
(7% Discount Rate)

Item	Mean	Low	High
MY 2012			
Fuel Saved (mill. gall.)	2,351,600	1,708,714	2,966,529
Total Cost ($mill.)	$4,183	$2,770	$5,384
Societal Benefits ($mill.)	$5,576	$2,292	$10,261
Net Benefits ($mill.)	$1,393	-$2,168	$6,324
% Certainty Net Ben. > 0	78%		
MY 2013			
Fuel Saved (mill. gall.)	5,101,261	4,241,046	6,006,703
Total Cost ($mill.)	$5,445	$4,255	$6,779
Societal Benefits ($mill.)	$12,588	$5,682	$21,969
Net Benefits ($mill.)	$7,143	$170	$16,280
% Certainty Net Ben. > 0	100%		
MY 2014			
Fuel Saved (mill. gall.)	7,085,206	5,951,278	8,124,710
Total Cost ($mill.)	$6,829	$5,244	$8,408
Societal Benefits ($mill.)	$17,806	$8,023	$30,965
Net Benefits ($mill.)	$10,977	$1,249	$23,938
% Certainty Net Ben. > 0	100%		
MY 2015			
Fuel Saved (mill. gall.)	9,107,029	7,720,755	10,515,156
Total Cost ($mill.)	$8,057	$6,233	$9,990
Societal Benefits ($mill.)	$23,241	$10,574	$40,045
Net Benefits ($mill.)	$15,184	$2,751	$31,402
% Certainty Net Ben. > 0	100%		
MY 2016			
Fuel Saved (mill. gall.)	11,268,179	9,840,046	12,649,674
Total Cost ($mill.)	$9,461	$7,356	$12,014
Societal Benefits ($mill.)	$29,110	$13,287	$49,454
Net Benefits ($mill.)	$19,650	$4,404	$39,532
% Certainty Net Ben. > 0	100%		

Table XII-9

UNCERTAINTY ANALYSIS RESULTS, LIGHT TRUCKS

(7% Discount Rate)

Item	Mean	Low	High
MY 2012			
Fuel Saved (mill. gall.)	1,794,729	1,447,139	2,245,130
Total Cost ($mill.)	$1,703	$1,075	$2,584
Societal Benefits ($mill.)	$4,156	$1,937	$7,634
Net Benefits ($mill.)	$2,453	$156	$5,448
% Certainty Net Ben. > 0	100%		
MY 2013			
Fuel Saved (mill. gall.)	3,805,850	3,196,950	4,611,444
Total Cost ($mill.)	$2,541	$1,708	$3,589
Societal Benefits ($mill.)	$9,011	$4,444	$16,318
Net Benefits ($mill.)	$6,470	$1,833	$13,010
% Certainty Net Ben. > 0	100%		
MY 2014			
Fuel Saved (mill. gall.)	5,246,353	4,403,640	6,201,065
Total Cost ($mill.)	$3,555	$2,398	$5,096
Societal Benefits ($mill.)	$12,644	$5,952	$22,334
Net Benefits ($mill.)	$9,089	$2,507	$18,269
% Certainty Net Ben. > 0	100%		
MY 2015			
Fuel Saved (mill. gall.)	6,512,008	5,558,529	7,441,376
Total Cost ($mill.)	$4,292	$2,929	$5,901
Societal Benefits ($mill.)	$15,919	$7,513	$28,049
Net Benefits ($mill.)	$11,626	$3,333	$23,292
% Certainty Net Ben. > 0	100%		
MY 2016			
Fuel Saved (mill. gall.)	7,947,335	6,926,197	8,817,021
Total Cost ($mill.)	$5,214	$3,941	$6,718
Societal Benefits ($mill.)	$19,600	$9,416	$32,950
Net Benefits ($mill.)	$14,386	$4,247	$27,807
% Certainty Net Ben. > 0	100%		

Table XII-10
UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS AND LIGHT TRUCKS
(7% Discount Rate)

Item	Mean	Low	High
MY 2012			
Fuel Saved (mill. gall.)	4,146,329	3,155,853	5,211,659
Total Cost ($mill.)	$5,886	$3,845	$7,968
Societal Benefits ($mill.)	$9,732	$4,229	$17,895
Net Benefits ($mill.)	$3,846	-$2,012	$11,772
% Certainty Net Ben. > 0	94%		
MY 2013			
Fuel Saved (mill. gall.)	8,907,111	7,437,996	10,618,147
Total Cost ($mill.)	$7,986	$5,963	$10,368
Societal Benefits ($mill.)	$21,599	$10,126	$38,287
Net Benefits ($mill.)	$13,613	$2,033	$29,290
% Certainty Net Ben. > 0	100%		
MY 2014			
Fuel Saved (mill. gall.)	12,331,559	10,354,918	14,325,775
Total Cost ($mill.)	$10,384	$7,642	$13,504
Societal Benefits ($mill.)	$30,450	$13,975	$53,299
Net Benefits ($mill.)	$20,066	$3,756	$42,207
% Certainty Net Ben. > 0	100%		
MY 2015			
Fuel Saved (mill. gall.)	15,619,037	13,279,284	17,956,532
Total Cost ($mill.)	$12,349	$9,162	$15,891
Societal Benefits ($mill.)	$39,160	$18,087	$68,094
Net Benefits ($mill.)	$26,810	$6,084	$54,694
% Certainty Net Ben. > 0	100%		
MY 2016			
Fuel Saved (mill. gall.)	19,215,514	16,766,243	21,466,695
Total Cost ($mill.)	$14,675	$11,297	$18,732
Societal Benefits ($mill.)	$48,710	$22,703	$82,404
Net Benefits ($mill.)	$34,036	$8,651	$67,339
% Certainty Net Ben. > 0	100%		

Table XII-11
UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS
(3% Discount Rate)

Item	Mean	Low	High
MY 2012			
Fuel Saved (mill. gall.)	2,384,741	1,774,115	2,990,158
Total Cost ($mill.)	4,202	2,747	5,379
Societal Benefits ($mill.)	7,041	2,982	12,519
Net Benefits ($mill.)	2,839	-1,316	8,562
% Certainty Net Ben. > 0	91%		
MY 2013			
Fuel Saved (mill. gall.)	5,153,970	4,272,330	6,089,001
Total Cost ($mill.)	5,516	4,115	6,878
Societal Benefits ($mill.)	15,713	7,186	26,921
Net Benefits ($mill.)	10,197	1,842	20,890
% Certainty Net Ben. > 0	100%		
MY 2014			
Fuel Saved (mill. gall.)	7,162,064	5,964,138	8,271,039
Total Cost ($mill.)	6,939	5,163	8,667
Societal Benefits ($mill.)	22,210	10,205	38,008
Net Benefits ($mill.)	15,271	3,440	30,520
% Certainty Net Ben. > 0	100%		
MY 2015			
Fuel Saved (mill. gall.)	9,183,889	7,723,966	10,555,661
Total Cost ($mill.)	8,179	6,304	10,405
Societal Benefits ($mill.)	28,858	13,264	48,823
Net Benefits ($mill.)	20,679	5,289	39,859
% Certainty Net Ben. > 0	100%		
MY 2016			
Fuel Saved (mill. gall.)	11,323,825	9,912,630	12,715,882
Total Cost ($mill.)	9,579	7,470	12,359
Societal Benefits ($mill.)	35,954	16,578	60,044
Net Benefits ($mill.)	26,376	7,779	49,538
% Certainty Net Ben. > 0	100%		

Table XII-12
UNCERTAINTY ANALYSIS RESULTS, LIGHT TRUCKS
(3% Discount Rate)

Item	Mean	Low	High
MY 2012			
Fuel Saved (mill. gall.)	1,813,345	1,447,105	2,307,152
Total Cost ($mill.)	1,748	1,091	2,494
Societal Benefits ($mill.)	5,342	2,505	9,888
Net Benefits ($mill.)	3,593	762	7,576
% Certainty Net Ben. > 0	100%		
MY 2013			
Fuel Saved (mill. gall.)	3,835,210	3,234,224	4,633,103
Total Cost ($mill.)	2,607	1,752	3,853
Societal Benefits ($mill.)	11,507	5,581	20,801
Net Benefits ($mill.)	8,900	3,069	17,396
% Certainty Net Ben. > 0	100%		
MY 2014			
Fuel Saved (mill. gall.)	5,292,250	4,493,060	6,162,987
Total Cost ($mill.)	3,645	2,396	5,173
Societal Benefits ($mill.)	16,128	7,563	28,155
Net Benefits ($mill.)	12,483	4,198	23,928
% Certainty Net Ben. > 0	100%		
MY 2015			
Fuel Saved (mill. gall.)	6,560,161	5,690,703	7,526,400
Total Cost ($mill.)	4,388	3,029	6,131
Societal Benefits ($mill.)	20,243	9,557	34,510
Net Benefits ($mill.)	15,855	5,399	29,602
% Certainty Net Ben. > 0	100%		
MY 2016			
Fuel Saved (mill. gall.)	7,970,500	6,937,291	9,002,284
Total Cost ($mill.)	5,292	3,945	6,903
Societal Benefits ($mill.)	24,799	11,856	41,130
Net Benefits ($mill.)	19,507	6,724	35,382
% Certainty Net Ben. > 0	100%		

Table XII-13

UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS AND LIGHT TRUCKS

(3% Discount Rate)

Item	Mean	Low	High
MY 2012			
Fuel Saved (mill. gall.)	4,198,086	3,221,220	5,297,310
Total Cost ($mill.)	$5,950	$3,838	$7,873
Societal Benefits ($mill.)	$12,383	$5,487	$22,407
Net Benefits ($mill.)	$6,432	-$554	$16,138
% Certainty Net Ben. > 0	99.9%		
MY 2013			
Fuel Saved (mill. gall.)	8,989,180	7,506,554	10,722,104
Total Cost ($mill.)	$8,123	$5,867	$10,731
Societal Benefits ($mill.)	$27,220	$12,767	$47,722
Net Benefits ($mill.)	$19,097	$4,911	$38,286
% Certainty Net Ben. > 0	100%		
MY 2014			
Fuel Saved (mill. gall.)	12,454,314	10,457,198	14,434,026
Total Cost ($mill.)	$10,584	$7,559	$13,840
Societal Benefits ($mill.)	$38,338	$17,768	$66,163
Net Benefits ($mill.)	$27,754	$7,638	$54,448
% Certainty Net Ben. > 0	100%		
MY 2015			
Fuel Saved (mill. gall.)	15,744,050	13,414,669	18,082,061
Total Cost ($mill.)	$12,567	$9,333	$16,536
Societal Benefits ($mill.)	$49,101	$22,821	$83,333
Net Benefits ($mill.)	$36,534	$10,688	$69,461
% Certainty Net Ben. > 0	100%		
MY 2016			
Fuel Saved (mill. gall.)	19,294,325	16,849,921	21,718,166
Total Cost ($mill.)	$14,871	$11,415	$19,262
Societal Benefits ($mill.)	$60,753	$28,434	$101,174
Net Benefits ($mill.)	$45,883	$14,503	$84,920
% Certainty Net Ben. > 0	100%		

FIGURE XII-13
Model Output Profile

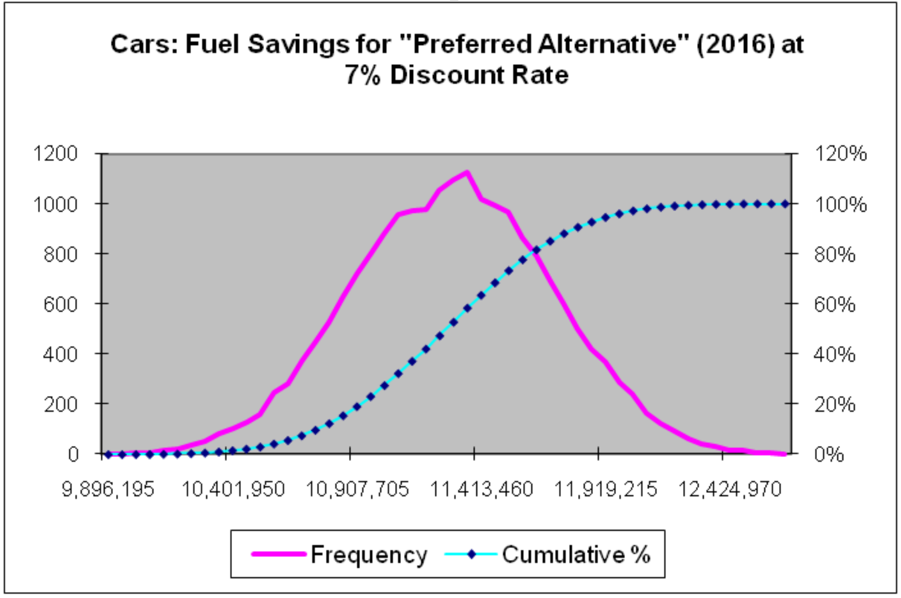


FIGURE XII-14
Model Output Profile

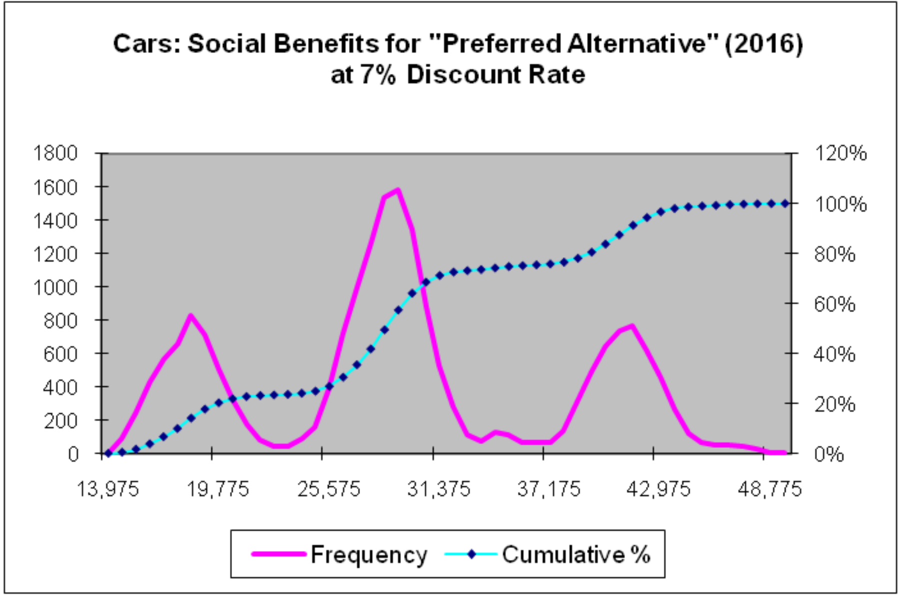


FIGURE XII-15
Model Output Profile

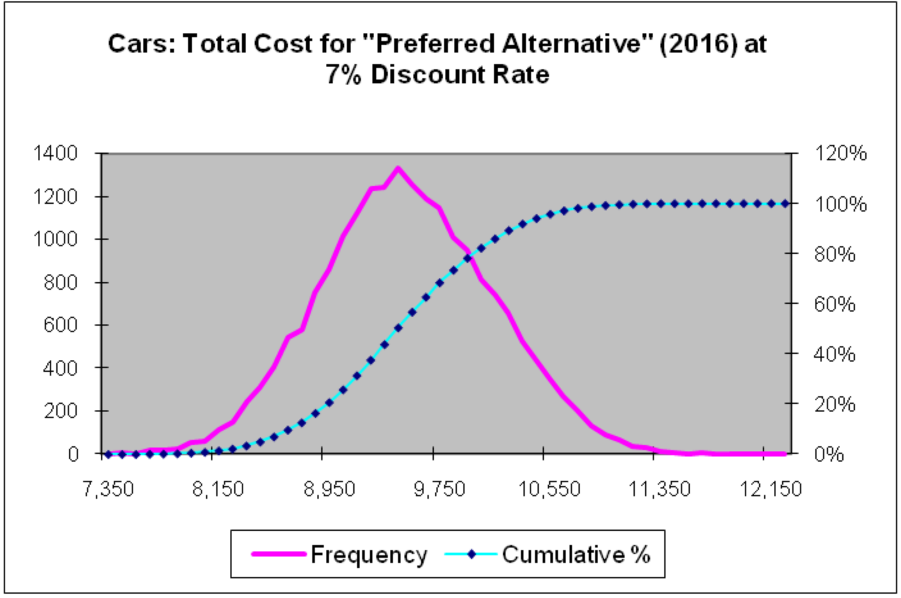
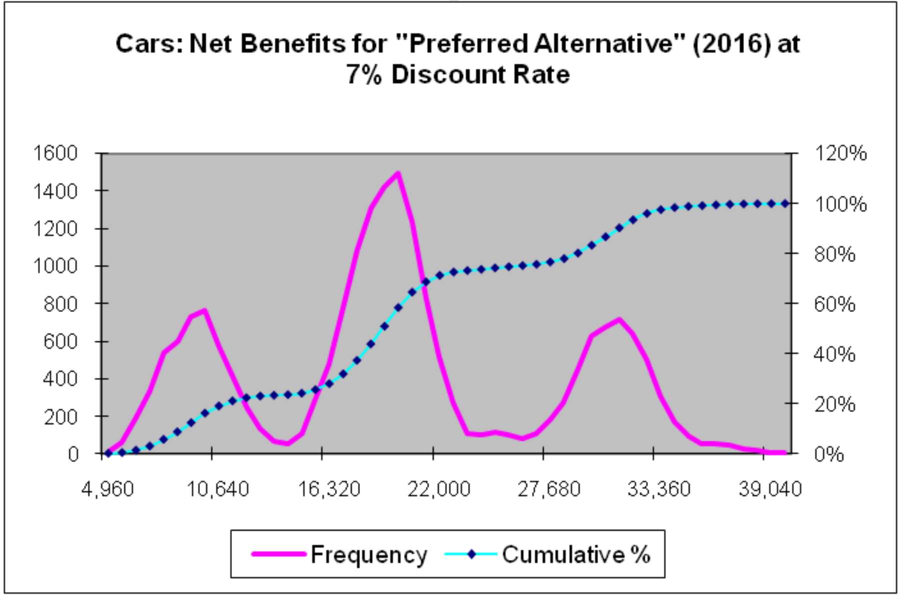


FIGURE XII-16
Model Output Profile



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. <u>Description of the reason why action by the agency is being considered</u>
NHTSA is proposing this action to improve vehicle fuel economy.

2. <u>Objectives of, and legal basis for, the final rule</u>
The Energy Policy and Conservation Act requires the agency to set light truck fuel economy standards every year and allows the agency to update passenger car fuel economy standards. 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. <u>Description and estimate of the number of small entities to which the final rule will apply</u>
The final rule will affect motor vehicle manufacturers. There are no light truck manufacturers that are small businesses. However, there are six 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 manufacturer 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 27.5 mpg standard 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 final rule.

Currently, there are six small passenger car motor vehicle manufacturers in the United States. Table X1II-1 provides information about the 6 small domestic manufacturers in MY 2007. 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***
Fisker Automotive**	N/A	15,000 projected	$80,000	N/A
Mosler Automotive	25	20	$189,000	$2,000,000
Panoz Auto Development Company	50	150	$90,000 to $125,000	$16,125,000
Saleen Inc.	170	1,000[#]	$39,000 to $59,000	$49,000,000
Saleen Inc.	170	16[##]	$585,000	$9,000,000
Standard Taxi***	35	N/A	$25,000	$2,000,000
Tesla Motors, Inc.	250	2,000	$65,000 to $100,000	N/A

* Assuming an average sales price from the sales price range.

** Fisker Automotive is a joint venture of Quantum Fuel Systems Technologies Worldwide, Inc. and Fisker Coachbuild, LLC.

*** Standard Taxi is a subsidiary of the Vehicle Production Group LLC. 35 employees is the total for VPG LLC.

[#] Ford Mustang Conversions

The agency has not analyzed the impact of the final rule 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.

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.

This final rule includes no new requirements for reporting, record keeping of other compliance requirements.

5. An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the final rule

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 final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

There are no other alternatives that can achieve the stated objectives without installing fuel economy technologies into the vehicle.

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 2006 results in $126 million (116.043/92.106 = 1.26). 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 final rule will not result in the expenditure by State, local, or tribal governments, in the aggregate, of more than $126 million annually, but it will result in the expenditure of that magnitude by vehicle manufacturers and/or their suppliers. In promulgating this final rule, NHTSA considered a variety of alternative average fuel economy standards lower and higher than those proposed. 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 final fuel economy standards are the maximum feasible standards for the passenger car and light truck fleets for MYs 2012-2016 in light of the statutory considerations.
