The U.S. Automotive Market and Industry in 2025

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CENTER FOR AUTOMOTIVE RESEARCH

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Introduction

On May 19, 2009, President Obama announced a new national fuel economy program requiring an average fuel economy standard of 35.5 miles per gallon for new light vehicles sales by 2016. The plan overruled the Energy Independence and Security Act which was signed into law in December 2007 and increases the new fuel economy standard four years sooner than previously planned. On May 21, 2010 the President directed two government agencies, the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration of the U.S. Department of Transportation (NHTSA), to start planning new fuel economy standard or levels of green house gas (GHG) emissions for 2017-2025. On October 1, 2010, these two agencies took the first step by announcing their initial assessment, or Notice of Intent (NOI), for stringent standards for model year 2017-2025 vehicles. In a joint document, the Interim Joint Technical Assessment Report (TAR), the California Air Resources Board (CARB) and EPA/NHTSA proposed four GHG emission reduction scenarios: 3, 4, 5, and 6 percent per year from the currently mandated 2016 level, representing four technology "scenarios" each with a separate level of cost per vehicle. The most extreme scenario (6 percent reduction per year) calls for a fuel economy mandate average of 62 mpg by 2025. Technology costs to the consumer are estimated for these scenarios through 2025 but no explicit discussions of the potential impacts of these estimates on U.S. motor vehicle demand, production, or employment were offered.[1]

This study conducted by the Center for Automotive Research (CAR) estimates the likely parameters of the U.S. motor vehicle market and industry in 2025. The first section discusses a general outlook for the U.S. motor vehicle market in the year 2025 based on long term social and economic factors. The second section of this study discusses the likely costs of higher fuel economy mandates to the American consumer of new light vehicles in 2025, in light of what is known by CAR regarding the potential for realistic technologies and their likely net costs to the consumer. This section also proposes four likely scenarios for fuel economy standards by 2025 (compared to 2009) and the types of fuel economy technologies that will be employed to meet those standards. The third section of this study analyzes how the impact of higher fuel economy costs, and likely costs of other federal mandates such as required safety features, will affect the U.S. motor vehicle market, production, and automotive manufacturing employment in the year 2025.

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[1] Interim Joint Technical Assessment Report (TAR), National Highway Traffic Safety Administration, U.S. Environmental Protection Agency, *2017 and Later Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: Supplemental Notice of Intent,* Washington D.C.: 75 FR 76337, December 8, 2010; National Highway Traffic Safety Administration, U.S. Environmental Protection Agency, *Notice of Upcoming Joint Rulemaking to Establish 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards,* Washington D.C.: 75 FR 62739, October 13, 2010; U.S. EPA Office of Transportation and Air Quality, National Highway Safety Traffic Administration Office of International Policy, Fuel Economy, and Consumer Programs, California Air Resources Board, and California E.P.A., *Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025,* Washington D.C.: U.S. EPA, September 2010.

Section I: The U.S. Motor Vehicle Market Outlook in 2025: A Baseline for Growth?

Despite many differences between countries, long-term growth in motor vehicle sales around the world is largely determined by two major elements: growth in the level of per capita income, and growth in population. In the United States, where the market has been saturated since the early 1970s, long-term growth in vehicle sales is more heavily reliant on growth in the adult population. Growth in per capita income now largely determines how quickly vehicle owners will replace their vehicles and how much they will spend. Since 1990, the U.S. adult population has been growing at an average annual rate of 1.2 percent, or 2.7 million adults each year. The U.S. driving age population reached 240 million in 2009.[2] During the same period, U.S. motor vehicle registrations also grew at an average rate of 1.8 percent per year.[3] In 2009 the number of operating light vehicles was equal to, if not larger than, the number of U.S. adults.

According to the Census Bureau, growth in the U.S. population will be slightly more than one percent per year for the next 15 years.[4] If the Census forecast is accurate, there will be an additional 42 million adults in the United States by 2025 compared to 2010 or 2.6 million more individuals each year added to one of the two largest automotive markets in the world. The growing adult population would normally ensure that U.S. market demand for vehicles will continually increase in the foreseeable future.

Households and Vehicles per Household

The number of households in the United States has been growing steadily over the past 60 years. There were 117 million households in the United States in 2009.[5] Since 1990, the number of U.S. households has grown at a rate of 1.2 percent per year or about the rate of annual growth in the overall adult population. Assuming household formation will continue to grow at the same rate as the adult population, the number of U.S. households can be expected to reach 137 million by 2025, or 20 million more than the current total.

The ratio of vehicles per household has followed different trends in the past 60 years. From the end of World War II through the late seventies, vehicles per household increased at a high rate due to the rapid growth of the post-war U.S. economy and the increasing participation of women in the labor force. By the late seventies, a two-car garage became standard across many U.S. households. However, once the two-car-per-household point was reached, there was a natural saturation point. From the late seventies through 2006, the growth rate in vehicles per household slowed, peaking at 2.1 vehicles per household (see Figure 1). During the recent recession, the ratio decreased to 2.03 as a result of households

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[2] U.S. Census Bureau, Population Division, "*Annual Estimates of the Resident Population by Sex and Selected Age Group for the United States, April 1, 2000 to July 1, 2009.*" (NC-EST2009-02), June 2010.)

[3] R.L. Polk & Co. "U.S. Vehicle Registration Data," provided upon request, Southfield, MI, 2010.

[4] U.S. Census Bureau, Population Division, "Projections of the Population by Selected Age Groups and Sex for the United States: 2010-2050," August 14, 2008: (NP2008-T2).

[5] U.S. Census Bureau, "Current Population Survey: Households by Type 1940 to Present," March and Annual Social and Economic Supplements 2009 and previous years, January 2009.

destocking their vehicles. Once the economy starts growing again, the ratio can be expected to slowly recover. By 2025, CAR estimates that vehicles per household should level out at 2.07 vehicles per household.

Figure 1: Vehicles per Household
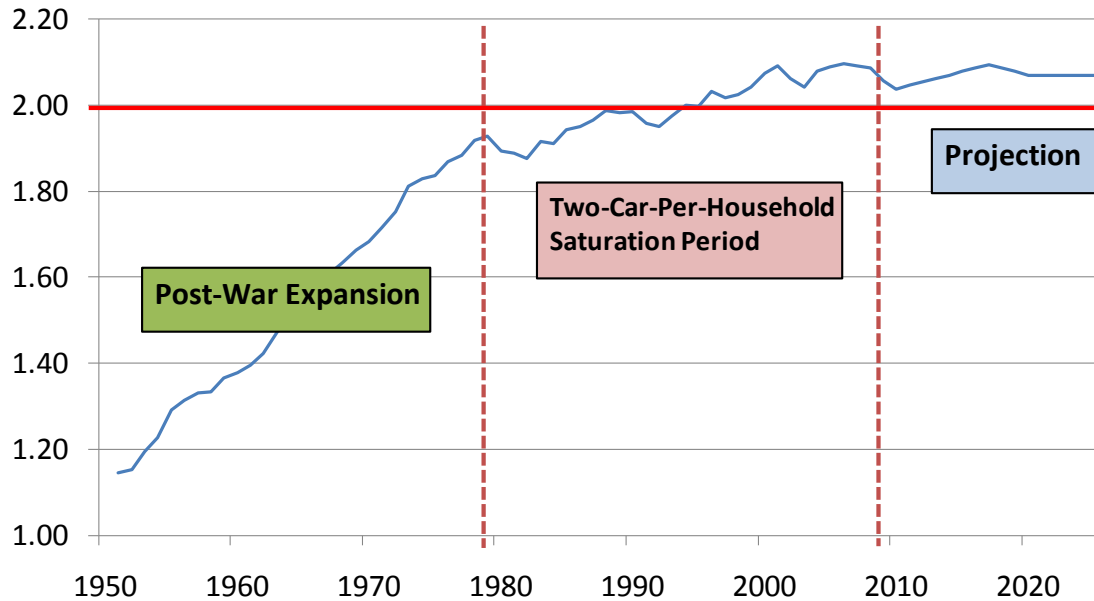
Source: U.S. Census Bureau, Current; R.L. Polk.

Based on trends in household formation and assuming 2.07 vehicles per household, it is estimated that by 2025, there will be 284 million operating light vehicles in the United States–44 million more than in 2009. Simple trends, however, can be altered by non-market and non-demographic realities, such as new regulations.

Urban and Non-Urban Split in Households

According to the 2007 American Household Survey,[6] 29 percent of U.S. households were located in central cities; 71 percent were in suburbs and outside the Metropolitan Statistical Area (MSA), as shown in Figure 2. For those who lived in central cities, 26 percent did not own any vehicles and 19 percent used public transportation regularly for commuting to school or work. For those households located outside of central cities, fewer than half had access to public transportation services, and only five percent used public transportation regularly. In total, only 53 percent of U.S. households had access to public transportation and fewer than nine percent used it regularly. The survey also showed that 87 percent of U.S. household occupants drove or carpooled as the principal means of transportation to work. Because of the lack of available or acceptable substitutes, the motor vehicle still remains the dominant transportation mode for most of U.S. households' everyday activities. The proportion of U.S.

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[6] U.S. Census Bureau, Department of Housing and Urban Development, Housing and Household Economic Statistics Division, "2007 American Housing Survey," September 2008. <www.census.gov/hhes/www/housing/ahs/ahs.html>.

households dependent upon motor vehicles for transportation hasn't changed since 1989, and very likely will not change much by 2025.[7]

Figure 2: Public Transportation Usage Rate

City Households: 29%

Suburban and Rural Households: 71%

Use Public Transportation Regularly: 9%
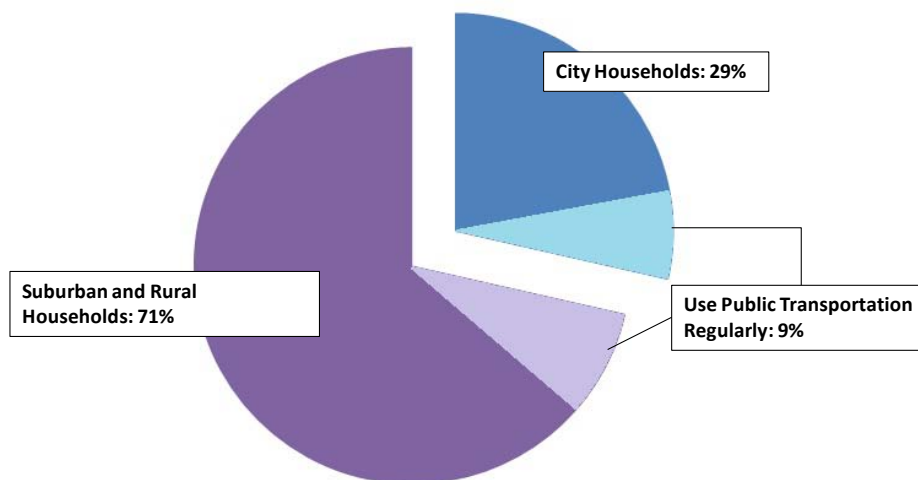
Source: U.S. Department of Housing and Urban Development

Growth in the Light Vehicle Fleet

The number of registered light vehicles registered in the United States was 240 million as of October 1, 2009. According to R.L. Polk, this level of the operating fleet was two million units below the level of 2008. From 1996 through 2008, the U.S. light vehicle fleet had grown at an annual average rate of two percent. However, in 2009, the U.S. motor vehicle fleet decreased by one-half of one percent from its level in 2008; for the first time in U.S. automotive history, the number of scrapped vehicles exceeded new vehicle registrations. Even so, in the next 15 years, the light vehicle fleet is expected to grow at a natural rate with the growth of U.S. households and population. By 2025, the U.S. light vehicle fleet should reach 284 million units, or 44 million more than in 2009.

It is true that both vehicle quality and durability have increased significantly in recent years through continuous improvements in vehicle design and engineering and the use of advanced materials and manufacturing processes. According to R.L. Polk, the average light vehicle age was 10.4 years in 2009, up 1.9 years from 1996. Yet, by 2025, more than 200 million units of U.S. vehicles now operating on the road will be scrapped.[8] Considering the projected net addition of 44 million units to the U.S. fleet, new vehicle sales should be expected to average 15.2 million units per year between 2010 and 2025. This would represent a baseline case given expected increases in new vehicle price inflation, modest

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[7] U.S. Census Bureau, Department of Housing and Urban Development, Housing and Household Economic Statistics Division, "American Housing Survey: 1989, 2007," 1990, 2008. <www.census.gov/hhes/www/housing/ahs/ahs.html>.

[8] R.L. Polk & Co. "Polk Finds More Vehicles Scrapped than Added to Fleet," press release (Southfield, MI, March 30, 2010.); U.S. Environmental Protection Agency, "Highway Vehicle Population Activity Data, Table 5-1, Survival Rate by Age and Source Type," p.20, August 2009.

scrappage rate and moderate growth in U.S. GDP. However, dramatic changes, not determined by market forces, in the price and/or the performance or attributes of new motor vehicles could significantly alter the baseline for growth, as well as the age of the U.S. motor vehicle fleet and annual sales of new products. This could result in the loss of hundreds of thousands of U.S. manufacturing jobs and reduce the standard of living and personal mobility of millions of U.S. consumers. The most likely dramatic changes for the automotive market through 2025 could well be a result of mandates by the federal government to improve the fuel economy performance of vehicles beyond what is required by the market as well as additional safety and environmental mandates and regulations in the period 2011 -2025.

The first set of potential mandates that could affect vehicle cost and performance are those for fuel economy, as discussed in Section II.

Section II: Pathways of Fuel Economy Improvements and Costs Through 2025

The Cost of Fuel Economy Technologies

The cost and effectiveness estimates for fuel consumption reduction technologies used in this study rely primarily on a study conducted by the National Research Council (NRC: www.nationalacademies.org/nrc/). The release of this nearly three-year study, entitled, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," was released by the NRC in June 2011.[9] The purpose of the NRC study was to estimate the availability of technologies, technology effectiveness for reducing fuel consumption and the related costs. While there are numerous studies in the literature (see references in the NRC study) that investigate technology effectiveness and cost, they are quickly dated, they tend to be narrowly focused (e.g., on one or two technology areas), they often provide incomplete cost estimation and they are often seen as biased and lacking peer review. The NRC study was chosen as the source for data because it is the most recent comprehensive and rigorously conducted study with independent peer review, providing objective information necessary for this analysis.

The National Research Council (NRC) is the operating arm of the National Academy of Science, National Academy of Engineering and Institute of Medicine. The NRC mission is to improve government decision-making and public policy, increase public understanding and promote the acquisition and dissemination of knowledge in matters involving science, engineering, technology, and health. The NRC conducts studies using expert committees that are subject to rigorous peer review before release, and they seek consensus-based reports. By design, these reports are independent, balanced and objective and based on the best science available at the time.

The National Highway Traffic Safety Administration (NHTSA) commissioned the NRC to conduct the study. A detailed Statement of Task is provided in Appendix B of the study, but an excerpt reads:

"The committee formed to carry out this study will provide updated estimates of the cost and potential efficiency improvements of technologies that might be employed over the next 15 years to increase the fuel economy of various light-duty vehicle classes."

The technology outlook of this study is close to 2025. Input to the study was gathered from a variety of sources over three years. Data sources include: NHTSA and other government agencies, the national laboratories, automakers and suppliers and commissioned work from independent consultants. Consultants focused primarily on providing cost estimates and modeling technology portfolios to estimate the impact from multiple technologies. Presentations, reports and publications were obtained from a wide spectrum of sources, and site visits were made to manufacturers and suppliers in the U.S., Europe, and Japan. The committee report was reviewed by thirteen (13) outside experts. The study began late in 2007; the pre-publication report was publically released in June 2010, and the final report was released in June 2011.

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[9] National Research Council of the National Academies, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, *Assessment for Fuel Economy Technologies for Light-Duty Vehicles*, Washington D.C.: The National Academies Press, June 2011.

The NRC study committee worked to identify **all significant fuel economy technologies that might be important for light-duty vehicles by the 2025 timeframe**; over forty were identified in the study. Without question, some of these technologies will not be broadly implemented for various reasons, while others that have not been included are likely to appear at some point over the fifteen year horizon. Fifteen years is a long time to project future technical and economic viability of developing technology, especially given the proprietary nature of breakthrough technologies. For example, fuel cell vehicles are not expected to be significant in volume over the next fifteen years. In addition, both battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) are recognized as becoming commercially available, but with limited deployment due to battery technology. A "battery cost breakthrough" is necessary for BEVs to become practical; the NRC study does not anticipate this happening in the next fifteen years. PHEVs may actually become commercially viable, but battery technology is expected to be the limiting technology restricting their range. Examples of individual technologies that were looked at but dismissed because of questionable cost and benefit include exhaust-gas recirculation,[10] homogenous charge compression ignition[11] and thermoelectric heat cost recovery.[12] These technologies (and others) may be in limited use today, but their importance, technical challenges or economic viability (cost-benefit) were seen as constraints to them becoming mainstream. The study was not designed to forecast unknown technologies yet to be conceived, or very early in development to assess technically or economically.

Retail Price Equivalent (RPE)
The NRC study chose to provide cost estimates for RPE because it was recognized as the most appropriate cost measure for long-run increases in the retail price paid by consumers. (*See Chapter 3 of the NRC study for a more complete explanation of RPE. The NRC report also points out that NHTSA has used the RPE method in the past for rulemaking involving model year 2011 light-duty vehicles demonstrating a level of acceptability*.) Incremental RPE represents the full, long-run economic cost of increasing fuel economy. Incremental RPE represents the average additional price that consumers will pay for a technology option implemented in a typical vehicle under average economic conditions and typical manufacturing practices. The RPE is marked-up from cost estimates and assumes competitive market conditions and comparable vehicle performance.

An important assumption made by the NRC study committee in estimating the incremental RPE for modifying a technology was that the equivalent vehicle size and performance were approximately maintained.

After significant review, the NRC committee agreed to use an average RPE mark-up factor of 1.5 times the fully manufactured component cost (the price that a Tier 1 supplier would charge the auto manufacturer) to estimate the total cost of doing business (including profit). The uncertainty around novel technologies prohibits the use of more specific factors by type of technology, except where

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[10] National Research Council of the National Academies, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, *Assessment for Fuel Economy Technologies for Light-Duty Vehicles*, Washington D.C.: The National Academies Press, June 2011, p. 50.
[11] Ibid., p. 142-5.
[12] Ibid., p 104.

indicated in the report. For example, a multiplier of 1.33 was used for hybrid technologies. This lower mark-up is used to adjust for engineering and development costs already included in the hybrid cost estimates.

Modeling Pathways

The NRC committee developed a range of technology pathways to estimate the cost and effectiveness of reasonable technology scenarios that "package" several technologies. Identifying specific technology pathways in practice would be highly dependent on a specific company's objectives and constraints. A method was employed whereby cost-effectiveness (fuel consumption reduction divided by incremental RPE), intended vehicle use, powertrain configuration and technology availability were considered.   Full System Simulation (FSS) was used to estimate the reduction in fuel consumption for the spark-ignited and compression-ignited pathways. FSS was chosen because it more accurately accounts for the interactive fuel-consumption effects of different technologies. Figure 3 illustrates the sequential decision process used by the NRC study for the base case in each of the three powertrain paths: SI, CI and HEV.[13] The estimated improvements in fuel economy, incremental RPE costs and technology pathways used by CAR are based on this NRC analysis.

Figure 3: Technology Paths and Results for Intermediate & Large Car and Unit-body Trucks.   Midsize Car Baseline Vehicle: 2007, V6, Double Overhead Camshaft, Intake Camshaft Phasing, Four-speed Automatic Transmission

SI Path	**Diesel Path**	**Hybrid Path**
Low Friction Lubricants (LUB)	Low Friction Lubricants (LUB)	Low Friction Lubricants (LUB)
Low Rolling Resistance Tires (ROLL)	Low Rolling Resistance Tires (ROLL)	Low Rolling Resistance Tires (ROLL)
Aerodynamic Drag Reduction (AERO)	Aerodynamic Drag Reduction (AERO)	Aerodynamic Drag Reduction (AERO)
Dual Clutch Trans (DCT)	Dual Clutch Trans (DCT)	Dual Cam Phasing (DCP)
Dual Cam Phasing (DCP)	Electric Power Steering (EPS)	*Electric Power Steering (EPS)
Stoichiometric GDI (SGDI)	*Mass Reduction 2% (MR2)	*Mass Reduction 2% (MR2)
Turbocharging and Downsizing (TRBDS)	Improved Accessories (IACC)	*Improved Accessories (IACC)
Electric Power Steering (EPS)	Mass Reduction 5% (MR5)	Mass Reduction 5% (MR5)
Engine Friction Reduction (EFR)	Conversion to Diesel (DSL)	*Higher Voltage/Improved Alternator (HVIA)
Continuously VVL (CVVL)	**Advanced Diesel (ADSL)	*12V BAS MHEV
*Mass Reduction 2% (MR2)	Total Fuel Consumption Reduction: 37.5%±10.7 Total Cost: $5,905±571	*Integrated Starter Generator (ISG)
Improved Accessories (IACC)		*Power Split Hybrid (PSHEV)
Mass Reduction 5% (MR5)		**Plug-in Hybrid (PHEV)
Total Fuel Consumption Reduction: 29.0%±2.8 Total Cost: $2,159±416		Total Fuel Consumption Reduction: 43.9%±15.6 Total Cost: $6,027±1,039

Note: * Item replaced by subsequent technology. ** Not included in total

CAR further extended these three baseline pathways from the NRC study with additional pathway options that included more aggressive reductions in vehicle mass. These scenario options were added

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[13] Figure 3 reprinted from NRC study, p. 146.

because of the emphasis given to this technology in the recent technology assessment report (TAR), "Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025," (September 2010, EPA, NHTSA and CARB). In the TAR, mass reduction in the order of 1/3 (33 percent) is suggested as a viable strategy. These more aggressive pathways were **not** explicitly modeled by the NRC, but both cost and effectiveness estimates from the NRC report were applied to the modeled scenarios. This resulted in three mass-extended pathways with additional cost and fuel consumption reduction levels as described below.

Extended Mass Reduction (15% Mass Reduction with Compounding)
CAR introduces three additional pathways that are identical to the three original NRC pathways, with more aggressive mass reduction – 15% instead of 5%. To adjust for the cost and reduction in fuel consumption, CAR subtracted the NRC estimates for 5% mass reduction, then added in the adjustments for 15% mass reduction. (The estimated impact of mass reduction on fuel consumption provided in the NRC study assumes a resized engine, so this compounding effect reflects a "long-term" solution where the total vehicle is re-optimized around the lower mass.) The mid-size baseline vehicle was modeled with a baseline mass of 3,625 pounds. The following cost and effectiveness estimates are drawn from the NRC study on mass reduction.[14] The mass reduction impact on fuel economy relied on two studies: Ricardo (reference: "Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicles Architectures," Prepared for The Aluminum Association, Inc., by Anrico Cassadei and Richard Broda, December 20, 2007), and Pagerit and Sharer ("Fuel Economy Sensitivity to Vehicle Mass for Advanced Vehicle Powertrains," 2006, SAE Paper 2006-01-0665.)

1. Subtract the Impact for 5% Mass Reduction
    a. Total mass reduced = 5% x 3625 pounds = 181 pounds
        Cost for 3.8% mass reduction = $226 (3.8% is netted for 30% mass compounding)
    b. Reduction in fuel consumption (5% total mass reduction) = 3.25%

2. Add the NRC Impact for 15% Mass Reduction
    a. Total mass reduced = 15% X 1.3 (to include mass compounding) = 707 pounds
        Cost to reduce 544 pounds of mass = $1156 ($2.125 x 544 = $1156)
    b. Reduction in Fuel Consumption (19.5% total mass reduction) = 11.7%

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[14] Ibid., Table 7-11, p. 115.

3. To calculate the Spark-Ignited with Extended Mass Reduction, the following adjustments are made to the Spark-Ignited with 5% Mass Reduction:

	Reduction in Fuel Consumption	Incremental RPE
Spark-Ignited With 5% Mass Reduction (from NRC)	29.0%	$2,159
Subtract out 5% mass reduction	-3.25%	($226)
Add 15% mass reduction (19.5% total mass reduction)	11.70%	$1,156
NET TOTAL	37.5%	$3,089

Similar calculations were performed for the compression-ignited (CI) and hybrid (HEV) pathways, which are summarized in the table below.

Table 1: Spark-Ignited, Compression-Ignited and Hybrid Pathways

Pathway:	Spark-Ignited Extended Mass Reduction (SI-E)	Compression-Ignited Extended Mass Reduction (CI-E)	Hybrid Extended Mass Reduction (HEV-E)
Technologies	Same as Spark-Ignited pathway, except 15% mass reduction (net 19.5% mass reduction after compounding)	Same as Compression-Ignited pathway, except 15% mass reduction (net 19.5% mass reduction after compounding)	Same as Hybrid pathway, except 15% mass reduction (net 19.5% mass reduction after compounding)
2008 Incremental RPE	$3,089	$6,835	$6,957
Reduction in Fuel Consumption	37.5%	46.0%	52.4%

Spark-Ignited Extended Mass Reduction with Stop/Start (SI-E-SS)

A third spark-ignited scenario is also introduced to be the most aggressive SI pathway for reducing fuel consumption. The spark-ignited extended mass reduction pathway was extended by adding stop/start capability. This pathway was not modeled by the NRC, but cost and effectiveness estimates were applied using results from the NRC study.[15] The modification to the spark-ignited extended mass reduction pathway by adding stop/start was to increase cost by an average of $885; fuel consumption would be further reduced by an additional 2.5%.

Plug-in Hybrid with Mass Reduction (PHEV)

The plug-in electric vehicle (PHEV) is an extension of the hybrid-electric vehicle. The key difference is the additional energy storage capacity (batteries) and changes in the electronic controls. The NRC study

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[15] Ibid., p. 95.

did not model this technology package explicitly, but the study does provide a cost estimate for a plug-in hybrid with lithium-ion battery capacity capable of a 40-mile electric range. This series hybrid was given an estimated 2009 incremental RPE (over the baseline vehicle) of $13,000.[16] CAR modified these estimates with an additional 15 percent mass reduction (19.5 percent with compounding), thus increasing the RPE by an additional $1,156 ($14,156 total RPE) using the earlier extended mass reduction estimates. The increase in fuel economy is estimated to be 250 percent (this increase will be explained in the next section of this report).

Battery Electric Vehicle with Mass Reduction (BEV)

The NRC report does not provide electric vehicle cost estimates. The study indicates that full electric vehicle technology is not expected to be commercially viable by 2025 and, therefore, does not fall within the scope of the study.

CAR used electric vehicle cost estimates provided in the recent TAR projected for 2025. These costs are then combined with the NRC cost estimate for reducing mass by 10 percent. As mentioned in both the NRC study and the TAR, there is a great degree of uncertainty in estimating future battery costs for 2025. The TAR indicates[17] the agencies recognize that costs reported by stakeholders range from $300/kWh to $400/kWh, while estimates from the Argonne National Laboratory cost model are lower. For the purpose of this study, CAR used $300/kWh. The cost estimates for these technologies are projected for the year 2025 but expressed in 2008 dollars. These are itemized below:

BEV Technology	Estimate	Source
Electric vehicle power train and controls	$1,946	TAR
Battery cost (27 kwh/$300 per kwh)	$8,100	TAR
10 percent Mass reduction	$538	NRC /CAR
(13 percent total with compounding)		
NET TOTAL	$10,584	

Cost Reduction (Learning Curve and Economies-of-Scale)

The initial estimates for incremental RPE were developed for 2008 (unless otherwise indicated). In the case of new technologies, the RPE represents costs **after** the initial period of accelerated cost reduction (after the "substantially learned" phase) that result from learning-by-doing (learning curve) of a new product and process. Additional low levels of learning-by-doing may be possible over subsequent years that further reduce the RPE estimates; however the NRC study indicates that, it is not appropriate to employ traditional learning curves to predict future reductions in cost as production experience

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[16] Ibid., p. 94.

[17] Interim Joint Technical Assessment Report (TAR), National Highway Traffic Safety Administration, U.S. Environmental Protection Agency, *2017 and Later Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: Supplemental Notice of Intent,* Washington D.C.: 75 FR 76337, December 8, 2010; National Highway Traffic Safety Administration, U.S. Environmental Protection Agency, *Notice of Upcoming Joint Rulemaking to Establish 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards,* Washington D.C.: 75 FR 62739, October 13, 2010; U.S. EPA Office of Transportation and Air Quality, National Highway Safety Traffic Administration Office of International Policy, Fuel Economy, and Consumer Programs, California Air Resources Board, and California E.P.A., *Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025,* Washington D.C.: U.S. EPA, September 2010.

increases.[18] In some cases, for a novel technology, there may be cost reductions from learning curve or economies-of-scale factors. Additional efficiencies gained in batter performance may be applied to extending battery life and vehicle range. The following learning curve/economies-of-scale assumptions were made specifically by CAR for this study:

- Since the cost estimates are provided after the initial "substantially-learned" phase of new product introduction (and after the initial investment hurdle and development risk), the duration of additional cost reduction is limited to five years of continuous cost reductions.
- The following annual cost reductions are provided based on the "newness" of various technologies being made at scale volumes for automotive applications:
  - 3.0 percent/year - battery and control electronics (electronic control systems)
  - 1.0 percent/year - electrical machines (motor, generator, gears, electrical accessories)
  - 0.5 percent/year - mature but still developing technologies (mass reduction materials)
  - 0.0 percent - established components (engine, alternator, automatic transmission, starter)
- Based on the relative mix of the technology pathways, a weighted combination of these cost reductions was developed for each pathway scenario. These annual cost reduction estimates are shown in Table 2 below in the column, "Annual % Cost Reduction (5 yr.)" and applied each year for five consecutive years, starting with the 2008 Total Estimated Incremental RPE. After five years, due to the long-range uncertainty, the RPE is assumed to be constant through 2025.

The summary of the nine technology pathways described above are in Table 2 below.

Table 2: Technology Pathways

Pathway	Source of Estimate	Technology Description	Reduction in Fuel Consumption	2008 Estimated Incremental RPE	Annual % Cost Reduction (5 yr)	2025 Total Incremental RPE
1) Spark-Ignited (SI)	NRC	DCT, GDI, Turbo & Downsize, 5% mass	29.0%	$2,159	0.5%	$2,105
2) SI Extended Mass (SI-E)	NRC/CAR	(Above plus:) 15% mass (10% addn. mass)	37.5%	$3,089	0.5%	$3,012
3) SI Extended Stop/Start (SI-E-SS)	NRC/CAR	(Above plus:) stop/start	40.0%	$3,974	0.6%	$3,855
4) Compression-Ignited (CI)	NRC	CI, DCT, 5% mass	37.5%	$5,905	0.5%	$5,757
5) Compression-Ignited Extended Mass (CI-E)	NRC/CAR	(Above with 15% mass (10% addn. mass)	46.0%	$6,835	0.5%	$6,664
6) Hybrid Electric (HEV)	NRC	Power Split, 5% Mass	43.9%	$6,027	2.2%	$5,364
7) Hybrid Electric - Extended Mass (HEV-E)	NRC/CAR	(Above with 15% mass (10% addn. mass)	52.4%	$6,957	1.9%	$6,296
8) Plug-in Hybrid Electric (PHEV)	NRC/CAR	Series PHEV 40, 15% mass (2009)	*	$14,156 (2009 est.)	2.1%	$12,670
9) Battery Electric Vehicle (BEV)	CAR/EPA/ NRC	BEV 75, 10% mass, 27kwh ($300/kwh in 2025)	*			$10,584

* Reduction of fuel consumption for PHEV and BEV is presented in the next section.

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[18] National Research Council of the National Academies, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, *Assessment for Fuel Economy Technologies for Light-Duty Vehicles*, Washington D.C.: The National Academies Press, June 2011, p. 25.

Four Scenarios for Higher Fuel Economy Mandates and the Per Vehicle Cost of these Scenarios

Scenario Description:

For comparison purposes, CAR researchers chose to use the four fuel economy scenarios developed by the EPA/NHTSA Technical Assessment Report for this analysis: 47, 51, 56 and 62 mpg. Each scenario was trended from the 2008 model year fuel economy ratings.[19] Each of the fuel economy scenarios represents a rate of CO_2 reductions, from 2017 to 2025. The rates of CO_2 reduction are 3, 4, 5 and 6 percent for fuel economy targets of 47, 51, 56 and 62 mpg respectively (Figure 4). Please note that while the EPA/NHTSA TAR evaluates the incremental cost of a vehicle from 2016 to 2025, this study will evaluate the incremental cost of a vehicle from 2008 to 2025.

Figure 4: United States CAFE Combined Passenger Car and Light Truck: Fleet Performance and Standards 1979-2025*
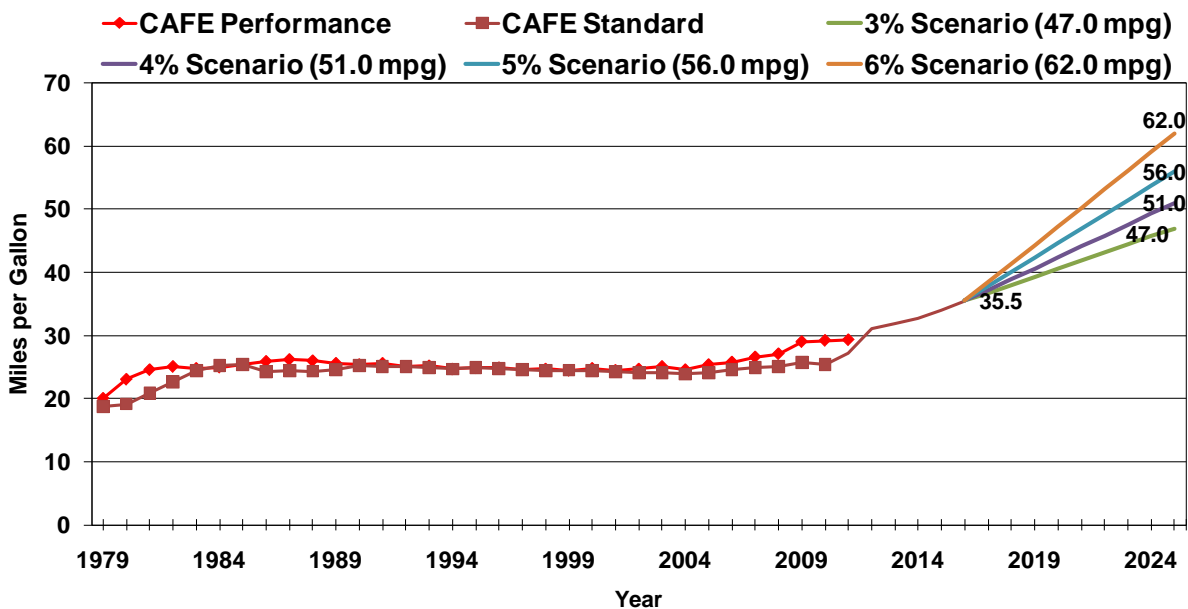
-*MY 2009, 2010, & 2011 reflect EPA's current estimates of CAFE performance.
-Light Truck (LT) standards 1979-1981 estimates based on standards set for 2WD & 4WD LT separately.
-MY 2011-2016 Reflect EPA/NHTSA estimated CAFE fleet averages based on the forecasted footprint of prospective sales models, and forecasted PC/LT Split. A.C. Credits included.

Source: NHTSA

As described earlier, the benefit associated with the technology pathways is calculated in terms of reductions in fuel consumption. However, the generally accepted method to determine fuel usage for automobiles in the United States is fuel economy. Therefore, for the segmentation analysis presented in this section, all reduction in fuel consumption values were converted to increases in fuel economy. The

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[19] The EPA initially reported a preliminary estimate of 31.4 MPG for the 2008 new passenger car fleet, and 23.6 MPG for the 2008 new light truck fleet, resulting in a non-weighted average of 27.5. These numbers have since been revised to 31.5 and 23.6 MPG for the new car and light truck fleets respectively, but the preliminary estimates and their non-weighted average of 27.5 were used for this paper.

conversion to fuel economy is simply the inverse of fuel consumption. The converted values for each of the technology pathways are shown in Table 3.

Table 3: Conversion From Reduction in Fuel Consumption to Increase in Fuel Economy

Pathway	Reduction in Fuel Consumption	Increase in Fuel Economy
Spark-Ignited (SI)	29.0%	40.8%
SI Extended Mass (SI-E)	37.5%	59.9%
SI Extended Stop/Start (SI-E-SS)	40.0%	66.5%
Compression-Ignited (CI)	37.5%	60.0%
CI Extended Mass (CI-E)	46.0%	85.0%
Hybrid Electric (HEV)	43.9%	78.3%
Hybrid Electric - Extended Mass (HEV-E)	52.4%	109.9%
Plug-in Hybrid Electric (PHEV)		*
Battery Electric Vehicle (BEV)		*

$$Increase\ in\ Fuel\ Economy = \left(\frac{1}{1 - Reduction\ in\ Fuel\ Consumption}\right) - 1$$

* A proxy is used to account for the impact of PHEV and BEV on fuel economy. This is explained later in the text.

For each of the scenarios, constraints were built into the model to prevent a trivial optimization from occurring. Absent any market constraints, a market share split between BEVs and conventional SI engines would occur as the split results in the highest fuel economy improvement at the lowest average cost. However, there are other factors that may prevent such a scenario from coming to fruition. The constraints built into the model are based on projected market shares for vehicles in the year 2020.[20] When the projected market share was no longer able to achieve the desired fuel economy targets, the constraints associated with hybrids and PHEVs were made less restrictive as they are seen as the most likely alternatives to increase overall fuel economy. "For example, increasing to a standard of 51 mpg from 47 mpg is not possible with the constraints applied at the 47 mpg. Therefore, the allowable PHEV and HEV market share at the 51 mpg standard was increased to 22.5 percent to achieve the required average fuel economy." Table 4 provides an overview of the market share constraints utilized for this study.

**Table 4: Technology Package Constraints Utilized for Development of Scenario Cost Models
(Percent Market Share)**

Powertrain	47 mpg	51 mpg	56 mpg	62 mpg
HEV + PHEV	<= 9.5%	<= 22.5%	<= 55%	<= 65%
PHEV	1.1%	unconstrained		
SI	<= 81.5%			
CI	<=8.1%			
BEV	<= 0.9%			

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[20] A.T. Kearney, *Auto 2020: Passenger Cars Expert Perspective*, January 2009; Credit Suisse, *Global Trends: The Choice Between Hybrid and Electric Cars,* July 2010; J.D. Power and Associates, *Drive Green 2020: More Hope than Reality,* November 2010; Roland Berger, *Powertrain 2020: Li-Ion Batteries- The Next Bubble Ahead?* February 2010.

The next step was to determine the most cost-effective technology mix to meet each standard. Using the technology pathways and costs described in the previous section, CAR researchers estimated the best, (i.e., least cost) technology mix for each scenario. Using these share forecasts, each technology's percent contribution to the fuel efficiency target and weighted cost of implementation was calculated. The combined weighted cost of implementing each of these technologies provides an average per vehicle cost estimate for obtaining the higher mile per gallon requirement in each scenario.

The four fuel economy scenarios present a 70.9, 85.5, 103.6 and 125.5 percent increases respectively, over the 2008 actual fleet average of 27.5 mpg. It is likely the advanced spark-ignited technology pathway will be used—perhaps even required—to meet the 2016 standards. Therefore, the fuel efficiency gains beyond 2016 will be calculated assuming the pervasive use of advanced spark-ignited (SI) technology has already been adopted. Another important assumption underlying CAR's analysis is that the fleet segmentation mix would remain constant. That is, for this analysis, it is assumed that vehicle downsizing is not contributing to the fuel efficiency gains.

The fuel economy measures used for PEVs (both PHEV and BEV) is possibly the most important variable in developing a technology mix for each scenario. Currently NHTSA uses the "Petroleum Equivalency" factor for electric vehicles when calculating their comparable mpg. Their example shows a pure BEV achieving a 360 mpg CAFE rating.[21] That would be roughly 10 times greater than a small car with a base SI engine, achieving about 35 mpg. Therefore, it is reasonable to say that BEVs are improved ten times over base spark-ignited engines.

However, the EPA measures GHG, not fuel economy. EPA has stated they have the legal power to, and likely will, include upstream GHG in vehicle emissions. Upstream emissions include GHG created in the production of electricity or gas. The example given by the EPA is that the electricity used to power a midsize BEV equates to about 180 grams of GHG/mile. The gasoline for a similar sized SI powered vehicle equates to about 60 g/m in upstream emissions. For reference, the EPA's target for 2012 is 295 g/mile combined. Combining the EPA 2012 target of 295 g/m, with the 60 g/m upstream emissions for gasoline, an SI vehicle will account for approximately 355g/m. Comparatively, a BEV will have 0g/m during use and 180 g/m upstream, for a total of 180 g/m or about 2 times the improvement over the current SI vehicle.[22]

Using current NHTSA and EPA policy as a benchmark, and adjusting for future incorporation of upstream GHGs, CAR researchers chose to place the fuel economy proxy for BEVs at 6 times the SI equivalent to a 500 percent increase in fuel economy of the baseline vehicle. This estimate will clearly have a significant impact on the final technology mix for each scenario. However, given the information available and discussions with numerous stakeholders, there is considerable uncertainty regarding how BEVs may be accounted for in the ruling. Further, it is clear that state-based CO2 regulation may influence the final national standards; this threat may lead to a compromise between the two endpoints. CAR researchers

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[21] Federal Register, "Building Blocks of the National Program," vol. 73, no. 88 (May 7, 2010): p. 25437.

[22] Ibid., 25434-25436.

believe the value to be a reasonable estimate; although through the vagaries of regulation development, final rulings may differ significantly from this estimate.

The fuel economy proxy for plug-in hybrid electric vehicles is derived from data presented by Toyota.[23] As estimate is made based on average consumer driving distance and the corresponding savings in fuel consumption (converted to fuel economy) that would be experienced with a PHEV. CAR researchers chose to place the fuel economy proxy for PHEV at 2.5 times the SI equivalent (a 150 percent increase in the baseline SI fuel economy).

The current rules include a complex set of allowances for manufacturers to use in fleet credits for PEVs. The credits, however, are limited and are set to expire in 2017. Therefore it is uncertain how, or if, regulation will be used to encourage vehicle manufacturers to offer PEVs. Without such encouragement, the expansive use of PEV faces many challenges.

In addition to questions concerning the treatment of BEVs and PHEVs, the implications of the changing methodology in CAFE calculations raises questions as well. The 2012-2016 CAFE standards will be based on vehicle footprint. Historically, CAFE was based on the weighted average fuel economy of a company's fleet, both passenger cars and light trucks. In order to increase their overall fuel economy to meet CAFE standards, manufacturers often sold smaller cars at a lower profit margin or even a loss. Increased sales of smaller more fuel-efficient vehicles allowed manufacturers to sell larger more desirable and more profitable cars, while still meeting CAFE. Under the new footprint-based regulation, this strategy becomes less viable. Although there has been great effort invested in the development of the footprint model, it is uncertain how this new methodology will affect the resulting technology mix. Unintended consequences are inevitable, and often unpredictable.

For example, it is reasonable to assume that the footprint standard may lead PEV technology to be applied to a broad range of segments. This may create the unintended consequences of limiting scale economies, and encouraging—even forcing—companies to apply PEV technology into larger vehicles. The latter may be troublesome given that many powertrain experts agree PEV technology (especially BEVs) is not ideal for larger vehicles. The former may raise costs by forcing manufacturers to develop technology sets for several vehicle platforms, each with limited volumes, thus negating the opportunity to achieve scale economies.

Because calculating CAFE standards based on vehicle footprint reduces the incentive for firms to subsidize the sale of larger vehicles through increased sales of smaller vehicles, the impact on the vehicle segment mix may be quite minimal. By basing each company's CAFE mandate according to the footprint of the vehicles it sells, NHTSA and the EPA sought to have the regulation be impartial to size. Firms that sell predominantly smaller footprint vehicles will face a comparable proportionate increase in their overall fuel economy, as will firms that sell primarily larger footprint vehicles.

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[23] Ward, Justin. "Pathway to Sustainable Mobility: Role of Plug-In Hybrid Vehicles", Management Briefing Seminars 2010, Traverse City, MI, August 3, 2010. Unpublished presentation.

Whether or not the regulation will be successful in minimizing its impact on the vehicle segment mix is a difficult question. Altering the segment mix (either smaller or larger) would affect overall fuel economy standards and would also represent a shift in value to the consumer. Given the change in incentives and the intent of the regulation, CAR estimates are based on maintaining the current product mix. This, too, may ultimately prove to be an inaccurate expectation.

Another policy-based estimate to consider is the prospective handling of alternative fuels under future CAFE standards. Again, guidance from the regulatory agencies has been unclear regarding how alternative fuels will be accounted for beyond 2016.[24] It is reasonable to expect some expanded use of ethanol (E85), and biodiesels by 2025. Yet, NHTSA and the EPA have made it clear that they will be less willing to give manufacturers fuel economy credits for producing vehicles capable of running on alternative fuels, unless it can be shown that consumers will actually use the alternative fuel. Limited availability, in addition to cost concerns, suggests that alternative fuels will continue to have low levels of utilization by consumers of alternative fuel-capable vehicles.

Concomitantly, it is likely that use of compressed natural gas (CNG) will increase in some applications. Limitations on availability and cost concerns may restrict its implementation to corporate fleets and other niche uses. Similarly, hydrogen-powered fuel cells may see initial market penetration within this time period. However, given the substantial infrastructure requirements, hydrogen is not likely to be a mainstream fuel in the next fifteen years. Each of these alternative fuels will play a role in increasing fuel economy, although that role is difficult to assess and will likely be negligible.

The estimates presented are based on maintaining a current product mix. Altering the mix (smaller or larger) would affect fuel economy performance. It would also represent a shift in value to the consumer. A case can be made that the higher fuel efficiency targets can be achieved using an advanced SI engine (with reduced horsepower), considerable lightweighting and downsizing. However, it is unlikely a consumer would consider a lightweight subcompact with a 100 horsepower engine similar to a midsized sedan with 250 horsepower.

The intent of the 2017 to 2025 ruling is to have a compatible target for both fuel economy and CO_2 emissions. However, certain credits applied by the EPA for improvements in air conditioning systems do not directly result in a fuel economy savings, resulting in a discrepancy between CO_2 emission and fuel economy requirements. To address the discrepancy between the two measures, the CAFE requirement may be reduced to match the required CO_2 emissions plus the air conditioning credit.[25] The resultant CAFE requirement with a built in air conditioning credit would be 43.5, 46.9, 51.1, and 56 mpg. Essentially the required rate of CO_2 reductions would be decreased by one percent for each scenario. It should be noted that the EPA/NHTSA Technical Assessment Report bases all of its analysis in terms of market share and cost with an associated air conditioning credit included. It is unclear whether such a

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[24] Federal Register, "Building Blocks of the National Program," vol. 73, no. 88 (May 7, 2010): p. 25434.

[25] U.S. EPA Office of Transportation and Air Quality, National Highway Safety Traffic Administration Office of International Policy, Fuel Economy, and Consumer Programs, California Air Resources Board, and California EPA, *Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025,* Washington D.C.: U.S. EPA, September 2010, p.F-3.

credit will be made available to the automakers at the final ruling.[26] An analysis of the vehicle market based on the modified CAFE requirement derived by air conditioning credits is provided in Appendix I.

Finally, this study relies on a basic analysis of corporate average fuel economy. A more rigorous evaluation may bring slightly different results (either higher or lower costs), but would not likely alter the findings in a significant way.

Figure 5: 2025 Market Penetration-Scenario I
(47 mpg CAFE standard)
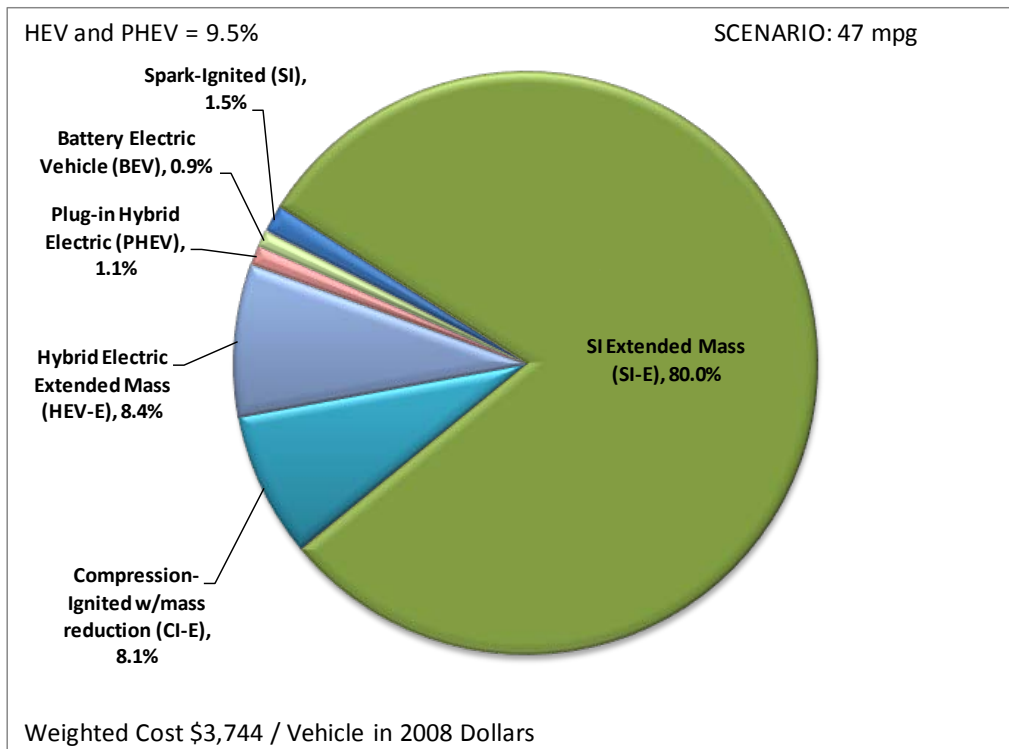
Source: CAR Estimates

Scenario I: (Figure 5) 47 mpg (3 Percent Decrease in CO2): The base case assumes a moderate increase over the 2016 requirements. The 47 mpg target is equivalent to a 70.9 percent increase from the 2008 actual fleet mpg. The estimated cost of achieving the target is $3,744. (This figure is determined by multiplying the percent distribution of each scenario in Figure 4 with its corresponding cost in Table 2). The relative cost increase, compared to the estimated cost of achieving the 2016 mandate, is due in great part to mass reduction strategies. Additional increases in cost are the result of an increased market share of HEVs driven by constraints in the model. The base case assumes the extended mass reduction will be implemented across almost all new vehicles sold.

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[26] U.S. EPA Office of Transportation and Air Quality, National Highway Safety Traffic Administration Office of International Policy, Fuel Economy, and Consumer Programs, California Air Resources Board, and California EPA., *Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025,* Washington D.C.: U.S. EPA, September 2010, p. 6-7.

There is a limited amount of electrification in the 47 mpg scenario. The majority of the fuel economy gains can be realized through the mass reduction of SI and diesel engine vehicles. Given the impact mass reduction has at the lowest fuel economy target for a relatively low cost, it is likely that automakers will take full advantage of mass reduction opportunities in the 2017 to 2025 time frame.

The scenario also forecasts that 8 percent of new vehicles sold will have diesels engines. This high (vis-a-vis current) penetration rate is due to the relative availability of diesel technology outside the U.S. market, enabling companies to bring the technology to market at a minimal developmental cost. However, the implementation of diesel technology is subject to regulation uncertainty. Increased emission standards will likely have an adverse affect on the cost viability of diesels. Finally, this scenario includes 9.5 percent HEV (PHEV and HEV) market penetration and 2 percent PEV (PHEV and BEV) market penetration.

Figure 6: 2025 Market Penetration-Scenario II
(51 mpg CAFE standard)
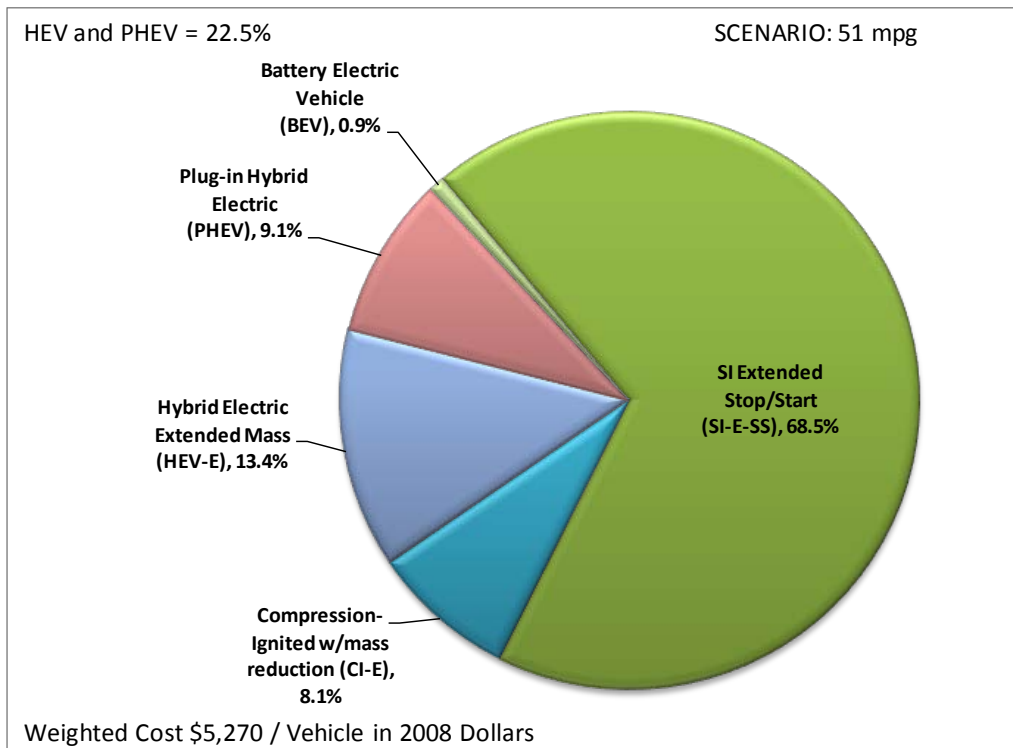
Source: CAR Estimates

Scenario II (Figure 6): 51 mpg—(4 Percent Decrease in CO2): The 51 mpg case assumes fuel economy standards using a 4 percent CO2 reduction rate. The case includes a dramatic shift toward stop/start technology and a concurrent per vehicle cost increase of $5,270. As noted above, without downsizing, it may be difficult for the spark-ignited engine to meet the 51 mpg standards. Therefore, if vehicle size is held constant, the electrification of the powertrain will be critical to meeting the 51 mpg case targets. As lightweighting measures and traditional means of increasing fuel spark-ignited engine fuel economy reach their limit, electrification will be required to meet higher standards.

Forecasting a 10 percent market share for PEVs by 2025 is, in many ways, an extremely aggressive target. However, within the bounds of the technology constraints defined earlier in this report, it appears that electrification will be necessary to meet the standards. An alternative scenario without PEVs, would push the total HEV market share upwards of 40 percent while reducing the amount of stop/start vehicles.

Numerous spark-ignited engine technologies have been proposed as potentially viable in the coming fifteen years. For example, homogeneous charge compression ignition—or even compression ignition for gasoline–and increased use of EGR technology strategies, offer an opportunity for increased fuel efficiency. However, some combination of massive (and costly) weight reduction, performance reduction and downsizing would likely be required for internal combustion engines to meet the higher standards.

Finally, stop/start technology will take a prominent role in the 51 mpg scenario. This is due, in part, to achieve higher fuel efficiency than advanced SI and mass reduction may offer. Because the full efficiency value of stop/start technology may not be captured by the current test cycle, it is possible that manufacturers would attempt to focus on HEV technology as the solution—with associated reductions in development expenditures for other technologies.

Figure 7: 2025 Market Penetration-Scenario III
(56 mpg CAFE standard)

Source: CAR Estimates
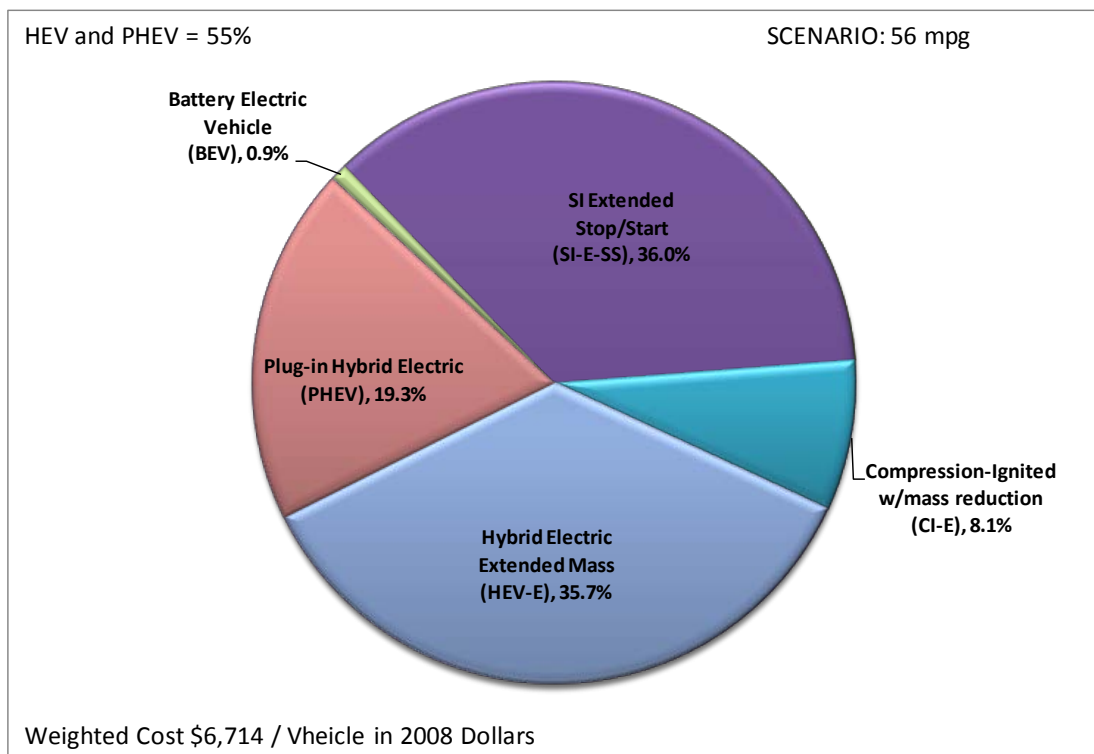
Scenario III (Figure 7): 56 mpg (5 Percent Decrease in CO2): The 56 mpg case assumes a 5 percent reduction per year of CO2 emission. Meeting this standard would increase the average cost of a vehicle

by $6,714. A significant increase in PHEV and HEV vehicles would come at the expense of stop/start vehicles.

This model requires a 20 percent PEV market share to meet the standards—drastic by any measure. It also includes 35 percent HEV penetration. In fact, this model only includes 8 percent non-electrified technology, entirely comprised of diesel engines. An alternative to this scenario (assuming no PEV market penetration) would require over 80 percent HEV market share–also drastic by today's predictions. To achieve a CAFE target of 56 mpg, the estimated market penetration by each technology would exceed most expectations of a 2025 market and would require a significant advancement in battery manufacturing technology beyond what is known today.

Figure 8: 2025 Market Penetration-Scenario IV
(62 mpg CAFE standard)
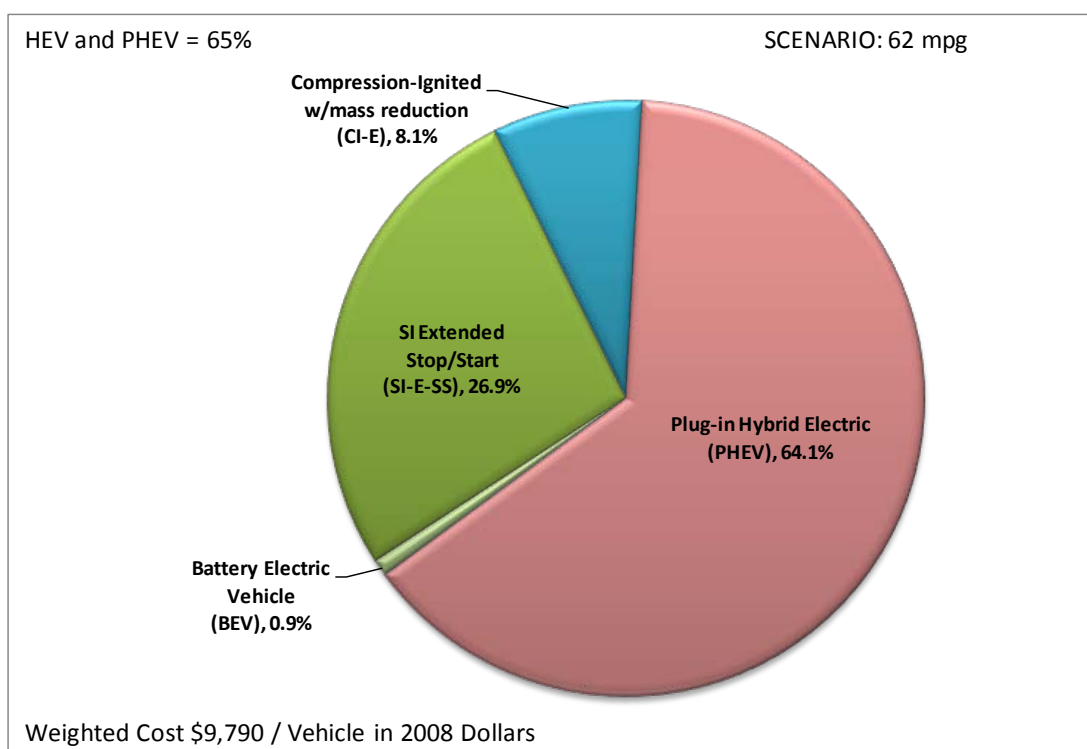
Source: CAR Estimates

Scenario IV (Figure 8): 62 mpg (6 Percent Decrease in CO2): The 62 mpg case assumes standards at the high-end of that currently being considered by the U.S. government. Meeting this standard would increase the average cost of a vehicle by $9,790. The two higher scenarios, 56 and 62 mpg, are reliant on both significant cost reductions in battery technology enabling higher penetration rates and radically higher gasoline prices. These changes are exogenous and extremely difficult to predict. There is a significant probability that they will not occur to the degree necessary to make achieving the mpg targets economically viable.

To achieve 62 mpg, a net increase of 225% in fuel economy over the 2008 baseline vehicle is required. In the model provided, there are only two technologies capable of achieving such an improvement:

PHEVs and BEVs. A 62 mpg target will result in a 65 percent market share of PEV vehicles at the expense of HEVs and stop/start technology. Even if constraints to the model were relaxed to allow for an HEV and PHEV market penetration of 90 percent, the PHEV market penetration would need to achieve levels exceeding 30 percent. To achieve 62 mpg, a high percentage of BEV and PHEV vehicles would be required to meet the targeted fuel economy.

It becomes evident that a considerable burden will be placed on advanced technology to achieve the required fuel economy level. As further proof, the EPA/NHTSA Technical Assessment Report estimates that the average passenger car would need to range between 68.3 to 77.4 mpg CAFE (or 54.6 to 62 mpg real world) to offset the lower fuel economy of the truck market (depending on the technology path chosen). The impact on the truck market is almost as dramatic with the electrification of light duty trucks ranging from 63 to 91 percent.[27] Whether looking at the results of this report or the EPA/NHTSA report, a 62 mpg target will require a significant shift from the type of vehicle people drive today.

The results for the four scenarios, shown in Appendix 1, are constrained by the cost and fuel efficiency improvements offered in the technology assessment. It is clear that, those constraints combined with holding the segment mix stable, present a costly and highly uncertain set of alternatives to meeting the higher standards.

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[27] U.S. EPA Office of Transportation and Air Quality, National Highway Safety Traffic Administration Office of International Policy, Fuel Economy, and Consumer Programs, California Air Resources Board, and California EPA, *Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025,* Washington D.C.: U.S. EPA, September 2010, p. 6-24.

Section III: The Economics of the U.S. Motor Vehicle Market and Industry in 2025

The Effect of Mandates on the Net Price for Motor Vehicles

This section forecasts the U.S. market for light vehicles, the U.S. production of such vehicles, and employment in the U.S. motor vehicle manufacturing industry in 2025. This forecast would be a relatively difficult task even without the likelihood of a massive regulatory intervention of EPA/NHTSA in the U.S. automotive product market. Since this intervention is very likely, it is necessary to estimate the economic effect of new federal mandates on the U.S. motor vehicle market and industry along with the effects of normal economic trend variables. Section II estimates the costs to the consumer of four fuel economy mandate scenarios. Higher vehicle costs result in higher vehicle prices, necessarily constricting demand if the consumer values the required technology at less than its cost. Higher fuel economy does reward the automotive consumer with at least one benefit: savings on the cost of fuel required to operate the motor vehicle. This value will be netted from the gross costs of the technologies in each pathway described in Section II to arrive at a net price result for each of CAR's pathways. The net price increase is then evaluated for its effect on demand for light motor vehicles in the 2025 U.S. market. The resulting change in vehicle sales will then be evaluated for its likely effect on U.S. motor vehicle production and employment in the U.S. motor vehicle manufacturing industry.

Price is the natural barrier to consumption. Motor vehicle regulations that require content have added to the cost and, thus, the price of a new motor vehicle for many years. It certainly can be argued that the negative effect on motor vehicle expenditures of such regulatory content can be modified for some safety features (airbags and seat belts) generally valued by consumers but this is certainly not the case for other safety features–and perhaps all emissions controls and other environmental features–over time. Content that reduces emissions, produces positive and non-exclusive externalities with a public value of little marginal consequence to the average consumer. As shown in Figure 9, the Bureau of Economic Analysis and the U.S. Census (BEA/U.S. Census) estimate an average expenditure of $23,186 for passenger cars sold in the U.S. market in 2009. About $4,724 of this price (20.4 percent) was estimated by the BEA/U.S. Census as the cost of required regulatory content for safety and emissions equipment. Only a portion of this content can be valued by the consumer and the rest clearly reduced consumer spending on new vehicles. Compared to required emissions technology, however, fuel economy technology does provide clear private benefits to consumers: fuel savings. The question is whether those potential savings will be equal to their cost.

Figure 9: Average Expenditure per New Car (1967-2009)
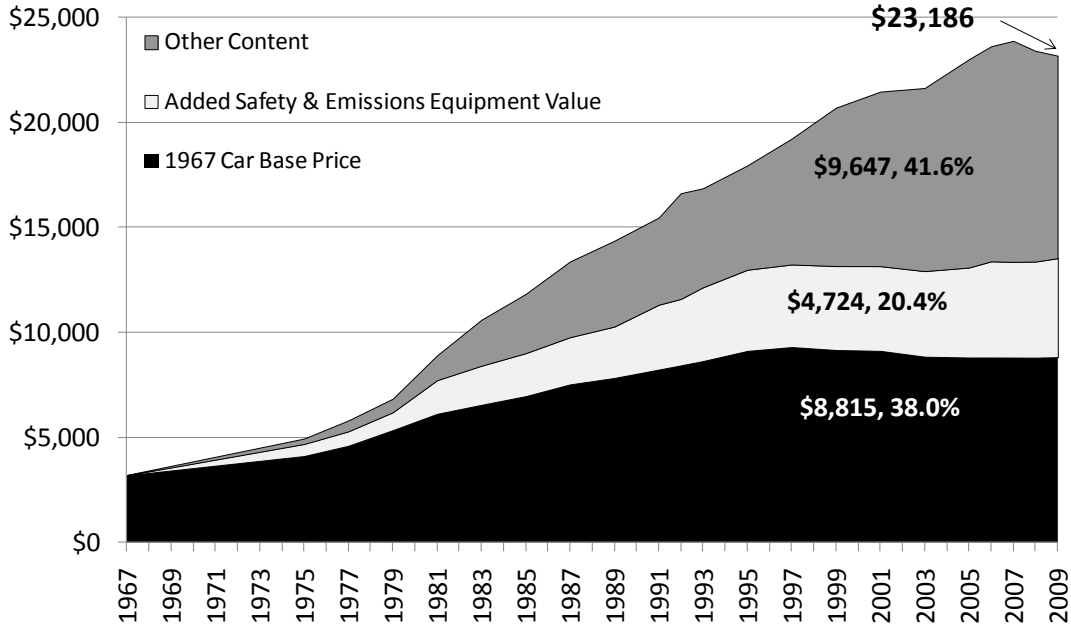
Source: Average Expenditure per New Car, Wards' Automotive Yearbook 2010, page 260.

In this section CAR will refer to fuel economy standards in terms of "real world fuel economy" performance or 80 percent of CAFE fleet standards. The following table shows the conversion from CAFE fleet standards to real world fuel economy performance levels. CAR makes this change in order to estimate real world fuel savings as a result of improved technology.

Table 5: Conversion of CAFE Fleet Standards to Real World Fuel Economy Performance Levels

	Scenario I	Scenario II	Scenario III	Scenario IV
Miles Per Gallon CAFE Fleet Standards	47.0	51.0	56.0	62.0
Miles Per Gallon "Real World Fuel Economy" Performance	37.6	40.8	44.8	49.6

Note: 2008 model year baseline CAFE Fleet assumed to be 27.5 mpg or a real world fuel economy performance level of 22.0 mpg.

A fairly simple formula, shown below, is used to calculate the economic value for vehicle buyers of higher fuel economy and safety mandates through 2025. CAR labels this construct as net price. A baseline 2009 price of $28,966 for new light vehicles supplied by the National Automobile Dealers Association (NADA) is used as the starting point in this calculation. The baseline or retail price is adjusted first by the four different scenarios or fuel economy technology manufacturing cost estimates shown in Equation 1 on the next page. These costs (in 2009 dollars) range from $3,744 (37.6 mpg), to $5,270 (40.8 mpg), to $6,714 (44.8 mpg) to $9,790 (49.6 mpg).

Equation 1: Formula for Net Price

Net Price (2009 $) =
Baseline Price ($28,966)
+ Fuel Economy Technology Manufacturing Cost (at RPE)
+ Cost of New Mandated Safety Equipment
+ Charging Equipment
+ PV of Electricity Usage Cost
− PV of Fuel Savings (at $3.50 and $6.00/gal. 2009 $)

CAR then includes the likely cost of additional safety mandates during 2010-2025, as well as the cost of additional environmental mandates such as increased recycling and the prohibition of many chemicals or materials in manufacturing deemed as "hazardous" by environmental authorities. CAR's Transportation Systems Analysis Group developed an estimate of such costs. A range of safety technologies was considered, most of them concentrated in the accident avoidance area. Costs in 2009 dollars are expected to range from $1,500 to $3,000 per unit. Table 6 was obtained from the Alliance of Automobile Manufacturers and contains a list of near-term anticipated safety actions by NHTSA through 2014 that were considered by CAR. Given the general unpredictability of forecasting regulatory change, it was decided to include only the lower boundary of $1,500 in the net price calculation. Other reasons to select the lower boundary of safety cost include some netting effect for the value of safety technologies to the average automotive consumer. Non-safety mandates, such as increased material recycling or chemical bans, should be assessed at minimal consumer value. Additional airbags face diminishing returns since current vehicles already contain multiple airbags. Collision avoidance systems are controversial; it is not yet clear how much value the consumer will assign to these technologies, if any.

CAR has purposely included the safety mandate cost with the fuel economy mandate cost. NHTSA is now in the position of regulating both safety and fuel efficiency characteristics of new vehicles. Yet there is no clear evidence the agency is accounting for the economic effects on the industry and the consumer market for their duel set of regulations. Both sets of future mandates will affect the same retail price for the vehicle. Extreme mandates in both areas of regulation will most certainly raise the price of future vehicles for American consumers. The combined effect may be to create such a barrier to vehicle replacement that consumers will resist by dramatically lengthening vehicle ownership. The result will be a failure of the CAFE system to actually improve fuel economy of the operating fleet and a similar failure of NHTSA to improve vehicle safety.

Table 6: Safety and Other Mandate Costs: 2025

SAFETY AND ENVIRONMENTAL REGULATORY CHANGES UNDER CONSIDERATION	
Issue Area	Anticipated Next Action
KT Safety Act Implementation	
Rearward Field of View	NPRM – Nov. 2010
Power Window Safety	Final Rule – Apr. 2011
Driver Distraction Plan – Voluntary Guidelines	
Visual-Manual – IEM Integrated Devices	Q3 – 2011
Visual-Manual – Portable Devices	Q3 – 2013
Voice Interfaces	Q1 – 2014
Crash Avoidance Technologies	
Forward Collision Warning (FCW)	Agency Decision – 2011
Lane Departure Warning (LDW)	Agency Decision – 2011
Blind Spot Detection (BSD)	Agency Decision – 2013
Vehicle Communications – V2V/V21	Agency Decision – 2013
Other	
Advanced Automatic Crash Notification (AACN)	Agency Decision – 2010
Compatibility	Agency Decision – 2010
Next Generation NCAP	Multiple Decisions - 2010~12
Pre-cash Airbag/Safety System Activation	Agency Decision – 2010
"Quieter" Cars	Agency Decision – 2010
Restraint Effectiveness in Rollover	Agency Decision – 2010
Ejection Mitigation	Final Rule – Jan. 2011
Oblique/Low-Offset Frontal Crash	Agency Decision – 2011
LATCH	Agency Decision – 2011
Seat Belt Reminder Systems	Agency Decision – 2011
Light Vehicle EDR Update	Agency Decision – 2012
Low Delta-V Restraint Protection	Agency Decision – 2012
Global Technical Regulations (GTRs)	
Pedestrian Protection	NPRM - 2010
Head Restraints – Phase 1	NPRM - 2010
Glazing	Final Rule – 2011
"Quieter" Cars	Draft Regulation – Feb. 2012
Head Restraints – Phase 2	Agency Decision – 2013

Source: Alliance of Automobile Manufacturers, Comments of the Alliance of Automobile Manufacturers On Notice of Intent for 2017 and Later Year Light Duty Vehicle GHG Emissions and CAFE and Interim Joint Technical Assessment Report, Docket ID Numbers: EPA-HQ-OAR-0799, NHTSA-2010-0131, October 29, 2010, page 9.

Total cost = $1,500 to $3,000 per vehicle depending on how much is "mandated."

Table 7: Total Additional Retail Price for CAFE and Mandated Safety: 2025

2025 MPG	CAFE 2025 Cost (at RPE)	Safety Cost (at RPE)	Total Additional Retail Price
37.6	$3,744	$1,500	$ 5,244
40.8	$5,270	$1,500	$6,770
44.8	$6,714	$1,500	$8,214
49.6	$9,790	$1,500	$11,290

1. 2025 mpg represents real world mpg, estimated at 80% of CAFE target
2. Charging equipment and installation cost for PHEV and EVs only at GM and Nissan estimated levels.
3. PHEV multiplier = 2.5; without A/C credit.

The initial effect on net price is shown above in Table 7. The safety and other non-fuel economy mandate cost is $1,500 for each fuel economy pathway. Totals range from $5,244 for 37.6 mpg to $11,290 for 49.6 mpg. These costs, evaluated at a retail price equivalent, will certainly be added to the price by auto manufacturers, by 2025.

Present Value of Fuel Economy Savings

Fuel economy, when compared to other attributes of a new vehicle, might be considered a classic inferior good in economic terms. To economists, an inferior good is a product or service whose demand falls when the income of consumers increases. This is almost certainly the case for fuel economy. Gasoline and other fuels, of course, are classic complementary goods with respect to motor vehicles in the consumer's demand for personal ground transportation. Consumer demand for motor vehicles and fuel is derived from the consumers' demand for personal ground transportation. A rise in the price of gasoline can depress demand for motor vehicles, and vice-versa. However, fuel economy must be seen technologically as a substitute for other vehicle attributes. In other words, consumers must sacrifice other attributes in the vehicle to obtain higher fuel economy. These attributes would include engine performance (acceleration and towing capacity), vehicle size and, possibly, safety. Luxury vehicles that sell to generally more affluent buyers command higher prices than non-luxury vehicles; luxury vehicles almost always possess lower fuel economy than non-luxury vehicles.[28] Light trucks possess lower fuel economy than cars–yet sell, in general, for higher prices. As the automotive consumer becomes more affluent, he/she usually substitutes power, performance, and interior space for fuel economy. This fact has been debated in numerous hedonic price studies of automotive consumer demand, for decades.[29]

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[28] *Model Year 2010 Fuel Economy Guide* (Washington D.C.: U.S. EPA. Office of Energy Efficiency and Renewable Energy, 2010); *Ward's Automotive Yearbook 2010* (Southfield, MI: Ward's Automotive Group, 2010), p224-228.

[29] S. Berry, S. Kortum and A. Pakes, " Environmental Change and Hedonic Cost Functions for Automobiles," *Proceedings of the National Academy of Sciences Online*, Vol. 93, No. 23, 1996: 12731-12738; J.N. Brown and S.R. Harvey. "On the Estimation of Structural Hedonic Price Models," *Econometrica*, Vol. 50, No. 3, May 1982: 765-768; M. Dreyfus and K. Viscusi, "Rates of Time

Higher fuel prices usually result in the consumer substituting fuel economy for these other attributes (or normal goods) that reduce fuel economy. Increasing personal income can offset the demand for fuel economy over time and has, in the case of the market for small cars in the United States in the last 40 years. The relative value of fuel economy to auto consumers can vary widely depending on income and can never exceed the savings in fuel costs themselves, except to the most environmentally concerned buyers.

Studies that forecast dramatic changes in fuel economy occurring without equally dramatic reductions in other attributes of the vehicle (including size, performance, and safety) are forecasting a change that has never before happened in the history of the automobile market and industry. To a certain extent, then, mandates for higher fuel economy are a form of progressive tax on auto consumers with higher incomes or on all consumers as incomes (in general) rise. However, the CAR study (like so many others) attempts to hold other attributes constant and merely investigate the net economic effect of the cost of higher fuel economy mandates on automotive sales.

The cost of fuel and oil is by far not the major expense of owning a vehicle. This is true even on an operating cost per mile basis. The American Automobile Association reported that, in 2010, gas and oil accounted for only 15.5 percent of car and 16.9 percent of truck operating costs per mile traveled for the average vehicle. The combined cost of finance and insurance ranged from 24.8 percent (car) and 20.6 percent (truck) of total operating costs, per mile traveled. More importantly, however, the cost of depreciation ranged from 44.6 percent (car) and 48.8 percent (truck) operating costs per mile traveled.[30] The total cost of travel for cars was $0.739 per mile, of which depreciation was 44.6 percent or $0.329 per mile. All vehicles, of course, wear out or depreciate. This is especially true for new vehicles whose initial market depreciation rates in the first few years of ownership are severe. Depreciation for vehicles in certain declining segments of the market, or for vehicles with unusual attributes or technologies not accepted by the market, can become even more severe than average and pose a considerable risk to new vehicle purchasers.

Typical new vehicle purchasers or first owners possess their vehicle for an average of six to seven years. The typical new vehicle loan length has, most recently, averaged 59 months; current leases range between two to four years. The length of new vehicle ownership for its original buyer is of great interest to this study. To estimate the present value of the future fuel savings a consumer would enjoy from increased fuel economy, it is necessary to know the probable length of ownership. CAR believes the first owner will value future fuel savings in a new vehicle for about five years. Even this length of time for fuel savings may be excessive given the unpredictability of fuel prices. To assign a value for fuel savings

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Preference and Consumer Valuations of Automobile Safety and Fuel Efficiency," *Journal of Law and Economics*, vol. 38, no. 1, 1995: 79-105; M. Espey and S. Nair, "Automobile Fuel Efficiency: What is it Worth?" *Contemporary Economic Policy*, Vol. 23, No. 3, 2005: 317-323; C. Fischer, W. Harrington, I.W.H. Parry, "Impacts of Tightening the Corporate Average Fuel Economy (CAFE) Standards," Resources for the Future, Washington, D.C., RFF DP 04-53, 2004; A.C. Goodman, "Willingness to Pay for Car Efficiency: A Hedonic Price Approach," *Journal of Transport Economics and Policy*, Vol. 17, No. 3 1983: 247-266; M. Ohta and Z. Griliches, "Automobile Prices and Quality: Did the Gasoline Price Increases Change Consumer Tastes in the U.S.?" *Journal of Business and Economic Statistics*, Vol. 4, No. 2, 1986: 187-198; K. Train and C. Winston, "Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers," *International Economic Review*, vol. 48, no. 4, 2007: 1469-1496.

[30] *Ward's Motor Vehicle Facts & Figures 2010*, "Car and Light Truck Operating Costs" (Southfield, MI: Ward's Automotive Group, 2010), p. 68, 69.

in the vehicle resale price (after the first period of ownership) is a chancy proposition, at best, for vehicles with dramatic new technologies. Vehicles that contain the new battery technologies may not even have a net resale value, given the potential for a short battery life of four to nine years. The expense of battery replacement beyond the warranty length of this component (current battery warranties are most probably subverted) may exceed the value of any future fuel savings.

Not everyone agrees with CAR's position that discounted fuel savings are valued by the new vehicle consumer for up to five years at the point of purchase. Several major automakers reviewing this study have protested this position. Economic and marketing research results obtained by these firms, indicates a much shorter period of two to two and one-half years as a more likely valuation period. Indeed, the economics literature on this subject seems to confirm the automakers' position, with implied discount rates for fuel savings of up to 48 percent. A number of consumer studies by automotive consulting firms have reinforced the importance of initial price as a barrier to consumers considering the purchase of vehicles with high fuel economy technologies, such as hybrids or electric cars.[31]

A real world fuel economy average of 22.0 mpg, or 80 percent, of the 2008 reported Corporate Average Fuel Economy (CAFE) level of 27.5 mpg was established as the base mpg value to determine the increase in fuel economy in each of CAR's four scenarios. As discussed above, CAR has modeled four prospective 2025 overall real world mpg scenarios: 37.6, 40.8, 44.8, and 49.6 mpg. Thus, depending on the scenario, consumers will enjoy an increase of 15.6, 18.8, 22.8, and 27.6 mpg in 2025, compared to a typical vehicle purchased in 2009 (model year 2008).

History has shown that increases in average fuel economy motivate the consumer to increase motor vehicle travel. This effect is allowed for in CAR's estimation of fuel savings from higher fuel economy technologies. CAR uses Vehicle Miles Traveled (VMT) estimates for new car buyers and calculates discounted fuel savings for a 5-year initial period of ownership to measure fuel savings.

VMT Estimation:
Data from the National Household Travel Survey (NHTS) are used to determine values for annual VMT in years 1-5 of vehicle ownership.[32] This was the same data source used by the National Center for Statistics and Analysis in 2006, to determine the typical mileage schedules for passenger cars and light trucks.[33] Mileage schedules were used to break down and distribute the expected total VMT of a typical vehicle over its entire duration of use. For each vehicle age, an annual VMT estimate is given. A new mileage schedule for a typical light vehicle needed to be constructed since the National Household Travel Survey was administered in 2008-2009. Results from this new survey were used by CAR to

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[31] Consumer Reports, "Most Car Buyers Don't Expect to Downsize with Their Next New Car Purchase," press release, Yonkers, NY, April 15, 2011; Deloitte-Touche, *Gaining Traction: Will Consumers Ride the Electric Vehicle Wave? Electric Vehicle Consumer Survey Results for China, U.S., Europe and Japan,* April 2011; Ernst and Young, *Automotive Survey: Measuring the Understanding of and Interest in Plug-in Hybrid and Electric Vehicles in the U.S.,* Detroit, MI, December 2009.

[32] U.S. Department of Transportation, Federal Highway Administration, "2009 National Household Travel Survey." URL: <http://nhts.ornl.gov>.

[33] S. Lu, *Vehicle Survivability and Travel Mileage Schedules,* Technical Report, National Center for Statistics and Analysis, Washington D.C.: National Highway Traffic Safety Administration , January 2006: p36.

construct news estimates for VMT by year, for new vehicle owners. Vehicle types, consistent with the definition of light vehicles (passenger cars, SUVs, vans and pickups), were included; all others were excluded from the data used by CAR. In addition, observations with annual VMT estimates equal to zero–or that NHTS defined as outliers–were excluded from the estimate. There were 94,223 observations of vehicles ages 1-5 in the light vehicle study population. The calculated average annual VMT for each vehicle age 1-5 is provided below:

Table 8: Mean VMT in 1st 5 Years of Vehicle Ownership

Vehicle Age	1	2	3	4	5
Mean VMT	13,629	12,887	12,611	12,589	12,420

The annual VMT estimates are adjusted to account for the decreased cost of driving attributable to the projected fuel economy gains. The percent increase in fuel economy for each of the four scenarios is calculated[34] and a rebound rate of ten percent is used to increase VMT in each of the first 5 years of ownership. For example, in the first scenario of 37.6 mpg, real-world mpg increases by 70.9%. This justifies an increase in each annual VMT by 7.09%. Fuel economy savings in gallons are then estimated for each year. The percent increase in fuel economy, the percent increase in VMT, and the annual VMT estimates used in each scenario are provided below.

Table 9: Percent Increase in Fuel Economy, the Percent Increase in VMT, and the Annual VMT Estimates by Fuel Economy Scenario

Scenario I: 22 to 37.6 mpg	Values	Scenario II: 22 to 40.8 mpg	Values	Scenario III: 22 to 44.8 mpg	Values	Scenario IV: 22 to 49.6 mpg	Values
Percent Increase mpg:	70.9%	Percent Increase mpg:	85.5%	Percent Increase mpg:	103.6%	Percent Increase mpg:	125.5%
Percent Increase VMT:	7.1%	Percent Increase VMT:	8.5%	Percent Increase VMT:	10.4%	Percent Increase VMT:	12.5%
Annual VMT Vehicle Age 1	14,595	Annual VMT Vehicle Age 1	14,794	Annual VMT Vehicle Age 1	15,041	Annual VMT Vehicle Age 1	15,339
Annual VMT Vehicle Age 2	13,801	Annual VMT Vehicle Age 2	13,988	Annual VMT Vehicle Age 2	14,223	Annual VMT Vehicle Age 2	14,504
Annual VMT Vehicle Age 3	13,505	Annual VMT Vehicle Age 3	13,689	Annual VMT Vehicle Age 3	13,918	Annual VMT Vehicle Age 3	14,193
Annual VMT Vehicle Age 4	13,482	Annual VMT Vehicle Age 4	13,665	Annual VMT Vehicle Age 4	13,894	Annual VMT Vehicle Age 4	14,168
Annual VMT Vehicle Age 5	13,301	Annual VMT Vehicle Age 5	13,481	Annual VMT Vehicle Age 5	13,707	Annual VMT Vehicle Age 5	13,978

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[34] Experienced fuel economy was used due to the estimated 20% difference between a vehicle's CAFE MPG and its estimated real world MPG. This percent difference was confirmed by the EPA. http://www.epa.gov

VMT rebound rate:

The tendency that consumers will drive more when fuel cost per mile decreases from improving fuel efficiency is generally referred to as the fuel economy rebound effect. Green, Kahn, and Gibson's study: "Fuel economy rebound effect for U.S. household vehicles" (1999), is one of the frequently cited studies discussing this effect. Greene et al.'s study suggested that the long-term rebound effect is equivalent to 20 percent, indicating VMT will increase by 2 percent for every 10 percent increase in mpg. However, CAR's study uses a 10 percent rebound rate to estimate VMT in 2025, based on proposed mpg increases. The discrepancy between Greene's finding and CAR's assumption can be explained by the ages of vehicles assumed in the models.

Greene's finding is the result of household vehicles of all ages; CAR's model only considers vehicles five years or younger. Because newer vehicles have a higher VMT, and old vehicles (especially vehicles older than 10 years) have much lower VMT, the same amount of VMT increase will result in very different rebound rates. For example, a 1,200-mile increase due to mpg increase may result in a 10 percent rebound rate on vehicles with 12,000 VMT, but 40 percent on vehicles with 3,000 VMT. According to NHTSA's publication[35] in January 2006, a weighted average yearly travel mileage of a 10-year-old passenger car is 6,737. When a passenger car reaches 15 years old, the mileage drops to 2,167 per year. Greene's result showed a much higher rebound rate, due to its arithmetic mean of household vehicles. Because CAR's model only concerns new vehicles' first five-year VMT, an assumption of a 10 percent fuel economy rebound rate is justified.

Once the annual VMT values for each of the four scenarios are determined, the reduction in gallons of gasoline consumed, attributable to fuel economy improvement, are calculated by taking a given scenario's adjusted VMT value and dividing it by both the baseline 22.0 mpg and the increased mpg level for each scenario. The difference between the total number of gallons consumed in the baseline case compared to the total consumed in a given scenario are the future fuel savings for a given year.[36] Once the number of gallons saved in each year is established, two monetary values are estimated using fuel prices of $3.50 per gallon and $6.00 per gallon to determine the values of annual fuels savings. The present value of total first-time owner fuel savings in dollars are then estimated over the five-year ownership period using a ten percent discount rate.

As noted above, two values of future gasoline prices are used to assign a monetary value to the annual reduction in gasoline consumption. Gasoline prices have varied to a great extent over the past 30 years. Therefore, any estimate of pump prices in 2025 may properly be labeled as somewhat probable at best. Although there appears to be a consensus that real gasoline prices will rise by 2025, estimates concerning the extent of the increase vary greatly. CAR used two price scenarios in the calculation of the economic value of fuel savings: a low gasoline price of $3.50 a gallon (2009 dollars), and a second

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[35] S. Lu, *Vehicle Survivability and Travel Mileage Schedules,* Technical Report, National Center for Statistics and Analysis, Washington D.C.: National Highway Traffic Safety Administration , January 2006: p3.

[36] Again, using the rebound rate adjusted VMTs in both the baseline case and the scenario being analyzed increased the difference in gallons consumed. Using the unadjusted 2008-2009 VMTs in the baseline would reduce the number of gallons saved by the increased fuel economy, when compared to any of the scenarios.

price of $6.00 a gallon (2009 dollars).[37] The first price is closer to current levels of the U.S. cost of various fuels. The second price can reflect either tightening supplies for petroleum, a low value of the dollar, or even the probability of an increased tax on petroleum fuels. It would represent a higher real price for fuel than any previously faced by American consumers. It is important to note that these are fuel prices measured in 2009 dollar values. With these prices and the fuel savings estimated at each of the 2025 mpg scenarios, it is possible to calculate two estimates for the monetary value of the annual fuel savings. These results are presented below.

Table 10: Consumer Present Value (PV) of Fuel Savings from Increased MPG

2025 MPG	VMTe	Price of Gasoline	PV of Fuel Savings	Price of Gasoline	PV of Fuel Savings
37.6	14,595 (1st Yr.) - 13,301 (5th Yr.)	$3.50	$3,451	$6.00	$5,917
40.8	14,794 (1st Yr.) - 13,481 (5th Yr.)	$3.50	$3,885	$6.00	$6,660
44.8	15,041 (1st Yr.) - 13,707 (5th Yr.)	$3.50	$4,363	$6.00	$7,479
49.6	15,339 (1st Yr.) - 13,978 (5th Yr.)	$3.50	$4,865	$6.00	$8,339

$$VMTe_t = VMT2008_t \cdot \left[0.1 \times \left(\frac{MPG_{2025}}{MPG_{2008}} - 1 \right) + 1 \right]; t = 1{\sim}5$$

$$PV_{fuel\ savings} = \sum_{t=1}^{5} \frac{P_{gas}(\frac{VMTe_t}{MPG2008} - \frac{VMTe_t}{MPG2025})}{(1+r)^t}; r = 0.1$$

Source: Center for Automotive Research, DOT NHTS 2009

As discussed above, CAR discounts the first five years of annual fuel savings at a rate of ten percent. Indeed, the RL Polk organization has recently reported that new buyers of vehicles are now holding onto a new vehicle, on average, for 63.9 months–based on second quarter 2010 data collected by the firm. This represents a rise of 4.5 months from the preceding year. Length of ownership has increased dramatically since the start of the U.S. economic recession. Length of ownership has also risen for buyers of used vehicles, as well. However, the value of fuel savings for second and third buyers of advanced fuel economy technology vehicles accruing to original owners is highly problematic. Such markets have not occurred before; in addition, there are questions regarding the durability of battery components. Other analysts have rashly proposed, with little or no justification, longer fuel savings timelines or horizons, especially for new technologies with little market or technical experience. In the case of electric vehicles, as stated above, there is no evidence that the expensive battery component will last beyond eight years, implying a resale value of zero, close to zero, or even less than zero with a high recycling charge. The predictability of fuel prices also plays a role in the heavy discounting of fuel savings. Early and the most recent literature on the subject of consumer discounting of high capital cost

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[37] Although fluctuations in gasoline prices have been shown to also affect VMT, VMT estimates were held constant. CAR recognizes this limitation of the model, that it overstates the estimated annual gallons of fuel saved and therefore the annual monetary value of that savings.

energy saving durables, especially electrics, appears to indicate a ten to twenty percent discount rate is far more suitable.[38]

The present value sums in both the high price and low gasoline price scenarios should represent what consumers are willing to pay to obtain improvements in fuel economy. If the cost of higher fuel economy technology, higher electricity recharging expenses and higher safety technology mandates exceeds the present value of future fuel savings and the value of increased safety, then the consumer has been made worse off by the cost of these mandated technologies. If the present value of future fuel savings and the value of higher safety technologies exceed the costs of increased mandates then the consumer is made better off by the mandated increase in fuel economy. This difference is referred to as the change in net price. A positive change in net price will represent a barrier to the consumer in terms of buying a new vehicle.

An additional analysis may prove helpful in understanding the net value of improved fuel economy to the vehicle consumer. It is certainly well known that the benefits of incremental fuel savings to the vehicle owner decline with higher levels of fuel efficiency (Figures 10 and 11). The total fuel cost of traveling 12,000 miles at various levels of fuel efficiency is shown in Figure 10. At a fuel price of $6.00 per gallon, a consumer would pay $7,200 to travel 12,000 miles in a vehicle with only 10 mpg in fuel efficiency. If the vehicle in question could achieve 70 mpg, fuel costs would fall to $1,029 or a savings to the consumer of $6,171. An inspection of Figure 10, however, shows that improvement in mileage efficiency and fuel savings is not constant throughout the range of 10 mpg through 70 mpg; in fact, it continuously declines. This is a common arithmetic result. Figure 11 shows this effect even more clearly. In Figure 11, values of fuel savings for 10 mpg increments are shown for 10 mpg through 70 mpg at two fuel prices: $3.50 per gallon and $6.00 per gallon, assessed at 12,000 miles of travel. An improvement of 10 mpg to 20 mpg results in a savings of $3,600, but the improvement in fuel savings for 60 to 70 mpg is only $171.

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[38] Cardell S. Beggs and Jerry Hausman, "Assessing the Potential Demand for Electric Cars." *Journal of Econometrics*, no. 16 (1981): 1-19; Richard Curtin, Yevgeny Shrago, and Jamie Mikkelsen, *Plug-in Hybrid Electric Vehicles,* The University of Michigan, 2009; Jerry A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy Using Durables," *The Bell Journal of Economics* vol. 10, no. 1 (1979): 33-54.

Figure 10: Average Fuel Expenditures at Increasing MPG Levels: Holding Annual Average VMT= 12,000
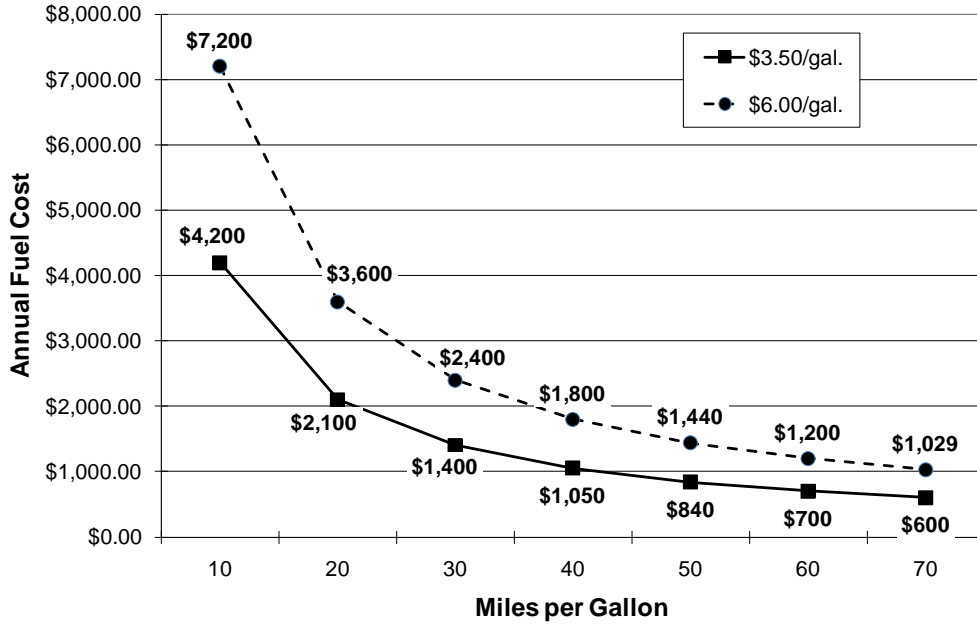
Source: Center for Automotive Research

Figure 11: Value of Fuel Savings Resulting from 10 MPG Increases: Holding Average Annual VMT = 12,000
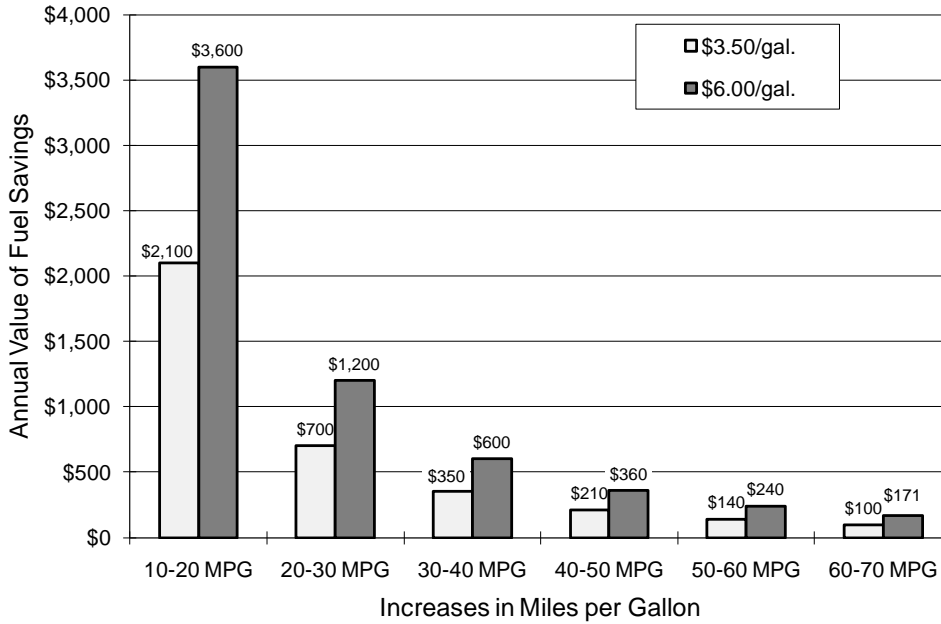
Source: Center for Automotive Research

The Cost of Electricity

Plug-in electric vehicles do not recharge their batteries for free. Not only will the cost of electricity be expected to rise significantly by 2025, it is also very likely that a large percentage of PHEV and BEV vehicle owners will opt for the purchase of 220-volt home charging systems to avoid lengthy and inconvenient recharging times. (However, one recent study estimates that less than 50 percent of vehicle owners have access to a home garage.) This subset of the cost of electrification must be added to the net price calculation for vehicles requiring external charging. (This cost is shown in Table 7.) Rather than use unreliable estimates of future electricity costs or charging sets, CAR opted for costs supplied by the two companies now introducing the most advanced models of PEVs: General Motors and Nissan-Renault. The EPA has estimated that the new Chevrolet Volt needs 36 kWh per hundred miles of travel at $.1147 for electricity needed to recharge the battery and $1,690 for the cost of a charger and its installation. The EPA has estimated that Nissan-Renault Leaf requires 34 kWh per 100 miles of travel also at $.1147 with a cost of $2,400 for the 220 volt recharger.[39,40] It was assumed in the case of the extended PHEV that the vehicle would be driven two-thirds of its VMT on its gasoline motor in order to achieve a 2.5 FE Improvement multiplier, as shown in Appendix I. The different scenario estimates of this cost (shown in Table 11) reflect the different market shares for PHEVs and BEVs in each fuel economy scenario in Section II. Five years of discounted electricity use are shown with the cost of the charger assessed up front at no discount.

Table 11: Charging Equipment and Electricity Cost (2009 Dollars)

2025 MPG[1]	Charging Equipment[2]	PV of Electricity Usage[3]	Total Cost of Electricity
37.6	$40	$26	**$66**
40.8	$175	$84	**$ 259**
44.8	$348	$159	**$ 507**
49.6	$1,105	$495	**$ 1,600**

1. MPG scenarios assumed different PHEV and EV shares, resulting in a different cost to charging equipment and electricity usage for each MPG scenario.
2. The charging equipment expenses are estimated to be $2,400 for BEV and $1,690 for PHEV.
3. Assumed $0.1147 per kWh. Chevrolet Volt consumes 36kWh per 100 miles. Nissan LEAF consumes 34kWh per 100 miles.
4. Discount rate = 10% for 5 years.

Source: Center for Automotive Research

[39] U.S. Department of Energy, Office of Energy and Renewable Energy, *Fuel Economy Guide Model Year(s) 2010/2011*, Washington D.C.: U.S. EPA, 2010/2011.

[40] Renault-Nissan, EV Solutions, "Price and Installation Costs for Home Charging Units," accessed April 2011. <www.mynissanleaf.com>, www.evsolutions.avinc.com; SPX, "Home Charging Units: Installation Prices Ranges," Accessed 2011, <www.homecharging.spx.com/volt/>.

Other elements of potential costs connected to electric vehicles have been left out of the CAR analysis. For example, insurance companies may be liable for the replacement cost of batteries and other components disabled in many accidents (not to mention the complete loss of an expensive vehicle). Premiums can be expected to be adjusted upwards for such PEV vehicles by a considerable amount. It is also likely that the battery component of such a vehicle will not match the life expectancy of the vehicle and that a subsequent owner will face additional replacement and recycling charges for a used component containing many exotic materials. These factors, along with the replacement cost of off-warranty batteries will confront potential consumers resulting in poor resale values for PHEVs or very high depreciation costs per mile traveled.

Cost/Benefit Analysis of Higher Fuel Economy Technologies

It is easy to translate these potential savings into totals for the purchaser of a new vehicle, considering an ownership length of five years and a discount rate of ten percent. CAR first nets the potential fuels savings at each real world mpg level (shown in Table 10) for the costs of electricity (displayed in Table 11). This savings is shown in Figure 12. The increments in fuel economy under consideration in this figure are 22.0 mpg to 37.6 mpg, 37.6 mpg to 40.8 mpg, 40.8 mpg to 44.8 mpg and 44.8 mpg to 49.6 mpg. These incremental fuel economy improvements (the discounted value of five years of fuel savings at the associated real world fuel economy level netted for electricity costs) correspond to the four fuel economy technology scenarios in Section II. CAR compares the five-year discounted value of savings with the incremental costs of higher fuel economy technologies needed to reach higher fuel economy levels. In the case of 22.0 mpg to 37.6 mpg (labeled Scenario I), the consumer saves $3,385 of fuel for 13,737 miles of travel at $3.50 a gallon but must pay for $3,744 of new fuel economy technology to accomplish these savings–a shortfall of $359. However, the consumer saves $5,851 in the same scenario if the price of fuel is $6.00 per gallon, which produces a gain of $2,107 when netted for incremental cost. The incremental fuel savings for moving from 37.6 to 40.8 mpg (labeled Scenario II) are only $241 at $3.50 a gallon and $551 at $6.00 a gallon. In this scenario, the net fuel savings falls short of the incremental cost of higher fuel economy technology, despite the fact that VMT has increased to 13,923. The same is true for Scenario III of 40.8 to 44.8 mpg, since net fuel savings are only $230 in the case of $3.50 per gallon of fuel and $571 at $6.00 a gallon even though VMT increases to 14,157. These savings are far below the incremental technology cost of $1,443. The results for the Scenario IV of 44.8-49.6 mpg (62.0 mpg CAFE) are striking. The incremental technology cost is $3,077 but fuel savings netted for electricity costs are negative at both prices for fuel. In other words, even if the incremental technology costs of moving to 49.6 mpg were zero (free batteries!), the extra cost of chargers and electricity costs would not make this move to a higher fuel economy target worth it.

Table 12 summarizes both total consumer savings from the adoption of higher levels of fuel economy technology and incremental savings gained by the consumer from moving to higher scenarios. As can be seen in the final two columns of Table 12, consumers maximize their net savings at 37.6 mpg at $2,107. Moving from 37.6 mpg to 40.8 mpg actually reduces consumer net savings by $976 which is shown in the final column. Moving higher to 44.8 mpg reduces total consumer net savings by an additional $873. Moving to the highest level of fuel economy of 49.6 mpg from 44.8 mpg reduces total savings by an impressive $3,309. It is true that total net savings are positive through 44.8 mpg (supposedly paying for

the technology) but no rational consumer would pick a level higher than 37.6 mpg where total net savings are maximized. In fact, it is likely that total net savings are maximized below 37.6 mpg but the NAS/NRC study does not provide finer technology cost levels for mpg levels below this target. It should be repeated that it does not matter whether net savings are sufficient to pay for a level of technology cost. What finally and ultimately matters is what is maximal for the consumer. That issue alone will control buyer behavior for fuel economy technology (aside from inefficient government mandates).

Figure 12: Improving MPG: Present Value of Five Years' Fuel Savings (netted for the cost of electricity)

r=10% (discount rate);
Rebound rate=10%;
Fuel Savings valued over 5 years
VMT average years 1-5: Scenario (S) I=13,737; SII=13,923; SIII=14,157miles; SIV= 14,436
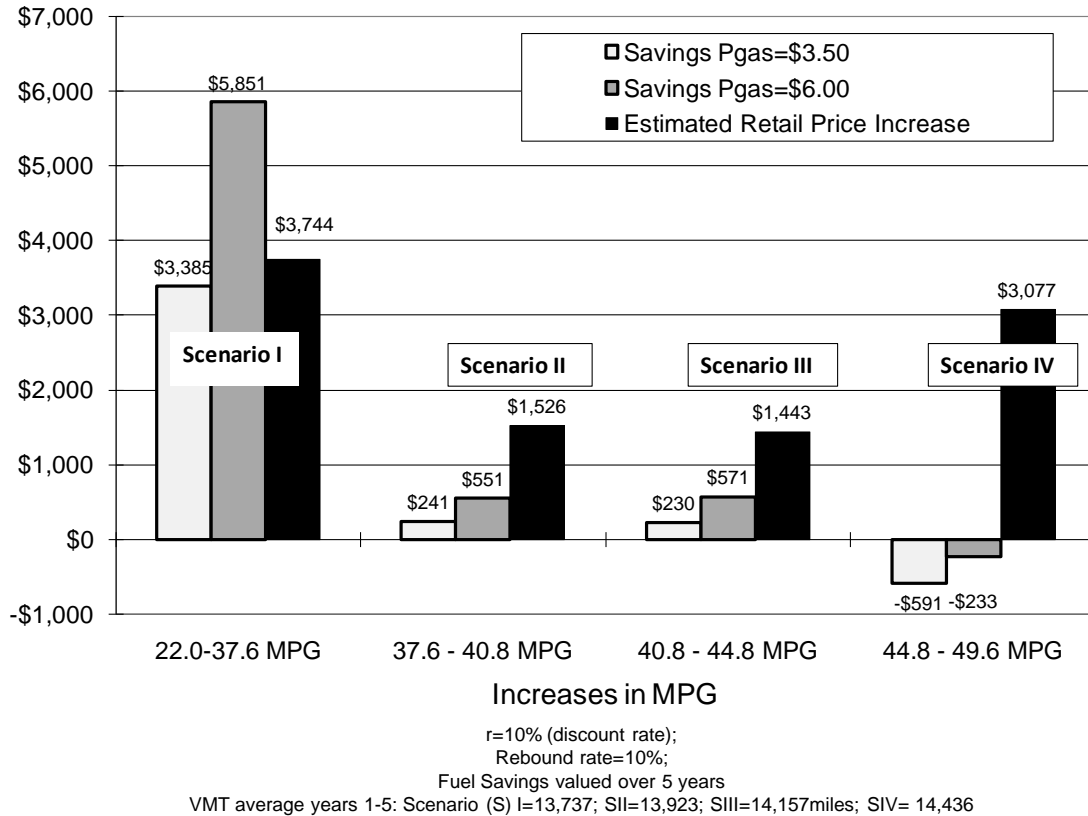
Source: CAR Research, DOT NHTS 2009

Table 12: Calculations of Net Consumer Savings from Higher Fuel Economy Technologies

Real MPG	Fuel Savings ($6.00/Gal.)		Technology Cost		Cost of Electricity		Total Consumer Net Savings	Changes in Consumer Savings
22.0	--	-	--	-	--	=	--	--
37.6	$5,917	-	$3,744	-	$66	=	$2,107	$2,107
40.8	$6,660	-	$5,270	-	$259	=	$1,131	($976)
44.8	$7,479	-	$6,714	-	$507	=	$258	($873)
49.6	$8,339	-	$9,790	-	$1,600	=	($3,051)	($3,309)

The Calculation of Net Prices

The percentage increase in retail price for the average vehicle due to fuel economy and safety mandates by 2025 are shown in Table 13. There are four retail prices, one for each level of fuel economy standards (since the cost of extra safety technology is the same $1,500 for each standard). A fuel economy standard of 37.6 mpg is associated with a price increase of $5,244, 18.1 percent higher than the 2009 NADA average price of $28,966. A fuel economy standard of 40.8 mpg is associated with a price increase of $6,770, 23.4 percent higher than the 2009 NADA price. A fuel economy standard of 44.8 mpg is associated with a price increase of $8,214, 28.4 percent higher than the 2009 NADA price. The fourth fuel economy standard of 49.6 mpg is associated with an $11,290 increase in retail price. It is assumed that manufacturers and dealers will pass on the cost increase in fuel economy and safety technology to the consumer, at a retail price equivalent.

CAR assumes that consumers will incorporate the net present value (NPV) of fuel savings, from the use of higher fuel economy technologies, in their purchasing behavior. CAR also assumes that consumers will subtract the NPV of these savings from the retail price. (These savings are shown for two gasoline price assumptions in Table 10 above.) CAR believes that owners of PHEVs and BEVs will also increase the retail price to include the NPV cost of electricity and charging equipment necessary to operate these vehicles. These costs are shown (on average) for the whole fleet, in Table 11.

The netting effects on retail price are illustrated in Table 13 for two gasoline price assumptions, $3.50 per gallon and $6.00 per gallon. The percentage increase in net price for each of the four 2025 mpg scenarios, due to the cost of meeting higher fuel economy and safety mandates and the corresponding markup is also presented below in Table 13. The base price of $28,966 is the average price for new motor vehicles in 2009. The effect of higher gasoline or fuel prices is immediately apparent in Table 13. The net price increase is lower at each fuel economy mandate level or scenario, at $6.00 per gallon versus $3.50 per gallon. This reflects the higher value of fuel savings for the consumer, in dollar terms. Thus, the lowest net price change in percentage terms is -2.1 percent ($606 in extra value to the consumer) at a mandated level of 37.6 mpg in a market with $6.00 per gallon gasoline. The highest net price change is 27.7 percent ($8,026 in extra cost to the consumer) at a mandated level of 49.6 mpg in a market with $3.50 per gallon gasoline. The second highest net price change is 15.7 percent ($4,551 in extra cost to the consumer) at a mandated level of 49.6 mpg in a market with $6.00 per gallon gasoline. Such price changes are not trivial for the typical vehicle. It should be repeated that CAR did not change the essential attributes of the vehicles available for sale in 2025 compared to 2009, except for fuel economy and safety content.

Table 13: Retail and Net Price Change
2009 – 2025

	Gross Price Change (Retail Price Change)				Net Price Change Net of Fuel Savings/Electricity Cost			
	FE Technology	Safety Equip	Equals	% change	$3.50		$6.00	
Scenario #1: 37.6 MPG	$3,744	+ $1,500	=$5,244	18.1%	$1,859	6.4%	($606)	-2.1%
Scenario #2: 40.8 MPG	$5,270	+ $1,500	= $6,770	23.4%	$3,144	10.9%	$369	1.3%
Scenario #3: 44.8 MPG	$6,714	+ $1,500	= $8,214	28.4%	$4,358	15.0%	$1,242	4.3%
Scenario #4: 49.6 MPG	$9,790	+ $1,500	=$11,290	39.0%	$8,026	27.7%	$4,551	15.7%

The Macro-economic Costs of Higher Fuel Economy Technologies

The Baseline Forecast for 2025

As a first step in forecasting the macro-economic costs of higher fuel economy mandates, CAR produced a baseline forecast of the 2025 light vehicle market that assumes no increase in safety or fuel economy standards or mandates for the 2009-2025 period.

CAR assumes an annual growth rate in the U.S. GDP of 2.5 percent during 2009-2025; total U.S. GDP will grow by 48 percent by the end of the period and personal income by 51 percent. CAR forecast U.S. household growth of one percent per annum, through 2025   A second order auto-regressive model was used to forecast total expenditures on new vehicles in 2025, measured in 2009 dollars. (The specifications and results for this model are shown in Appendix II.) Baseline results estimate that total expenditures on new vehicles will grow by a 5.6 percent annual rate, through 2025. Total expenditures on new vehicles are forecast to grow from $297 billion in 2009 to $713 billion (in current dollars) in 2025. In a similar fashion, the average price for motor vehicles ($28,966) reported by NADA in 2009 was also inflated by two percent per annum yielding a current dollar average price of $39,764 per vehicle in 2025. This results in a U.S. sales level of 17.9 million vehicles in 2025. The results for this baseline forecast are shown in Table 14, in the first data column.

Impact of Higher Net Price on the Quantity of Vehicle Demand: Short-Run and Long-Run Price and Income Elasticities of New Vehicle Demand

In order to approximate the effect of increases in the net price of new vehicles on new vehicle sales or revenue, CAR estimated the own price elasticity of vehicle demand, using an econometric model. CAR

did not directly estimate the effect of price change on unit sales of vehicles, but rather the effect of price change on expenditures for new vehicles (motor vehicle expenditures). The effect on unit sales due to price change was further estimated by dividing revenue by the estimated average price for new vehicles, in 2025.

Several dynamic models were constructed to estimate short-run and long-run price and income elasticities of new motor vehicle demand. These models vary only slightly from those discussed previously in the literature; the estimations are shown in Appendix III. CAR's results show that the short-run price elasticity of demand has been highly elastic in recent years compared to past estimations; the long-run price elasticity is relatively inelastic and similar to results obtained in the past. CAR also estimated the income elasticity of demand for motor vehicles. Results show that short-run income elasticity is inelastic while the long-run income elasticity is relatively elastic. The statistics and calculation for income and price elasticities are shown in Appendix III.

Our findings do differ in several ways from previous studies.[41] The previous studies indicated short-run income elasticity to be highly elastic but gradually become unitary in the long run. Automobiles in the '60s, for example, were considered luxury goods rather than required durable goods; people spent proportionally more on automobiles as their income increased. In recent years, automobiles have become less and less expensive relative to personal income. For the majority of American consumers, an automobile is more of a necessity for everyday activities than a luxury good, as was the case a half century ago. The change in consumer perception in automobiles is reflected in the stable values of both short- and long-run income elasticity of motor vehicle demand. Today, people spend more (but proportionally less) on automobiles, when their incomes increase. On the other hand, when income decreases, people cut back their expenditures on automobiles proportionally less, because many of them bought their vehicles on installments. They are less likely to reduce the payments in a short period of time.

The longer durability and lifespan of current light vehicles reinforces the dynamic effect of price changes over time. Previous studies showed short-run price elasticity of motor vehicle demand as somewhat elastic and long-run price elasticity as inelastic. The study estimation showed short-run price elasticity as relatively more elastic (-1.92) than in the past while long-run price elasticity is still inelastic (-0.58). A possible explanation for this transition is that the quality and durability of automobiles have improved dramatically in the past several decades. Today's vehicles can easily last for ten years with an 80 percent survival rate, compared to the 15 percent survival rate for automobiles produced in the 1960s.[42] Since today's cars can operate at a high performance level for a very long time, consumers have more options in motor vehicle purchases. Consumers can more easily substitute the purchase of used vehicles or simply keep their current cars for a longer period of time. Hence, the short-run price elasticity is much higher than it was in the past. CAR has discovered that the short-run and long-run

[41] S.H. Hymans, "Consumer Durable Spending: Explanation and Prediction," *Brookings Papers on Economic Activity,* Brookings Institute, no. 2 (1970): p. 173-199; Richard C. Porter, *Economics at the Wheel* (San Diego, CA: Academic Press, 1999), p. 33.
[42] Alan Greenspan and Darrel Cohen, "Motor Vehicle Stocks, Scrappage, and Sales," *Review Economics and Statistics* vol. 81, no. 3 (August 1999): 369-383.

used vehicle price elasticities of new vehicle demand are both positively elastic. This finding would suggest used vehicles are strong substitutes for new vehicles.

Higher vehicle durability has lowered the consumers' necessity to *immediately* replace their old vehicles and has depressed the demand for new vehicles, in the short run, in the face of higher prices. In the long run, the maintenance cost and dissatisfaction of driving an old vehicle will eventually overcome resistantance to the price of a new car. Mass transit is not an acceptable substitute for a vehicle, new or used, in all but the largest U.S. cities. Consumers will eventually retire their old vehicles for new ones. Therefore, the long-run price elasticity is still considerably weaker than the short run price elasticity.

CAR's results for long-run own price and income elasticities of motor vehicle expenditures are shown in Appendix III, -0.58 for price and 1.34 for income. To determine the effect of net price changes over a period of 16 years (2009-2025), CAR evaluated data for the period 1994-2009 to compute an estimate of arc elasticity. Arc price elasticity was estimated at -0.39: a 10 percent increase in net price during 2009-2025 would result in a 3.9 percent drop in motor vehicle expenditures. Arc income elasticity was estimated at 1.2 for the same period.

CAR directly estimates the effect of higher net prices due to the costs of mandates by using the percentage estimates shown in Table 13 and the long-run arc elasticity of -.39. For example, a percentage change of +15.0 percent in the case of a fuel economy standard of 44.8 mpg and a gasoline price of $3.50 per gallon is estimated to reduce baseline consumer expenditures on vehicles by 5.9 percent by 2025. Expenditures would fall from $713 billion (in the baseline case) to $671 billion in a 44.8 mpg/$3.50 gallon scenario. There are eight such net price effects–seven that result in a lower level of consumer expenditures on new vehicles in 2025. At the same time, there are four separate changes or increases in vehicle retail price. These four prices are based on cost increases as a result of four separate fuel economy standards and a total of $1,500 for safety mandates through 2025. In the case of the 44.8 mpg standard, the retail price is expected to rise by 28.4 percent to $37,180 in 2025 from $28,966 in 2009 dollars. The four retail prices are also inflated at a rate of two percent per annum for 2009 – 2025, to arrive at a 2025 retail vehicle price. For the 44.8 mpg standard, the 2009 dollar price of $37,180 inflates to a current dollar price of $51,040 in 2025. This is true for the 44.8 mpg standard, regardless of gasoline prices. To estimate the number of vehicles sold in 2025, 2025 current prices are then divided into eight estimates for 2025 total consumer expenditures. For example, in the case of the 44.8 mpg standard assuming $3.50 per gallon, $671 billion in consumer expenditures on new vehicles are divided by the 2025 current price of $51,040 to yield total light vehicle sales of 14.7 million. Eight estimates for light vehicle sales are shown in Table 14, one for each combination of gasoline price and fuel economy standard. Total expenditures on vehicles and net expenditures on motor vehicles are both shown in Table 14. The difference between the two is the total cost of fuel economy and safety mandates netted for fuel savings (netted in turn for the costs of electricity).

Table 14: Effect on U.S. Vehicle Sales, Production and Automotive Employment of Higher Retail and Net Vehicle Prices due to Higher Fuel Economy and Safety

	Baseline	Net Price Increase							
		-2.1%	1.3%	4.3%	15.7%	6.4%	10.9%	15.0%	27.7%
Net MV Exp. (Billion $)	713	718	709	701	669	695	682	671	636
Total MV Exp. (Billion $)	713	867	864	847	803	771	760	748	692
Gross Vehicle Price (2009$)	$28,966	$34,210	$35,736	$37,180	$40,256	$34,210	$35,736	$37,180	$40,256
Gross Vehicle Price (2025$)	$39,764	$46,963	$49,058	$51,040	$55,263	$46,963	$49,058	$51,040	$55,263
Net Vehicle Price (2025$)	$39,764	$38,932	$40,271	$41,469	$46,012	$42,316	$44,080	$45,747	$50,782
Light Vehicle Sales (Million Units)	17.9	18.5	17.6	16.9	14.5	16.4	15.5	14.7	12.5
Light Vehicle Production (Million Units)	10.8	11.1	10.6	10.1	8.7	9.9	9.3	8.8	7.5
Automotive Employment	877,075	903,135	861,739	826,950	711,538	803,548	757,700	717,626	612,567
MPG/GAS Price	22.0/n.a.	37.6/$6.00	40.8/$6.00	44.8/$6.00	49.6/$6.00	37.6/$3.50	40.8/$3.50	44.8/$3.50	49.6/$3.50

Seven of the sales levels for all of the fuel economy standard estimates are below the baseline case of 17.9 million in Table 14. The only exception is the 37.6 mpg/$6.00 per gallon scenario which actually reduces net price by 2.1 percent and increases net motor vehicle expenditures to $718 billion. In this case, total vehicle sales rise to 18.5 million. The 49.6 mpg/$3.50 per gallon scenario calls for a sales level of only 12.5 million vehicles in 2025. In the scenarios with sales levels below 15.0 million vehicles, it is not likely that the operating fleet will reach the level of 284 million vehicles needed to maintain current household ownership patterns (2.07 vehicles per household) under any of the higher fuel economy standards unless the average age of a vehicle rises by a considerable amount above the 2010 level of 10.4 years. This could happen if there is a dramatic decline in the scrappage rate of vehicles in use. It is true that the price of used vehicles may rise under any of these scenarios as new vehicle sales levels fall and the stock of used vehicles ages, as well. It is very likely that the U.S. aftermarket for replacement parts and repair services, already very large and sophisticated, will increase to replace declining consumer expenditures on new vehicles with expenditures on maintaining older vehicles.

The rate of de-carbonization from the use of higher levels of safety technology in motor vehicles is likely to slow, as well, if consumers elect to hold onto more expensive vehicles for a longer period of time. That is because the replacement rate for existing vehicles will fall due to higher prices for vehicles with expensive mandated equipment. CAR refers to these phenomena as the "Cuban effect," or the rapid

aging of the vehicle fleet due to a supply-side shock of mandated costs. In Cuba, new cars were not sold for many years, because western imports were not available. Many cars operating in Cuba in the 1950s were kept in operation for decades (and still are) because new substitutes were unavailable. In the heavily mandated U.S. market leading to 2025, high prices will make vehicles unaffordable for many more Americans than was true in the past. Higher prices reflect a different reduced supply schedule for new vehicles. Although the restriction of supply in the U.S. is not as severe as that in Cuba, the effect in the two countries is uncomfortably similar. Regardless of expensive government mandates, the U.S. motor vehicle fleet is already the oldest among developed countries. [43]

U.S. Vehicle Production and Employment in 2025

In order to forecast the U.S. light vehicle production and automotive manufacturing employment in 2025, several parameters were estimated. First and foremost is the sourcing ratio for U.S. production. The U.S. sourcing ratio is defined as the ratio of U.S. vehicle production to U.S. sales. Although production is not a subset of sales, because sales include imported vehicles and production includes vehicles for export, it is nonetheless highly correlated to U.S. sales. The model provided and estimate of the ratio is at a level of 60 percent, indicating that for every 100 vehicles sold, there are a corresponding 60 vehicles produced in the United States. (The calculation methodology for deriving the sourcing ratio is shown in Appendix IV.) Since the sourcing ratio is the same in every fuel economy standard and gasoline scenario, the 60 percent ratio is applied to the eight scenario estimates for 2025 U.S. light vehicle sales shown in Table 14. This generates eight estimates for U.S. light vehicle production, as shown in Table 14. For example, the baseline estimate of 10.8 million vehicles produced falls to 7.5 million in the case of a 49.6 mpg standard and a $3.50 per gallon price for fuel. The second lowest production total, 8.7 million units, is also for the fuel economy level of 49.6 mpg–even when fuel is assumed to cost $6.00 per gallon.

The next parameter is automotive manufacturing labor productivity. Labor productivity is defined here as vehicles per worker per year. Workers are those employed in two U.S. automotive industries: Motor Vehicle Manufacturing and Motor Vehicle Parts Manufacturing, as defined by the Bureau of Labor Statistics (NAICs 3361 and 3363). This productivity ratio can be highly volatile over time. Figure 13 shows indexed U.S. automotive manufacturing labor productivity for 1960-2008. The shaded areas highlight U.S. economic recessions in the past fifty years. As Figure 13 shows, each recession was accompanied by a steep drop in productivity and was followed by a rapid productivity recovery before the next economic cycle. Despite the economic cycles, automotive labor productivity grew steadily at a 0.4 percent annual rate over the total period. The productivity showed measures a worker's annual output in units of vehicles. It is true that, over time, motor vehicles have become more and more content-laden. Higher content and more features have been added to new models and now require more manufacturing processes and effort to make a final product. Actual labor productivity, then, has grown by a higher rate than that shown in Figure 13.

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[43] European Automobile Manufacturers' Association (ACEA), "Average Car Age by Country 2008," Accessed 2011, <www.acea.be/index.php/collection/statistics>; Japan Automobile Manufacturers Association, *The Motor Industry of Japan 2010*, Tokyo, May 2010. <www.jama.or.jp>; R.L. Polk & Co. "Polk Finds More Vehicles Scrapped than Added to Fleet," press release, Southfield, MI, March 30, 2010.

Figure 13: Automotive Labor Productivity: 1962-2010
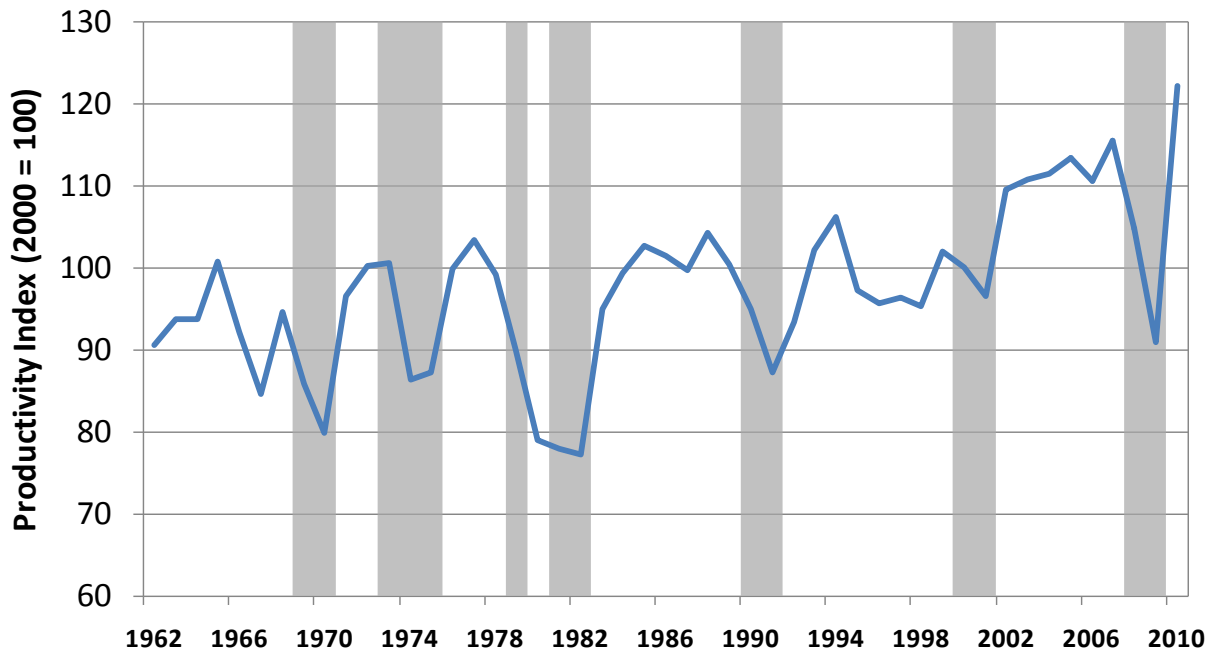
Note: Automotive Productivity Index consists of SIC 3711/3714 and NAICS 3361/3363.
Year 2000 is the base year.

Source: BLS, USDOL (Employment); Wards Auto (Production)

CAR uses the long-term 0.4 percent productivity growth rate (1960 – 2008) to estimate a ratio of 12.26 vehicles produced in the United States per worker, in 2025. This ratio is used to forecast automotive manufacturing employment for each of the U.S. production scenarios shown in Table 14. For example, the baseline scenario would be an auto manufacturing employment level of 877,075 in 2025. Seven of the eight fuel economy gasoline price scenarios show a drop from this baseline level. Figure 14 shows the worst employment outcome is the scenario of 49.6 mpg/$3.50 a gallon with industry employment estimated at 612,567, or a loss of just over 264,500 jobs. The best employment scenario is for 37.6 mpg/$6.00 a gallon with an estimate of 903,135 or an increase of just over 26,060 from the baseline case.

Figure 14: Net Vehicle Price Change Percentages and Automotive Manufacturing Employment
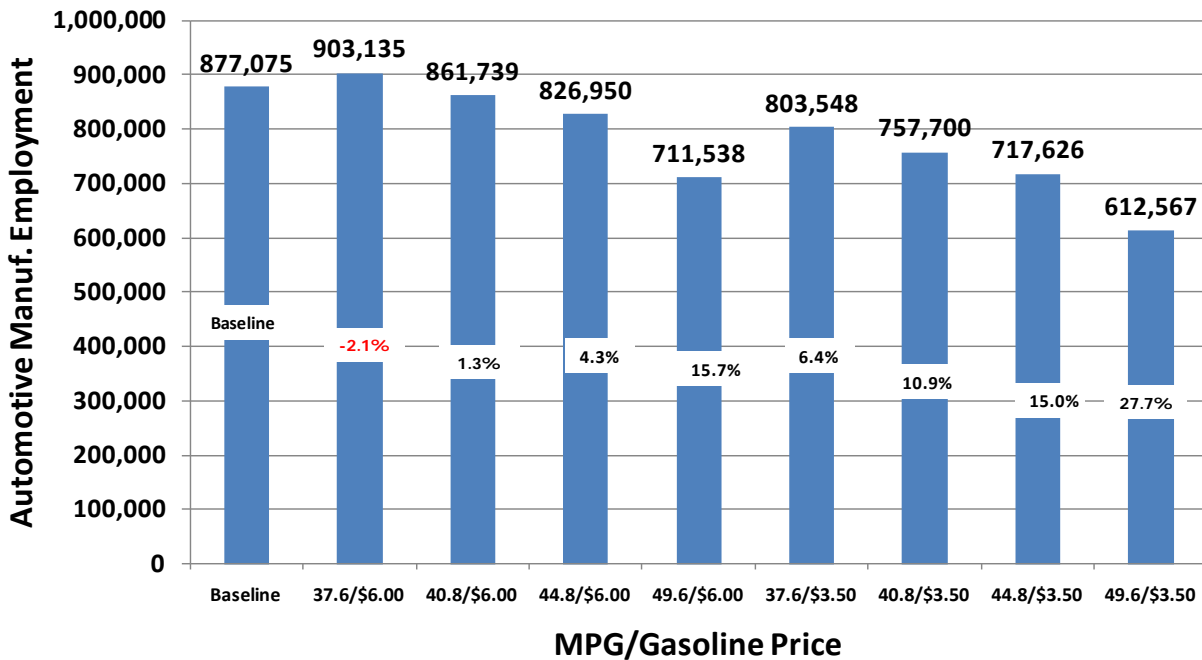
Figure 14 shows that employment levels decline with the increase in fuel economy standards given the same price of gasoline. In general, the higher the fuel economy standard the greater the increase in retail price and the higher the fuel price the lower the increase in net price. These two effects can offset each other, to a certain extent, in certain ranges of technology change and fuel price. Certain combinations of these two factors produce different levels of consumer expenditures and automotive production.

If employment in automotive manufacturing falls by up to 264,500 the effects on the overall U.S. economy in terms of lower employment, lower income, and tax revenues will be severe. In numerous studies, CAR has shown that the jobs multiplier for U.S. automotive manufacturing is one of the highest of any industry. In CAR's most recent study of the economic contribution of the motor vehicle manufacturing industry to the U.S. economy,[44] the jobs multiplier for direct employment at automakers and auto parts manufacturers was estimated to be 6.4. In other words, 5.4 jobs are created elsewhere in the U.S. economy for every job located at an automotive vehicle or parts manufacturing firm. In 2010, about 1 million direct U.S. jobs were located at auto and auto parts manufacturers; these jobs generated an additional 1.966 million supplier jobs, largely in non-manufacturing sectors of the economy. The combined total of 2.966 million jobs generated a further spin-off of 3.466 million jobs that depend on the consumer spending of direct and supplier employees, for a total jobs contribution from U.S. auto manufacturing of 6.432 million jobs in 2010. This figure actually rises to 7.960 million when direct jobs located at new vehicle dealerships (connected to the sale and service of new vehicles) are considered.

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[44] Kim Hill, Debbie Menk, and Adam Cooper, *Contribution of the Automotive Industry to the Economies of All Fifty States and The United States,* The Center for Automotive Research, Ann Arbor, MI, April 2010.

The grand total of 7.960 million U.S. jobs supported by the auto industry represented 4.4 percent of all the jobs in the U.S. economy and 3.5 percent of total compensation. The job loss range of higher fuel economy mandates extending from 40.8 to 49.6 mpg by 2025 will range from .098 million(15,336 direct jobs) to 1.693 million jobs (264,500) in the U.S. economy if the 6.4 manufacturers' multiplier is used, and even larger totals if the impact on new vehicle dealerships is considered.

These are well and truly catastrophic jobs impact numbers for the future of an economy still locked in a historic jobs recession.

Section IV: Conclusions and Recommendations for Policy

This study conducted by the Center for Automotive Research (CAR) estimates the likely parameters of the U.S. motor vehicle market and industry in 2025. The first section considers a general outlook for the U.S. motor vehicle market in the year 2025, based on long term social and economic factors. CAR estimates that by 2025, there will be 284 million operating light vehicles in the United States–44 million more than in 2009. Considering the projected, net of scrappage, addition of 44 million units to the U.S. fleet, new vehicle sales should be expected to average 15.2 million units per year, between 2010 and 2025. This would represent a baseline case–given only expected increases in new vehicle price inflation, modest scrappage rate and moderate growth in U.S. GDP. As a part of this expected average trend of 15.2 million sales per year during 2010 - 2025, CAR forecast a market of 17.9 million sales in the year 2025. CAR's baseline forecast assumes no further mandates for higher fuel economy or safety technology beyond those present in 2009 and estimates that personal consumption expenditure on new vehicles will grow by a 5.6 percent annual rate during 2010 - 2025. Total personal consumption expenditures on new vehicles will grow from $297 billion in 2009 to a total of $713 billion in current dollars in 2025. In a similar fashion, the average price for motor vehicles ($28,966), reported by NADA in 2009, was also inflated by two percent per annum, yielding a current dollar average price of $39,764 per vehicle in 2025.

However, dramatic changes (not determined by market forces) in the price and/or the performance or attributes of new motor vehicles could significantly alter the baseline for growth, the age of the U.S. motor vehicle fleet and annual sales. The most likely dramatic changes for the automotive market through 2025 would appear to be those soon to be mandated by the federal government for the purpose of improving the fuel economy performance of vehicles beyond what is required by the market, as well as additional safety and environmental mandates and regulations.

The National Research Council of the National Academies (NRC) conducted a study under contract to NHTSA called, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," released in June 2010.[45] Incremental retail cost and performance estimates are provided for over forty technologies expected to be commercially available over the next fifteen years. CAR uses this study to estimate the likely cost and price impact on new motor vehicles for three broad technical areas or pathways to higher fuel economy.   The estimated improvements in fuel economy, retail price equivalent costs and technology pathways (packages) proposed by CAR are based on the NRC data and modeling results from three different alternative powertrain pathways: spark-ignited, compression-ignited, and electrification. CAR expanded the three basic pathways to a total of nine pathways, primarily by adding additional extensions for increased mass reduction in the vehicle, further variants of vehicle electrification, and the use of stop/start technology. Each of these nine pathways produced a specific fuel economy standard and cost estimate measured at retail price equivalence. In a similar fashion to the analysis carried out

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[45] National Research Council of the National Academies, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, *Assessment for Fuel Economy Technologies for Light-Duty Vehicles*, Washington D.C.: The National Academies Press, June 2011.

by the NRC, CAR did not assume any "downsizing" of the vehicle sales fleet or significant reduction in performance by vehicles in any segment as a means for increasing fuel economy standards by 2025.

For comparison purposes, CAR researchers chose to use the four fuel economy scenarios developed by the EPA/NHTSA Technical Assessment Report: 47, 51, 56 and 62 mpg. Each scenario was trended from the 2008 model year fuel economy ratings.[46] Each of the fuel economy scenarios represents a rate of CO_2 reductions from the years 2017 to 2025. The rates of CO_2 reduction of 3, 4, 5 and 6 percent convert to fuel economy targets of 47, 51, 56, and 62 mpg respectively. Please note that, while the EPA/NHTSA TAR evaluates incremental cost from a 2016 vehicle to a 2025 vehicle, this study will evaluate the incremental cost from a 2008 vehicle to a 2025 vehicle.

CAR determined the most cost-effective technology mix to meet each standard. Using the technology pathways and costs described earlier, along with market caps for certain technology pathways, CAR researchers estimated the best (i.e., least cost) technology mix for each scenario. Using these shared forecasts, each technology's percent contribution to the fuel efficiency target and weighted cost of implementation, was calculated. The combined weighted cost of implementing each of these technologies provides an average per vehicle cost estimate for obtaining the higher mile per gallon requirement in each scenario. The results for each fuel economy scenario follow:

Scenario I: (47 mpg CAFE standard, 37.6 "real world fuel economy") - 3 Percent Decrease in CO2: The base case assumes a continuation of the fuel economy increase from the 2010 to 2016 regulation. The 47 mpg target is equivalent to a 70.9 percent increase from the 2008 actual fleet mpg. The estimated cost of achieving the target is $3,744.

Scenario II: (51 mpg CAFE standard, 40.8 "real world fuel economy") - 4 Percent Decrease in CO2: The next scenario represents an average CO_2 reduction of 4 percent, or a corporate average fuel economy of 51 mpg, by the year 2025. The case includes a dramatic shift toward stop/start, HEV and PEV technology and a corresponding per vehicle cost increase of $5,270.

Scenario III: (56 mpg CAFE standard, 44.8 "real world fuel economy") - 5 Percent Decrease in CO2: At a 5 percent reduction in CO_2 emission per year, or a fuel economy of 56 mpg by 2025, the next scenario experienced a major shift to HEV and PHEV technology. Meeting this standard would increase the average cost of a vehicle by $6,714.

Scenario IV: (62 mpg CAFE standard, 49.6 "real world fuel economy") - 6 Percent Decrease in CO2: The final scenario of 62 mpg by 2025 represents a yearly reduction of CO_2 by 6 percent. The stretch case assumes standards at the high-end of what is currently being considered by the U.S. government. A major shift to PHEV technology occurs as only two technologies, PHEV and BEV, are capable of achieving the targeted fuel economy. Meeting this standard would increase the average cost of a vehicle by $9,790.

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[46] The EPA initially reported a preliminary estimate of 31.4 MPG for the 2008 new passenger car fleet, and 23.6 MPG for the 2008 new light truck fleet, resulting in a non-weighted average of 27.5. These numbers have since been revised to 31.5 and 23.6 MPG for the new car and light truck fleets respectively, but the preliminary estimates and their non-weighted average of 27.5 were used for this paper.

CAR then forecasts the U.S. market for light vehicles, the U.S. production of such vehicles and employment in the U.S. motor vehicle manufacturing industry in 2025. A fairly simple formula, shown below, is used to calculate the economic value for vehicle buyers of higher fuel economy and safety mandates through 2025. CAR labels this construct as net price. A baseline 2009 price of $28,966 for new light vehicles, supplied by the National Automobile Dealers Association (NADA), is used as the starting point in this calculation. The baseline or retail price is adjusted first by the four different scenarios or fuel economy technology manufacturing cost estimates used in Equation 1. These costs (in 2009 $) range from $3,744 (37.6 mpg), to $5,270 (40.8 mpg), to $6,714 (44.8 mpg) to $9,790 (49.6 mpg).

Equation 1: Formula for Net Price

Net Price (2009 $) =
 Baseline Price ($28,966)
 + Fuel Economy Technology Manufacturing Cost
 + Cost of New Mandated Safety Equipment
 + Charging Equipment
 + PV of Electricity Usage Cost
 − PV of Fuel Savings (at $3.50 and $6.00/gal. 2009 dollars)

CAR then includes the likely cost of additional safety mandates during 2010 -2025 as well as the cost of additional environmental mandates such as increased recycling and the prohibition of many chemicals or materials in manufacturing deemed as "hazardous" by environmental authorities. CAR's Transportation Systems Analysis Group developed an estimate of such costs. A range of safety technologies was considered, with most of them concentrated in the accident avoidance area. Costs in 2009 dollars are expected to range from $1,500 to $3,000 per unit.

The percentage increase in net price for each of the four 2025 mpg scenarios, due to the cost of meeting higher fuel economy and safety mandates and the corresponding markup, are also presented in Table 13. The base price is the average price for new motor vehicles in 2009, of $28,966. The effect of higher gasoline or fuel prices was apparent, as shown in Table 13. The net price increase is lower at each fuel economy mandate level or scenario, at $6.00 per gallon versus $3.50 per gallon. Obviously, this reflects the higher value of fuel savings (in dollar terms) for the consumer. Thus, the lowest net price change in percentage terms is -2.1 percent ($606 in extra value to the consumer) at a mandate level of 37.6 mpg in a market with $6.00 per gallon gasoline. The highest net price change is 27.7 percent ($8,026 in extra cost to the consumer) at a mandate level of 49.6 mpg in a market with $3.50 per gallon gasoline. Such price changes are not trivial for the average vehicle. It should be recognized that CAR did not change the essential attributes of the vehicles available for sale in 2025 compared to 2009, except for fuel economy and safety content.

In order to estimate the effect of increases in the net price of new vehicles on new vehicle sales or revenue, CAR estimated the own price elasticity of vehicle demand using an econometric model. This allowed CAR to estimate the effects of higher mandated net prices for new vehicles on sales and vehicle prices in 2025. Eight sales and average price levels were estimated, one for each fuel economy scenario and fuel price level. CAR also uses a calculated sourcing ratio for U.S. production and a trend analysis on

automotive labor productivity to estimate eight production and employment levels for the U.S. automotive industry in 2025. All but one economic scenario were significantly lower in terms of U.S. production and employment than the baseline case without mandates.

Based on the results, CAR believes the risk connected to mandating permanent fuel economy standards in the long run is very serious. In this study, for example, CAR estimated the potential cost to the consumer of a 49.6 mpg fuel economy standard as well as likely safety technology mandates through 2025. The cost to the consumer of purchasing a motor vehicle would rise by nearly 40 percent and the net cost by 27.7 percent over five years. As a result, U.S. sales of vehicles would fall by 5.4 million units and U.S. vehicle production by 3.3 million units. Motor vehicle and parts manufacturing employment would fall by 264,500, causing a total employment loss for the U.S. economy of 1.69 million. This loss would happen by 2025 but would start to cumulate with the increase in standards in 2017. Requirements to downsize vehicles would only increase these loss estimates, as the consumer value of vehicles would be seriously reduced. The average age of vehicles on U.S. highways and roads would certainly rise from its record level of 10.4 years in 2010, since it is assumed that consumers will still have the option of holding on to their remarkably durable vehicles for a much longer period of time. This would reduce the effect of safety and fuel economy mandates, as the replacement rate for operating vehicles would fall to record low levels.

The motor vehicle manufacturing industry is the largest manufacturing industry in the United States. This marvelous job and income machine, now contributing so much to the comeback of the U.S. economy after a severe recession, will be placed at serious economic risk if the industry is committed by law to the use of technologies that are too expensive or inefficient or to the production of vehicles that consumers do not want or need. That is why the potential cost of a rush by regulatory authorities to mandate permanent, long-run fuel economy standards could be very high in both economic and social terms. The automotive industry is a high capital cost, long product cycle industry. The 2012-2025 period contains only two standard vehicle platform cycles and one powertrain product cycle at current development rates. These product cycles will cost the industry many tens of billions of dollars; major errors in forecasting technology development and efficiency or consumer acceptance could put a vast investment at risk. This risk includes the potential of a second automotive crisis threatening the very existence of the U.S. motor vehicle industry. Technical progress of these cycles must be continually monitored. If progress does not occur, prices for consumers will rise dramatically and U.S. sales and production of vehicles will fall.

The use of older vehicles, and the reduction of value in new vehicles by 2025, will severely impact the personal mobility of Americans and, thus, their personal freedom. This freedom, based on the unparalleled mobility provided by modern vehicles, currently allows Americans the greatest possible range and efficiency to search for and obtain employment and to maximize the value of their purchasing, the value of their leisure time and the value of their social and family connections. All of these freedoms are under threat by extreme mandates and, if restricted, will lower the standard of living in the United States for years to come.

A Policy Recommendation

CAR has a major policy recommendation based on the results and conclusions contained in this study. CAR proposes that the EPA and NHTSA, under their current statutory authority, adopt a periodic review process of the proposed and final MY 2017-2025 fuel economy and greenhouse gas rules. The review process would permit the agencies to determine (on an ongoing basis) whether fuel economy and greenhouse gas standards should be adjusted, based on consumers' willingness to buy vehicles that must comply with the standards, as well as any new developments in technology, costs, safety, fuels, infrastructure and other relevant factors. In addition, the review process would allow the agencies to determine what other developments or policies might be needed to achieve the standards.

CAR believes that FE technology progress must be reviewed on a regular basis and mandates adjusted accordingly to set realistic goals. A permanent NRC/NAS review committee should be formed to monitor real FE technology development; the committee should be comprised of representatives from leading manufacturers, engineering service firms, and government regulators with a role for environmental NGOs and academics.

CAR believes a new process is needed for the review of technologies, the consumer market and proposed fuel economy standards. CAR further believes this review process should be ongoing, even after the standards have been mandated. CAR recommends a periodic review process be completed every three years. The need is justified by the many uncertainties existing for the major technologies being considered for improving fuel economy and the equally uncertain prospects for consumer acceptance of these technologies in the light vehicle market. It is important that this review process begin immediately, prior to the NHTSA/EPA deadline of July 31, 2011. CAR proposes that workshops and meetings be organized by NHTSA/EPA without delay.

The risk of permanent, inflexible mandates can be minimized through periodic review. The need for such reviews may, indeed, pass in time as technologies develop and as the market for new products becomes better understood. The review process is available to EPA, NHTSA, and CARB and should be connected to rule-making. The global automotive industry has never been more competitive. Many new technologies will appear and be tested in auto markets all over the world. Vehicle firms operating in the U.S. market will have every incentive to employ these technologies if they are efficient and if there is consumer support. If they don't employ the technologies, other companies will. A flexible standards-setting process permitting automotive firms to introduce the most valuable product in an era of ever-rising energy prices is the best and surest way of improving fuel economy and reducing emissions in the long run.

Appendix I: Fuel Economy Technology Segmentation

Table 15: Fuel Economy Technology Segmentation without Air Conditioning Credits

Baseline Target MPG: 27.5
Baseline Real MPG: 22

Pathway	Source of Estimate	FE Improvement (FE2025/FEbaseline)	2025 Total Estimated Incremental Cost	MPG Target: 47 / MPG Real: 37.6 Share	Contrib to FE	Weighted cost	MPG Target: 51 / MPG Real: 40.8 Share	Contrib to FE	Weighted cost
1) Spark-Ignited	NRC	1.41	$2,105	1.5%	1.2%	$32	0.0%	0.0%	$0
2) SI Extended Mass	CAR	1.60	$3,012	80.0%	74.9%	$2,409	0.0%	0.0%	$0
3) SI Extended Stop/Start	CAR	1.67	$3,855	0.0%	0.0%	$0	68.5%	61.6%	$2,641
4) Compression-Ignited	NRC	1.60	$5,757	0.0%	0.0%	$0	0.0%	0.0%	$0
5) CI w/mass reduction	CAR	1.85	$6,664	8.1%	8.8%	$540	8.1%	8.1%	$540
6) Hybrid Electric (HEV)	NRC	1.78	$5,364	0.0%	0.0%	$0	0.0%	0.0%	$0
7) Hybrid Electric - Extended Mass (HEV-E)	CAR	2.10	$6,296	8.4%	10.3%	$529	13.4%	15.2%	$846
8) Plug-in Hybrid Electric (PHEV)	CAR/NRC	2.50	$12,670	1.1%	1.6%	$139	9.1%	12.2%	$1,149
9) Battery Electric Vehicle (BEV	CAR	6.00	$10,584	0.9%	3.2%	$95	0.9%	2.9%	$95
Total				100.0%	100.0%	$3,744	100.0%	100.0%	$5,270

Baseline Target MPG: 27.5
Baseline Real MPG: 22

Pathway	Source of Estimate	FE Improvement (FE2025/FEbaseline)	2025 Total Estimated Incremental Cost	MPG Target: 56 / MPG Real: 44.8 Share	Contrib to FE	Weighted cost	MPG Target: 62 / MPG Real: 49.6 Share	Contrib to FE	Weighted cost
1) Spark-Ignited	NRC	1.41	$2,105	0.0%	0.0%	$0	0.0%	0.0%	$0
2) SI Extended Mass	CAR	1.60	$3,012	0.0%	0.0%	$0	0.0%	0.0%	$0
3) SI Extended Stop/Start	CAR	1.67	$3,855	36.0%	29.5%	$1,388	26.9%	19.9%	$1,038
4) Compression-Ignited	NRC	1.60	$5,757	0.0%	0.0%	$0	0.0%	0.0%	$0
5) CI w/mass reduction	CAR	1.85	$6,664	8.1%	7.4%	$540	8.1%	6.7%	$540
6) Hybrid Electric (HEV)	NRC	1.78	$5,364	0.0%	0.0%	$0	0.0%	0.0%	$0
7) Hybrid Electric - Extended Mass (HEV-E)	CAR	2.10	$6,296	35.7%	36.9%	$2,250	0.0%	0.0%	$0
8) Plug-in Hybrid Electric (PHEV)	CAR/NRC	2.50	$12,670	19.3%	23.7%	$2,441	64.1%	71.0%	$8,117
9) Battery Electric Vehicle (BEV	CAR	6.00	$10,584	0.9%	2.7%	$95	0.9%	2.4%	$95
Total				100.0%	100.0%	$6,714	100.0%	100.0%	$9,790

Table 16: Fuel Economy Technology Segmentation with Air Conditioning Credits

Baseline Target MPG: 27.5
Baseline w/AC MPG: 27.5
MPG Target: 47 MPG w/ AC: 43.5
MPG Target: 51 MPG w/ AC: 46.9

Pathway	Source of Estimate	FE Improvement (FE2025/FEbaseline)	2025 Total Estimated Incremental Cost	Share	Contrib to FE	Weighted cost	Share	Contrib to FE	Weighted cost
1) Spark-Ignited	NRC	1.41	$2,405	68.3%	60.8%	$1,643	3.5%	2.9%	$84
2) SI Extended Mass	CAR	1.60	$3,312	13.2%	13.4%	$437	78.0%	73.2%	$2,583
3) SI Extended Stop/Start	CAR	1.67	$4,155	0.0%	0.0%	$0	0.0%	0.0%	$0
4) Compression-Ignited	NRC	1.60	$6,057	0.0%	0.0%	$0	0.0%	0.0%	$0
5) CI w/mass reduction	CAR	1.85	$6,964	8.1%	9.5%	$564	8.1%	8.8%	$564
6) Hybrid Electric (HEV)	NRC	1.78	$5,664	0.0%	0.0%	$0	0.0%	0.0%	$0
7) Hybrid Electric - Extended Mass (HEV-E)	CAR	2.10	$6,596	8.4%	11.2%	$554	8.5%	10.5%	$561
8) Plug-in Hybrid Electric (PHEV)	CAR/NRC	2.50	$12,970	1.1%	1.7%	$143	1.0%	1.5%	$130
9) Battery Electric Vehicle (BEV)	CAR	6.00	$10,884	0.9%	3.4%	$98	0.9%	3.2%	$98
Total				100.0%	100.0%	$3,439	100%	100.0%	$4,020

Baseline Target MPG: 27.5
Baseline w/AC MPG: 27.5
MPG Target: 56 MPG w/AC: 51.1
MPG Target: 62 MPG w/AC: 56.0

Pathway	Source of Estimate	FE Improvement (FE2025/FEbaseline)	2025 Total Estimated Incremental Cost	Share	Contrib to FE	Weighted cost	Share	Contrib to FE	Weighted cost
1) Spark-Ignited	NRC	1.41	$2,405	0.0%	0.0%	$0	0.0%	0.0%	$0
2) SI Extended Mass	CAR	1.60	$3,312	0.0%	0.0%	$0	0.0%	0.0%	$0
3) SI Extended Stop/Start	CAR	1.67	$4,155	68.5%	61.5%	$2,846	36.0%	29.5%	$1,496
4) Compression-Ignited	NRC	1.60	$6,057	0.0%	0.0%	$0	0.0%	0.0%	$0
5) CI w/mass reduction	CAR	1.85	$6,964	8.1%	8.1%	$564	8.1%	7.4%	$564
6) Hybrid Electric (HEV)	NRC	1.78	$5,664	0.0%	0.0%	$0	0.0%	0.0%	$0
7) Hybrid Electric - Extended Mass (HEV-E)	CAR	2.10	$6,596	12.7%	14.4%	$841	35.5%	36.7%	$2,345
8) Plug-in Hybrid Electric (PHEV)	CAR/NRC	2.50	$12,970	9.8%	13.1%	$1,265	19.5%	23.9%	$2,523
9) Battery Electric Vehicle (BEV)	CAR	6.00	$10,884	0.9%	2.9%	$98	0.9%	2.7%	$98
Total				100%	100.0%	$5,614	100%	100.0%	$7,026

Appendix II: Forecast of U.S. Light Vehicle Demand

The U.S. light vehicle demand consists of personal consumption expenditure, private fixed investment and government spending on new motor vehicles. An autoregressive model, shown as follows, is formulated to forecast 2025 light vehicle demand:

$$MVEt = \alpha + \beta 1 \ HOUSEHOLDS_t + \beta_2 GDP_t + \beta_3 INCOME_t + U_t$$

$$U_t = \rho 1 U_{t-1} + \rho 2 U_{t-2} + \epsilon_t$$

Where

MVE = Total motor vehicle expenditure, billions of dollars.
$HOUSEHOLDS$ = Number of U.S. households in the United States, thousands.
GDP = Gross Domestic Product in billions of 2005 chained dollars.
$INCOME$ = Personal Income in billions of 2005 chained dollars.
Source : National Income and Product Accounts, Bureau of Economic Analysis, Bureau of Labor Statistics, U.S. Department of Labor.

And U_t is an autoregressive term of order two which incorporates the residuals from the past two observations into the regression model for the current observation. All variables are converted into logarithm forms.

The annual data retrieved from Bureau of Economic Analysis covered in the period from 1967 to 2009. The regression result is shown, as follows, with t-Statistic in parentheses:

$$\widehat{MVE} = -17.82 - .338 \cdot HOUSEHOLDS + 4.739 \cdot GDP - 1.822 \cdot INCOME + U$$

$$(-1.11) \quad (-.26) \quad\quad (7.13) \quad\quad (-2.49)$$

$$U = 1.527 \cdot U_{t-1} - .561 \cdot U_{t-2} + \epsilon_t$$

$$(9.88) \quad\quad (-3.85)$$

To forecast the 2025 motor vehicles expenditure, a measurement of 2.5 percent GDP and personal income growth rate is estimated. Household growth rate is estimated to be 1.0 percent from 2009 to 2025, parallel to the Census Bureau's U.S. population projection through 2025.

Once an estimate of 2025 total motor vehicle expenditures is forecasted, the expenditure is divided by the vehicle average retailer price, and an estimate of 2025 light vehicle sales is yielded. The U.S. light vehicle average retail price is provided by the National Auto Dealer Association (NADA).[47] The 1998-2009 NADA prices indicate an average inflation at 2.0 percent per year, which is carried over through the forecasted period to yield a 2025 vehicle average price.

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[47] NADA Price Data: Automotive Executive, National Association of Automobile Dealers, 1995-2010.

Appendix III: Calculation of Short and Long Run Price and Income Elasticities

Calculation of Short-Run Price and Income Elasticities

The dynamic characteristics of short-run price and income elasticities are evaluated through a quarterly model of motor vehicle demand shown as follows:

$$AUTO_t = \alpha + \beta_1 INCOME_t + \beta_2 PROFIT_t + \beta_3 PPI_t + \beta_4 CPI\_USED_t + u$$

$$u = \sum_{i=1}^{6} \theta_i \epsilon_{t-i} + \epsilon_t$$

Where

$AUTO$ = Total private motor vehicle expenditure, billions of dollars.
$INCOME$ = Personal Income excluding current transfer receipts, billions of dollars.
$PROFIT$ = Corporate profits with inventory valuation adjustment, billions of dollars.
PPI = Producer Price Index – Motor Vehicles
CPI_USED = Consumer Price Index – Used Vehicles

And u is the moving average process of order six which is generated by a weighted average of random disturbances going back six quarters.

The data covered the period from Q1 1995 to Q1 2010. The regression result is shown as follows with t-Statistic in parentheses:

$$\widehat{AUTO} = 572.07 + .039 \cdot INCOME - .0178 \cdot PROFIT - 5.393 \cdot PPI + 1.674 \cdot CPI_{USED} + u$$
$$\quad\quad (1.38) \quad\quad (2.44) \quad\quad\quad\quad (-0.56) \quad\quad\quad\quad (-2.07) \quad\quad\quad (3.26)$$

$$u = .807 \cdot \epsilon_{t-1} + .744 \cdot \epsilon_{t-2} + .934 \cdot \epsilon_{t-3} + .901 \cdot \epsilon_{t-4} + .821 \cdot \epsilon_{t-5} + .315 \cdot \epsilon_{t-6} + \epsilon_t$$
$$(5.63) \quad\quad\quad (4.38) \quad\quad\quad (5.99) \quad\quad\quad (6.39) \quad\quad\quad (5.70) \quad\quad\quad (2.02)$$

$$R^2 = 0.907; \text{ D-W Stat} = 1.93; \text{ F-Statistic} = 48.49$$

In order to calculate arc elasticity of interested variables, variable means are used in elasticity calculation. The calculations are shown as follows:

Short Run Price Elasticity:
$$\eta_P^{SR} = \frac{dAUTO}{dPPI} \cdot \frac{\overline{PPI}}{\overline{AUTO}} = (-5.393) \cdot \frac{137.47}{385.96} = -1.92$$

Short Run Income Elasticity:
$$\eta_I^{SR} = \frac{dAUTO}{dINCOME} \cdot \frac{\overline{INCOME}}{\overline{AUTO}} = 0.039 \cdot \frac{8364}{385.96} = 0.84$$

Calculation of Long Run Price and Income Elasticities

In order to calculate long-run elasticities, an econometric model with annual data was formulated. Variable *PROFIT* was dropped because of multicollinearity. Variable *PPI* was replaced by *RP*, the relative price of new vehicle to used vehicle. The data covered the period between 1978 and 2009. The longer span of data period allowed both the dependent and explanatory variables change beyond the short term, while eliminating short-run fluctuations. The result is shown as follows with t-Statistic in parentheses:

$$\widehat{AUTO} = 62.69 + .05557 \cdot INCOME - 1.569 \cdot RP + u$$

$$\qquad\qquad (0.60) \quad\ (8.60) \qquad\qquad\quad (\text{-}2.04)$$

$$u = 1.137 \cdot \epsilon_{t-1} + .372 \cdot \epsilon_{t-2} + \epsilon_t$$

$$\qquad (6.05) \qquad\qquad (1.89)$$

$$R^2 = 0.97; \text{D-W Stat} = 1.82; \text{F-Statistic} = 200.00$$

The long-run arc elasticities are calculated based on variable means:

Long-Run Price Elasticity:
$$\eta_P^{LR} = \frac{dAUTO}{dRP} \cdot \frac{\overline{RP}}{\overline{AUTO}} = (-1.569) \cdot \frac{102}{276.45} = -0.58$$

Long-Run Income Elasticity:
$$\eta_I^{LR} = \frac{dAUTO}{dINCOME} \cdot \frac{\overline{INCOME}}{\overline{AUTO}} = .05557 \cdot \frac{6683}{276.45} = 1.34$$

Next, 16-year arc elasticity was calculated to estimate the impact over the next sixteen years. The result shown below was used in the study to evaluate the impact of a change in price on motor vehicle expenditure.

Long-Run (16-Year) Price Elasticity:

$$\eta_P^{16y} = \frac{dAUTO}{dPPI} \cdot \frac{RP_{1994-2009}}{AUTO_{1994-2009}} = (-1.569) \cdot \frac{94.867}{381.69} = -0.39$$

Long-Run (16-Year) Income Elasticity:

$$\eta_I^{16y} = \frac{dAUTO}{dINCOME} \cdot \frac{INCOME_{1994-2009}}{AUTO_{1994-2009}} = .05557 \cdot \frac{8209}{381.69} = 1.20$$

Appendix IV: Calculation of U.S. Sourcing Ratio

The U.S. light vehicle sales consists of sales of domestic vehicles, sales of imported vehicles and the change of inventory. The U.S. light vehicle production can be categorized into three groups: vehicles sold in the United States, vehicles exported and the change of inventory. The change of inventory can be seen as an error term in the long run, and its expectation value is zero; therefore, the sales and production equations are written as follow:

(1.1) $S = SDV + IM$
(1.2) $P = SDV + EX$

Where

S =   U.S. light vehicle sales
SDV =   Sales of domestic vehicles
IM =   Sales of imported vehicles
P =   U.S. light vehicle production
EX =   Vehicle exports

Since the sales of domestic vehicles is a subset of total vehicle sales and the vehicle exports is a subset of production, the equations can be rewritten as follow:

(2.1) $S = \beta_1 \cdot S + (1 - \beta_1) \cdot S$
(2.2) $P = \beta_1 \cdot S + \beta_2 \cdot P$

Where

β_1 = share of domestic vehicle sales to total sales
β_2 = share of exports to U.S. production

Rewrite equation (2.2) and we get:

(3) $\dfrac{P}{S} = \dfrac{\beta_1}{1 - \beta_2}$

Due to import competition and globalized automotive manufacturing, the shares of domestic vehicle sales have been falling, and the U.S. vehicle production for exports has been growing, since the end of twentieth century. It is projected the share of domestic sales will be as low as 48 percent, and the production for exports will reach 20 percent. As a result, an assumption of a 60 percent sourcing rate was used to calculate the U.S. light vehicle production in 2025.

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