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U.S. Autos & Auto Parts

Fuel Economy Focus: Perspectives on 2020 Industry Implications

- Industry Overview

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- **What's New?** — In collaboration with Ceres and the Investor Network on Climate Risk, we, along with the University of Michigan Transportation Research Institute, Baum and Associates, Meszler Engineering Services, and the Natural Resources Defense Council, evaluated the potential impact that changes to the U.S. Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emissions program may have on the industry in 2020. The analysis is meant to provide investors with a framework of thinking about the potential industry impact from changing regulations. We note that analyzing this dynamic subject involves making assumptions that are subject to a healthy debate, and therefore we also provide sensitivity analysis to help investors frame key inputs into the model.

- **New CAFE and GHG Emission Standards** — In May 2010, President Obama directed EPA and NHTSA to work with California to develop the next phase of the National Program (for model years 2017-2025). The agencies are considering a range of standards representing an annual decrease in carbon dioxide (CO_2) emissions of 3 to 6 %—that is, nominally a range of 47mpg to 62mpg in 2025. The federal agencies and California have committed to propose the new standards by September 1, 2011.

- **Key Takeaways** — Our baseline analysis suggests that a future improvement in fuel economy may actually have positive implications for sales units and variable profits for both the industry and the Detroit 3 in particular. In the baseline scenario, we assumed an industry-wide standard in 2020 of 42mpg (6% improvement per year). Under the simulation, the Detroit 3 gain relative to the industry due to a number of factors, including: (1) Narrowing the historical gap between Detroit 3 fuel economy and competitors; and (2) Light trucks and larger cars, in which the Detroit 3 sport a greater share, have greater potential to add consumer value through improved fuel economy than do smaller cars and car-based trucks. This is because future fuel economy increases have a greater impact on the fuel economy of these larger vehicles, thereby providing more utility to the consumer, and since full-size trucks tend to be used for commercial purposes, this is a key factor in the purchase decision. Finally, the prices—and therefore the estimated variable profits—are higher for trucks and larger cars. Key sensitivities to the baseline assumptions are provided as well.

- **Suppliers of Key Technologies Will Benefit**— The U.S. auto industry is still in the early stages of adopting fuel saving technologies to meet rising regulatory standards. Within our coverage universe, key beneficiaries with relevant technologies include BorgWarner (BWA) and Johnson Controls (JCI). BorgWarner appears best positioned to benefit as the company derives most of its sales from fuel savings technologies such as turbochargers and dual-clutch transmissions.

See Appendix A-1 for Analyst Certification, Important Disclosures and non-US research analyst disclosures.

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U.S. Autos: CAFE and GHG Emissions

Background

In early 2010, President Obama announced that the U.S Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) would work with California to develop fuel economy and greenhouse gas (GHG) emission standards for the years 2017-2025. In the Interim Joint Technical Assessment issued by EPA, NHTSA, and the California Air Resources Board (CARB) in September 2010, the agencies assessed a series of scenarios ranging from 3% (resulting in a nominal standard of 46.8mpg in 2025) to 6% (resulting in a nominal standard of 62.1mpg in 2025) annual decreases in CO_2 emissions. To assess the most challenging scenario for the auto industry, this report attempts to analyze the potential impact on the auto industry in 2020, including overall financial impacts, and impacts on individual manufacturers' vehicle mix and suppliers.

Regulatory Update on Fuel Economy and GHG Standards

Since our last update, EPA and NHTSA have finalized fuel economy and GHG emission standards for new cars and light trucks for model years 2012-2016. Currently, EPA and NHTSA are in the process of developing fuel economy and GHG emission standards for passenger vehicles for model years 2017-2025. European Union GHG emissions standards will continue to be more stringent than those of the U.S., although they would begin to converge if the U.S. adopts the 6% scenario.

Phase I of the National Program: 2012-2016

In May 2009, President Obama announced the first national policy (the "National Program") governing both fuel economy and GHG emission standards for new cars and light trucks for model years 2012-2016. This program grew out of an agreement between the automakers, the state of California and the Obama administration in 2009 and had the support of environmentalists, United Auto Workers (UAW) and other states. EPA and NHTSA adopted the final rule in April 2010.

The National Program for 2012-2016 is noteworthy because it was the first time the U.S. set GHG emissions standards for any source, as well as the first time fuel economy standards were meaningfully strengthened in decades. The National Program established that California's program could exist side-by-side with the CAFE and federal GHG programs since compliance with EPA's GHG standards constitutes compliance with those of California. Under section 209 of the Clean Air Act, California is empowered to set its own vehicle emission standards, provided that they are at least as stringent as federal standards, and the state receives a waiver from EPA. Under section 177 of the Clean Air Act, once California receives a waiver, other states are permitted to adopt California's standards as well. In the fall of 2010, the California Air Resources Board (CARB) announced that compliance with EPA's GHG emissions standards would constitute compliance with California's standards, and in April 2010, EPA and NHTSA issued new CAFE and GHG emissions standards for model years 2012 through 2016, requiring an estimated fleet wide average of 34.1 mpg and 250 grams of CO_2 per mile by 2016.

Phase II of the National Program: 2017-2025

In May 2010, President Obama directed EPA and NHTSA to work with California to develop the next phase of the National Program (for model years 2017-2025). In October 2010, EPA and NHTSA issued a Joint Notice of Intent

(NOI), with an Interim Joint Technical Assessment Report (TAR) authored by CARB, NHTSA and EPA, followed by a Supplemental NOI in November 2010. On January 24, 2011, EPA, NHTSA and California announced that both the federal and the California proposed standards would be issued simultaneously by September 1, 2011. Note that while California retains the legal authority to seek to set its own standards, it continues to collaborate and closely coordinate with the federal agencies in developing the new standards.

The TAR found that scenarios ranging from 3% to 6% annual increases in stringency would be technically feasible. These percentages nominally represent a range of 47mpg to 62mpg in 2025, although the actual CAFE standard would be about 5 mpg lower when air conditioning GHG credits are considered. If air conditioning GHG credits and a battery electric vehicle (BEV) penetration of 10% are assumed, then the actual CAFE standard for the gasoline portion of the fleet would be about 10 mpg lower.

According to the TAR, 3% targets can be met primarily with improvements to conventional internal combustion engine (ICE) technology, with no penetration of plug-in hybrid electric vehicles (PHEVs) or full battery electric vehicles (BEVs). Conventional hybrid electric vehicles (HEVs) are a critical strategy for meeting the 5% and 6% targets (about 50% penetration), while the 6% target is the only target that will necessitate significant penetration of PHEVs and BEVs. Note that under all scenarios, mass reduction would be an important strategy, accounting for about 15% to 20% of improvements.

Figure 1. New Fleet Technology Penetration, Model Year 2025

Scenario	Technology	New Vehicle Fleet Technology Penetration				
		Gas & Diesel	HEV	PHEV	BEV	Net Mass Reduction
3%/year	Path A	89%	11%	0%	0%	15%
	Path B	97%	3%	0%	0%	18%
	Path C	97%	3%	0%	0%	18%
	Path D	75%	25%	0%	0%	15%
4%/year	Path A	65%	34%	0%	0%	15%
	Path B	82%	18%	0%	0%	20%
	Path C	97%	3%	0%	0%	25%
	Path D	55%	41%	0%	4%	15%
5%/year	Path A	35%	65%	0%	1%	15%
	Path B	56%	43%	0%	1%	20%
	Path C	74%	25%	0%	0%	25%
	Path D	41%	49%	0%	10%	15%
6%/year	Path A	23%	68%	2%	7%	14%
	Path B	44%	47%	2%	7%	19%
	Path C	53%	44%	0%	4%	26%
	Path D	29%	55%	2%	14%	14%

Source: Interim Joint Technical Assessment, September 2010, EPA, NHTSA, and CARB

Comparison of U.S. and International Standards

Even under the strictest proposal, U.S. standards are expected to be less stringent than many foreign standards; however, they are beginning to converge. The annual rate of improvement between 2016 and 2020 for the 2020 European Union (EU) target of 95 grams per km is 6% per annum, identical to the most stringent proposal under consideration by the U.S. However, the EU is on a faster track, so the EU target in 2020 is virtually identical to the nominal 62 mpg that would be required in 2025 under the 6% improvement scenario.[1]

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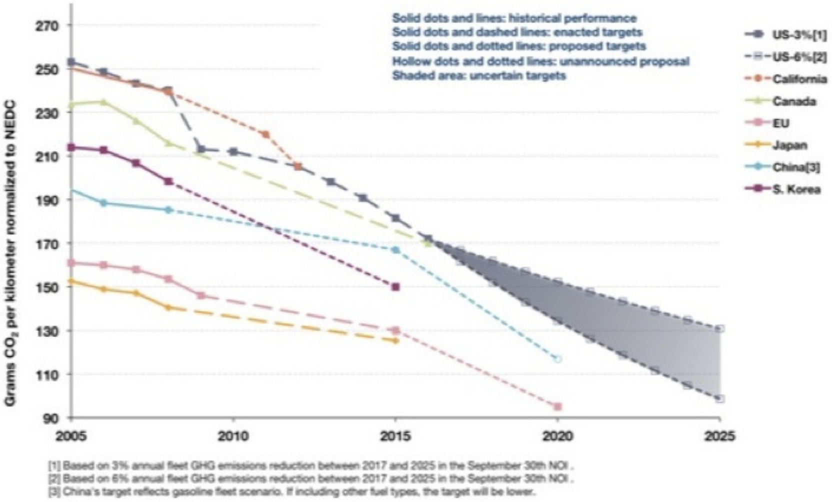
[1] When converted to the EU drive cycle, the U.S. 6% improvement target (143 g/mile) is virtually identical to the EU target in 2020 of 95 g/km.

Figure 2. Historical Fleet CO2 Emissions Performance and Current/Proposed Standards



[1] Based on 3% annual fleet GHG emissions reduction between 2017 and 2025 in the September 30th NOI.
[2] Based on 6% annual fleet GHG emissions reduction between 2017 and 2025 in the September 30th NOI.
[3] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.

Source: Preliminary analysis by International Council on Clean Transportation (ICCT), January 2011

Potential Financial Implications of 2020 Standards

Impacts on Sales and Profits in 2020

Our baseline analysis suggests that improving fuel economy could have positive implications for sales units and variable profits, both for the industry as a whole and the Detroit Three, with the latter possibly fairing better that the industry. Relative to our initial forecast for 2020, improving fuel economy results in a 6% increase in industry sales and a 9% increase in Detroit Three sales. More importantly, total industry variable profit rises by 8% and Detroit Three variable profit rises by 12%. The detailed sales results by segment and automaker are presented in Figure 14 of Appendix A.

These observations indicate that, given our mainstream assumptions about costs and consumer preferences, consumers value the improvements in fuel economy more than the technology's incremental retail cost (which includes variable profit). Variable profits increase more than sales units due to our assumption that variable profit rates do not change, combined with the scenario's overall higher retail prices for vehicles.[2]

In the baseline scenario, the Detroit Three gain relative to the industry as a whole, due to a number of factors in the model. Historically, and in our initial forecast, the Detroit Three lag behind the Japan Three (Honda, Nissan and Toyota) in average fuel economy and the regulations narrow that gap. Trucks and larger cars, in which the Detroit Three are more invested, have greater potential to add consumer value through improved fuel economy than do smaller cars and car-based trucks, in which the Japan Three are more invested. This is because the increases that are required under the National Program have a greater impact on the fuel economy of these larger vehicles, thereby providing more utility to the consumer which results in lower operating costs. Since many of these vehicles are used for commercial purposes, this is a key factor in the purchase decision. And finally, the prices—and therefore the variable profits—are higher for trucks and larger cars than for smaller cars and car-based trucks.

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[2] We assumed lower variable profit rates for hybrids, plug-in hybrids, and all-electric vehicles.

We conducted an econometric analysis of the industry in 2020 to assess the direction of sales and profits based upon the fuel economy requirements described above. In the baseline scenario, we assumed an industry-wide standard in 2020 of 42mpg, a regular unleaded gasoline price of $4.00 per gallon, and that consumers consider only about 48% of future fuel costs (and only seven years of fuel costs) in buying vehicles.

The following sections below detail the steps of the baseline analysis. In recognition that this analysis is subject to a number of debatable assumptions, sensitivities are also provided later in the report.

Sales Forecast 2020

We chose to focus on the year 2020 due to our opinion about the limits of plausibility of detailed long-term forecasts. We developed our forecast of 2020 sales units in two steps before fuel economy improving technologies were applied. The first step was the development of a detailed, bottom-up projection of production and sales at the vehicle configuration level. This included electrified vehicles (hybrid, plug-in, and all-electric) as well as conventional gasoline-powered and diesel-powered vehicles. Detail was provided at the nameplate and powertrain level.

In the second step, we organized the 2015 vehicle configurations into aggregates of segments by manufacturers. These aggregates (along with a projected increase in penetration of electrified vehicles) were then projected to 2020. The 2020 sales forecast, prior to improvements in fuel economy to increase overall industry miles per gallon to 42 mpg, is shown in Figure 3 below.

Figure 3. 2020 Sales Forecast (000's): Prior to Impacts of Higher Fuel Economy (to 42.8 mpg)

Segment	**Ford**	**GM**	**Honda**	**Nissan**	**Toyota**	**Others**	**All automakers**
Car - Luxury	48	151	55	113	195	810	**1,372**
Car - Midsize	509	656	443	370	649	1,181	**3,808**
Car - Small	422	435	495	486	699	1,004	**3,541**
CUV - Luxury	67	48	67	24	163	38	**407**
CUV - Midsize	280	276	174	74	161	465	**1,430**
CUV - Midsize	483	263	225	174	247	437	**1,829**
Minivan	-	-	149	-	132	370	**651**
Pickup - Large	670	649	-	41	128	244	**1,732**
Pickup - Small	-	-	-	60	148	-	**208**
SUV - Large	45	228	-	28	-	-	**301**
SUV - Luxury	10	24	-	-	27	267	**328**
SUV - Midsize	-	-	-	62	76	164	**302**
SUV - Small	-	-	-	-	-	155	**155**
Van - Large	120	75	-	17	-	30	**242**
All Segments	**2,654**	**2,805**	**1,608**	**1,449**	**2,625**	**5,165**	**16,306**

Source: University of Michigan Transportation Research Institute

In our subsequent analysis, we held these 70 market entries fixed in definition and estimated the impacts on sales and profits of introducing technologies that would improve the fuel economy of these specific entries. (Note that we applied the average cost and improvement from the six named automakers to "Others".)

The Detroit Three have 10 entries each. Honda has 7 entries, differentiating it from the other Japan Three automakers (Nissan and Toyota) that have 11 entries each. Other automakers have vehicles that were aggregated into 11 entries.

Econometric Model

The econometric model used to simulate the industry is based on a 70 by 70 matrix of price elasticities and cross-price elasticities. The matrix was derived from historical analysis by General Motors and later published, with permission, by academics and others. The General Motors matrix was also the basis for our 2009 study of CAFE.[3]

In the model, consumers respond to changes in the full cost of vehicles from two sources: changes in price (a capital cost) and the present value of future fuel savings from higher fuel economy (an operating cost). We projected 2020 vehicle prices based on historical information from J.D. Power and Associates, Ward's, and other sources.

In particular, we modeled the consumer demand for each entry as influenced by the prices and fuel costs of the entry itself and the prices and fuel costs of all 69 other entries. The elasticity matrix specified how the changes in prices and fuel economy values influence sales. The full price (purchase price *plus* expected future fuel costs of operation) of each entry was defined by the following:

Full Price = Purchase Price + (Fuel Price Risk Factor) (Present Value of Fuel Costs)

Present Value of Fuel Costs = Function of the Consumer Discount Rate, the Relevant Life of the Vehicle, Expected Future Fuel Prices, and Vehicle Miles Traveled (VMT)

All of the elements in these expressions, except the purchase price, are subjective and depend on consumer preferences. In recognition that these assumptions are subject to a healthy debate, we examine the impacts of a range of subjective values for these factors in the sensitivity analysis of Appendix A.

The fuel price risk factor measures the rate at which consumers are willing to trade reductions in fuel costs for increases in purchase price. For example, a factor of 1.0 would indicate that consumers would be willing to pay $1 for an improvement in fuel economy that resulted in reducing by $1 the present value of fuel costs.

The consumer discount rate is the rate at which consumers discount future savings of fuel, with the discounting including the ordinary preference for money now rather than later, as well as the expected decline in VMT per year as the vehicle ages. The value for VMT in the definition sets the starting value for the annual miles traveled.

The relevant life of the vehicle is the number of years of future fuel costs that the consumer is influenced by in choosing among the 70 alternative entries. Some observers have claimed that consumers consider only the first 3 years, while others have claimed that consumers consider many more years.

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[3] "CAFE and the Auto Industry Revisited; A Growing Auto Investor Issue, 2011-2016," Citi, October 13, 2009.

Expected future fuel prices are what consumers buying new vehicles anticipate facing over the length of the relevant life of the vehicle. We have chosen to treat this as a single value that does not vary over time. The risk factor in the definition of full price serves to adjust for attitudes of consumers toward risks in this fuel price relative to risks in capital costs of the vehicle.

The present values of future fuel savings for 2020 entries were projected using the technology-driven improvements in fuel economy described in another section of this report and mainstream assumptions about consumer preferences with respect to time and risk.

We conducted an analysis of the sensitivity of our results to differing assumptions about consumer preferences (but not to differing assumptions about variable profit rates or manufacturing costs). The sensitivity analysis shows, with respect to Detroit Three profits, (1) that negative values (losses by Detroit Three) require harsher assumptions and (2) that there is more upside than downside to our baseline fuel economy scenario. Details of the sensitivity analysis are in Appendix A.

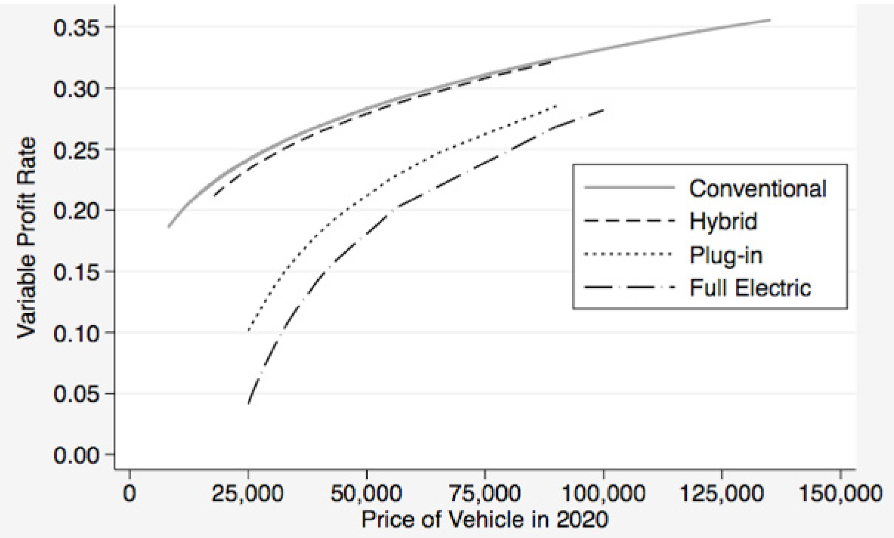
Variable Profit

Our analysis of the impacts of improving fuel economy includes the impacts on variable profit. Projecting sales and prices to 2020 is not an exact science. Neither is projecting variable profit rates.

We projected variable profit rates for the 70 market entries assuming that by 2020 all automakers would be roughly equally profitable, given their target customers and the types of vehicles they sell. For example, an automaker selling less expensive cars has somewhat lower margins than one selling more expensive cars. But the relationship between price and variable profit rate is not linear. We modeled the variable profit rate as a function of price, with the variable profit rate increasing with price but at a diminishing rate.

Conventional vehicles are likely to have the highest variable profit rates at a given price. Among electrified vehicles, we expect that by 2020 the variable profit rates of hybrid vehicles should be converging toward traditionally powered vehicles. Between plug-in and all-electric vehicles, we expect plug-ins to have higher variable profit rates than all-electrics, at a given price. Figure 4 on the following page is a graphical representation summarizing our expectations.

Figure 4. Variable Profit Rate by Powertrain Type



Source: University of Michigan Transportation Research Institute

Baseline Scenario: Technology-Driven Improvements in MPG

In the baseline scenario[4] we developed technology packages that would improve industry-wide average fuel economy to 42 mpg and applied them to the 70 market entries as appropriate and feasible. These packages were characterized by the improvement in fuel economy that each entry realized and by their incremental manufacturing costs.

These improvements in fuel economy are valued by consumers according to the definition of full price using our mainstream assumptions concerning the factors in the definition (Figure 5).

Figure 5. Baseline Scenario Assumptions

Consumer discount rate	12.2%
Consumer relevant life of the vehicle	7 years
Beginning annual vehicle miles traveled (VMT)	15,000
Consumer fuel price risk factor	75%
Expected future price of fuel ($/gal regular gas)	$ 4.00

Source: University of Michigan Transportation Research Institute

For each of the 70 entries, we computed the resulting percentage change in full price. The percentage change in sales units for all 70 entries was then determined by applying the elasticity matrix to the set of 70 percentage changes in full price. We then calculated the sales units of each of the 70 entries by applying these percentage changes in sales. The variable profit analysis was performed by applying our estimated variable profit rates to revenue (unit sales times price) before and after the changes in fuel economy.

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[4] This is denoted as a “baseline” scenario because we also performed a sensitivity analysis (see Appendix A) that involved multiple alternative scenarios.

The financial impacts are detailed in Figure 6, showing that aggregate industry variable profits would increase by 8%, while Detroit Three variable profits would increase by 12%. This increase in variable profits is driven by both increased average retail prices and increased sales. We estimate that vehicle sales could increase by 6% for the industry as a whole, and by 9% for the Detroit Three. Again, sensitivities to assumptions underpinning the baseline scenario are described later in this report.

Figure 6. Baseline Scenario Impacts on Sales and Variable Profits

$ billions	Forecast	Change	% Change
Industry variable profit	108.0	9.1	8%
Detroit Three variable profit	44.1	5.1	12%

$ millions	Forecast	Change	% Change
Industry sales	16.3	1.0	6%
Detroit Three sales	7.0	0.6	9%

Source: University of Michigan Transportation Research Institute

Market Analysis

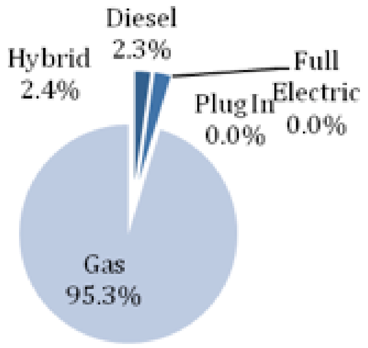
Our analysis also focused on the impact of the CAFE proposal on the various automakers in terms of sales volume, miles per gallon, revenue and profit in 2020. The increase in fuel economy may actually somewhat increase vehicle demand as consumers embrace the reduced operating cost of vehicles that obtain more miles per gallon than would otherwise be available without the fuel economy requirements.

The Role of Alternative Fuel Vehicles

While the focus of many seeking to improve fuel economy has been on hybrid and electric vehicles, the internal combustion engine is expected to remain the primary powertrain for years to come. Diesel engines are used primarily in large pickups, but some increase is occurring in other vehicle segments, often among vehicles offered by European manufacturers (building on their significant share of diesel engines in Europe). Stricter emissions standards for diesels are under development and may slow adoption because the standards will likely increase costs, but stricter standards should not prevent diesels from growing in share.

The graphs below present a *conservative* view of the share of U.S. sales among the various powertrain types. It is important to note that “regular” hybrids are expected to continue to grow even as plug-ins and full electrics enter the market. Each of these alternative vehicle types serves a particular consumer purpose and their varying cost position (including various incentives offered over a period of time) should enable hybrids, plug-ins, and electrics to coexist. Another reason for this result is that different automakers are focusing on different technologies, which will be further described below.

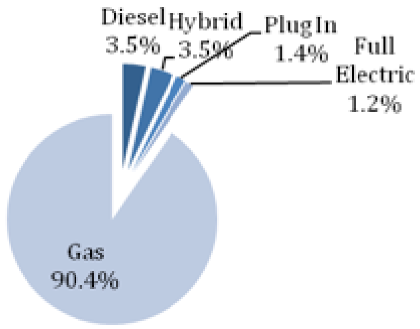
Figure 7. U.S. Sales by Powertrain Type in 2010



Source: Baum and Associates

In 2010, hybrids represented 2.4% of the market in a period of modest sales and low gas prices. The importance of Toyota in the hybrid market (with the Prius being the clear sales leader) had a negative impact on the overall volume of hybrid sales due to the problems that Toyota faced in 2010. A large number of new entries, the increasing price of gasoline, and overall growth in the vehicle market over the next few years will lead to a significant increase in market share for hybrids. Furthermore, the launch of a significant number of plug-ins and full electrics in the near term will enable increased market share going forward.

Figure 8. U.S. Sales by Powertrain Type in 2015E



Source: Baum and Associates

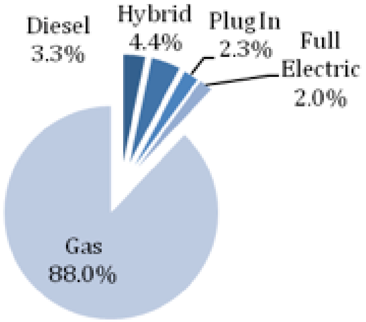
Market shares of alternative vehicles through 2020 are subject to a wide range of factors. The figure below is a very conservative view of the share of alternative fuel vehicles that could occur assuming some combination of the following:

1. Relatively low gas prices
2. Modest or no consumer purchase incentives
3. Modest or no manufacturer incentives

4. A relatively modest decline in costs, including those affecting the lithium ion battery, the associated electronic controls and cooling mechanisms, and/or key materials and components

The key takeaway is that the automakers are expected to be able to meet the required fuel economy regulations in 2020 with the modest share of alternative fuel vehicles shown below.

Figure 9. U.S. Sales by Powertrain Type in 2020E



Source: Baum and Associates

Specific Impacts on Automakers

This detailed analysis examines individual companies' respective strategies to meet the proposed CAFE requirements. The automakers included are General Motors, Ford, Honda, Nissan, Toyota and Hyundai/Kia.

General Motors

GM's most visible product when it comes to fuel efficiency is the extended-range electric Chevrolet Volt, namely with its ability to often run only on electricity and the ability to deal with "range anxiety" by having the engine keep the batteries charged after the initial charge has been used. The Volt technology is also expected to be utilized in a number of other products in the U.S. and abroad, in order to leverage and reduce the cost as well as increase the demand for this technology in a variety of vehicle segments.

GM has not embraced full electric technology, since it believes the extended range approach utilized in the Volt will provide the consumer with maximum flexibility. However, it has experience in regular hybrids of several types, including the Two Mode used in larger vehicles, regular hybrids, and mild hybrids (primarily utilizing stop/start technology and a high efficiency alternator).

Besides these advances in powertrains, GM is introducing or has introduced a number of small vehicles including the Chevrolet Cruze, Spark, and Sonic, the Buick Verano and Encore, and a number of other products. GM will continue to leverage its global resources for vehicles and powertrains (and associated technologies) including from its Opel division. Opel has significant responsibility for both vehicle and powertrain design, particularly with respect to smaller vehicles. Like its competitors, GM will offer a large number of vehicles with the most common set of technologies that improve fuel economy in internal combustion engines, namely variable valve lift and timing, direct injection, turbocharging in some cases, mass reduction, electronic power steering (a technology where GM is a market leader) and advanced transmissions (including automated manuals and continuously variable transmissions). While some products continue to be powered by 8-cylinder engines, this share is clearly on the decline and will likely decline further as GM updates its full size pickup and utility lineup in 2013 and 2014.

Ford

Ford's product approach has revolved around harmonizing its global product line under common platforms. One result of that approach has been to significantly expand its small car offerings in the U.S. Beyond modifying its product line, the company is a leader in improving the fuel economy of its powertrain offerings. Ford's EcoBoost (which includes direct injection and turbocharging) is a leading-edge product that is offered in a variety of displacements and products, including the F150 and the new Explorer. Besides being technically advanced, Ford's marketing of the EcoBoost has been very effective as the consumer recognition of the technology has been impressive.

Ford's strategy is to use this product to reduce the displacement of its engines and provide performance and fuel economy that customers will be willing to pay a premium to obtain. This allows for a considerable reduction in the usage of 8-cylinder engines and the growth of 4- and 6-cylinder products. Because the EcoBoost is offered in a variety of displacements (ranging from 1.6 liters to 3.5 liters, with a 1.0 liter 3-cylinder engine scheduled), it can be used across the product line. In the F150, the 3.5-liter V6 is the premium engine and carries a premium price. The new Explorer offers a 2.0-liter 4-cylinder EcoBoost, which provides the appropriate horsepower and torque along with exceptional fuel economy, again at a premium price.

Ford is ahead of most of its competitors in offering start-stop technology that turns off the engine while the vehicle is at a complete stop (e.g. at a traffic light) and then instantly restarts the engine as the driver removes his or her foot from the brake. The technology is quite inexpensive, can improve fuel economy from 4% to 10% and is particularly useful in city driving. The technology is common in hybrids, but Ford will lead its competitors in widespread use of the feature on smaller vehicles with internal combustion engines as early as 2012. Later, the feature will spread to most vehicles except large trucks, and most automakers will incorporate the product. Wider use of the product will occur if the automakers are successful in lobbying the Environmental Protection Administration to change their test cycle, as the current methodology does not give credit to automakers for the fuel savings of start-stop.

Ford is well positioned in regular hybrids such as the Escape, Fusion, and Lincoln MKZ (offered as a no-charge option), but is also moving into the plug-in and full electric market with key products such as the Focus and new products such as the C-Max and Transit Connect. In this way, it is meeting its fuel economy requirements in a variety of forms thereby enabling it to expand production to products that best meet its corporate goals based on consumer acceptance of its products.

Honda

Honda is unusual among the major manufacturers in that it has a very limited product lineup, largely based on two platforms anchored by the Civic and Accord.

Honda's fuel economy has always been among the best in the industry given its heritage as an engine company that has applied its prowess to a variety of products including motorcycles, lawn mowers, snow blowers, automobiles, and even airplanes.

Honda has a long history with regular hybrids, beginning with the launch of the Insight in 1999. Honda's hybrids are less expensive than Toyota's, although they deliver somewhat less improvement in fuel economy. Honda's strategy is based on its belief that there is a strong market for more economical products. However, the Insight has never been as popular as the Toyota Prius and that remains true for the current generation. In 2010, Honda launched the CR-Z as a hybrid-only sports car, but sales have been disappointing due to its high price, disappointing performance, and relatively modest fuel economy increment relative to non-hybrids.

Nonetheless, Honda is adding more hybrids to its product line, including some of its Acura products. The Civic hybrid remains in relatively high volume after the Accord hybrid was terminated due to poor sales. Honda is also developing a full electric car based on the Civic platform. Honda also continues to develop the FCX Clarity, a vehicle powered by fuel cells. Additionally, fuel economy requirements have led Honda to step back from the introduction of larger engines and a rear wheel drive platform.

Nissan

Nissan was a latecomer to alternative engine technology, but has staked its strategy on the all-electric Leaf. The technology will be offered in a number of other Nissan, Infiniti, and Renault (outside the U.S.) products. Production in three locations across the globe should ensure adequate supply of the Leaf.

Nissan's internal combustion engines are highly regarded, particularly in terms of performance, and have average to above average fuel economy. Nissan, along with all other industry players, is improving its capability to provide strong performance and improved fuel economy.

Nissan is a leading user of continuously variable transmissions (CVT), based on products provided by JATCO, a supplier in which it holds a large ownership stake. CVTs generally provide a 5% improvement in fuel economy, compared to standard automatic transmissions.

Besides the Leaf, Nissan also currently offers the Altima in hybrid form (based on a license from Toyota) and is looking to offer its own hybrid technology on its products in the near term. Nonetheless, the full electric technology of the Leaf should represent Nissan's primary focus with respect to alternative fuel vehicles.

Toyota

Toyota is clearly the industry leader in regular hybrids and it is expected continue to leverage this leadership, with several products currently offered and more to come. U.S. sales of the Prius since its launch in 2000 have surpassed 1 million units and should continue to grow as the Prius brand moves from one vehicle to several vehicles. This move includes regular hybrid technology and plug-in and full electric products, as well as additional regular hybrid entries including a wagon and a smaller vehicle. The cost to the company and the consumer of the Prius and related products has continued to drop (with profits thereby increasing) as Toyota has improved its products and reduced its manufacturing costs. Toyota officials have stated that they seek to reduce the cost of the hybrid content in the Prius by an additional fifty % in the next generation product.

Toyota will continue to leverage its leadership in hybrids by offering the technology on other mainstream products including the Corolla, RAV4, and Sienna. These offerings supplement its existing higher-volume hybrid offerings of the Lexus RX450h and HS250h and the Toyota Camry and Highlander.

Besides expanding its hybrid offerings, the company is also working on a high volume plug-in and a number of full electrics, with a RAV4 being developed in partnership with Tesla. Toyota is looking to leverage Tesla's battery technology and its "entrepreneurial spirit" as a means to improve its product line and better connect with customers. Although hybrids will continue to be its primary alternative fuel offering, the company does not want to be left out if other approaches prove popular with consumers.

Over the years, the success of Toyota's products and strong marketing of its fuel-efficient products have led many of its competitors to improve their position and make for a more competitive marketplace, resulting in less of an advantage for Toyota. This advantage may decline further in the future as more stringent CAFE regulations reduce the lead Toyota has enjoyed over its competitors. However, Toyota still has the advantage of a strong capital position and should continue to use this advantage to research and offer a variety of fuel-efficient products across its product line.

Hyundai/Kia

Hyundai (and its affiliate Kia) has gained significant market share recently with strong marketing, improved products with distinctive design, and a number of powertrain innovations. On the new Sonata, only 4-cylinder engines are offered, with a 4-cylinder turbo for those desiring higher performance. Designing the vehicle without a V6 option is unusual in the industry for midsize cars, but it allowed for less weight in the vehicle frame and a number of other fuel saving characteristics.

Both the Sonata and the Kia Optima are now available with a hybrid powertrain. The company is using lithium polymer batteries as opposed to the soon-to-be industry standard lithium ion chemistry. The company is relying upon LG Chem, another Korean-based company, for its battery technology. Compact Power, a subsidiary of LG Chem, is also supplying the battery pack for the Chevrolet Volt and the Ford Focus Electric. Hyundai and Kia are also looking at plug-ins.

Hyundai has recently shown improvement in fuel economy across its product line, with its Model Year 2010 rating higher than all other mainstream automakers (although its lack of large truck product certainly contributes to this result).

The company has attracted attention by pledging fuel economy of 50 miles per gallon by 2025 in a Summer 2010 presentation by John Krafcik, the President and CEO of Hyundai Motor America. It has also pledged that it will release to the public its sales weighted fuel economy results each month. Given that its fuel economy ratings are higher than for its competitors, the company is taking this step as a part of its marketing program.

Fuel Efficiency Technologies and Costs

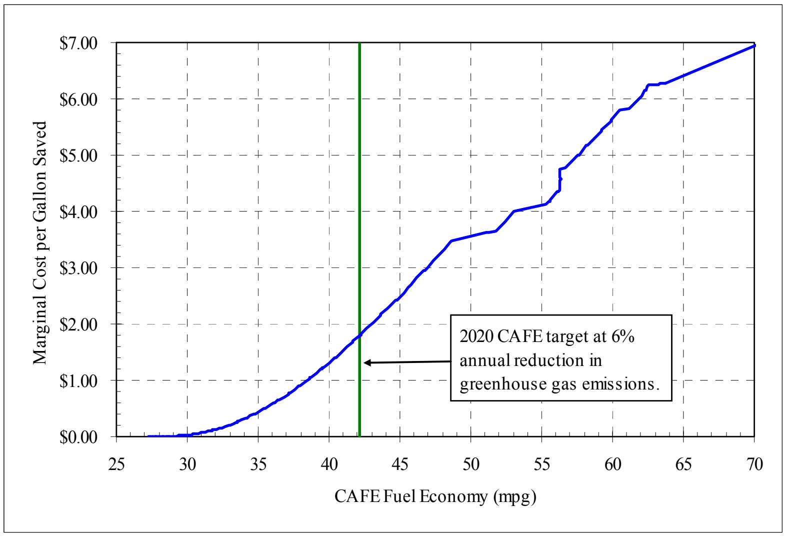
Costs are clearly a key issue in setting new standards and remain a key point of industry debate. For this study, Meszler Engineering Services (MES) undertook a limited meta-analysis to estimate the fuel economy and cost impacts of various vehicle efficiency technologies. Details regarding the analysis can be found in Appendix B.

Cost-Effectiveness of Fuel Economy Increases

Figure 10 shows the marginal cost—from a societal perspective—of a range of fuel economy standards. By expressing cost in terms of the marginal cost per gallon of fuel saved, the cost-effective level of CAFE can be estimated by equating the depicted marginal cost with an expected fuel price. Thus, for example, for fuel prices of $3.00, $3.50, and $4.00 per gallon, CAFE standards of about 47, 49-52, and 53 mpg would be cost-effective on a fleet average basis respectively.[5] The expected value of 2020 CAFE fuel economy evaluated in this study, 42 mpg, is cost-effective (from a societal viewpoint) at a fuel price of $1.80 per gallon. Given that current fuel prices are well above this level, it is hard to envision a scenario in which the necessary investment in fuel economy technology would not be prudent from both a consumer savings and energy security standpoint.

In considering these data, it is important to recognize that the estimated cost of fuel savings does not assume any ancillary benefits for reduced fuel consumption such as the economic savings of reduced foreign energy dependence or the direct savings of reduced military expenditures necessary to protect that dependence. Inclusion of such benefits would further reduce the effective cost of CAFE.

Figure 10. Marginal Fuel Economy Cost in 2020 by CAFE Level



Source: Meszler Engineering Services

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[5] The range for the $3.50 fuel price results from the fact that a discontinuity in the marginal cost curve (when expressed in terms of CAFE fuel economy) spans this marginal cost level.

Appendices

Appendix A. Sensitivity Analysis

We assessed the sensitivity of our results to ranges of alternative assumptions about the consumer preference and expectations factors. Figure 11 shows the values we examined for each of the factors. For each factor we developed 90% confidence intervals.

The minimum column shows the values of the factors that would result in the lowest value (positive or negative) for changes in unit sales and variable profits (of the three alternatives). The maximum column shows the values of the factors that would result in the highest positive value for changes in unit sales and variable profits (of the three alternatives). The baseline column contains our mainstream assumptions that were used in our baseline scenario.

Figure 11. Uncertainties in Consumer Preferences and Expectations

	Scenario Alternatives		
	Minimum	**Baseline**	**Maximum**
Discount rate	17.2%	12.2%	5.2%
Life of a vehicle	3 years	7 years	15 years
Beginning annual VMT	10,000	15,000	20,000
Fuel price risk factor	30%	75%	140%
Future price of fuel ($/gal)	$ 2.00	$ 4.00	$ 7.00

Source: University of Michigan Transportation Research Institute

In the sensitivity analysis we varied the factors two at a time by combining the extreme values (holding the others at their baseline values), generating 20 additional alternative scenarios. Two factors at a time, the alternative scenarios involved combining the minimums in one alternative and the maximums in the other alternative. For example, holding all other factors at their baseline values, we ran the model varying both vehicle life and fuel price, adding two alternative scenarios. In one alternative, life was set to 3 years (minimum) and fuel price to $2 per gallon. In the other, life was set to 15 years and fuel price to $7 per gallon.

The results of the sensitivity analysis for variable profit are shown in Figure 12 (for the industry) and Figure 13 (for the Detroit Three). The rows in the tables are sorted by the swing of the percentage change in variable profit between the two new extreme with extreme alternatives.

Sensitivity Results for Industry

The rows report results for each pair of factors. The cells columns “Minimum & Minimum” and “Maximum & Maximum” define the 20 alternative scenarios. The output value columns report the percentage change in variable profit for the corresponding alternative scenario. For example, the Minimum & Minimum scenario for vehicle life & fuel price results in a 2.7% drop in variable profits for the industry as a whole.

The baseline columns (in input values and output values) are included for the reader’s convenience.

For the industry as a whole, the change in variable profit ranges from a drop of 2.7% to an increase of 24%. (These two values are underlined in the tables below.) Both of these extremes occur with varying vehicle life & fuel price together. The overall high and low values of the output are commonly (but not always) determined by the pair of factors with the greatest swing, as is the case for industry variable profit.

Of the 20 alternative scenarios, there are three in which industry variable profit falls (Min. & Min. for Vehicle Life & Fuel Price, VMT & Fuel Price, and Vehicle Life & VMT), and one in which industry profit is essentially unchanged (Min. & Min. for Discount Rate & Fuel Price). The factors in these alternatives represent the greatest risk to industry profits.

Figure 12. Change in Industry Variable Profit

	Corresponding Input Values			Output Value			
Input Variables	**Min & Min**	**Baseline**	**Max & Max**	**Min & Min**	**Baseline**	**Max & Max**	**Swing**
Vehicle Life and Fuel Price	3 & $2.00	7 & $4.00	15 & $7.00	(2.7%)	8.0%	24.0%	27.0%
VMT & Fuel Price	10,000 & $2.00	15,000 & $4.00	20,000 & $7.00	(1.5%)	8.0%	22.0%	24.0%
Discount Rate & Fuel Price	17.2% & $2.00	12.2% & $4.00	5.2% & $7.00	0.1%	8.0%	21.0%	21.0%
Discount Rate & Vehicle Life	17.2% & 3	12.2% & 7	5.2% & 15	1.0%	8.0%	22.0%	21.0%
Vehicle Life & VMT	3 & 10,000	7 & 15,000	15 & 20,000	(1.1%)	8.0%	19.0%	20.0%
Fuel Price & F.P. Risk Factor	$2.00 & 30%	$4.00 & 75%	$7.00 & 30%	1.2%	8.0%	20.0%	19.0%
Vehicle Life & F.P. Risk Factor	3 & 30%	7 & 75%	15 & 30%	1.7%	8.0%	16.0%	15.0%
Discount Rate & VMT	17.2% & 10,000	12.2% & 15,000	5.2% & 20,000	2.4%	8.0%	16.0%	14.0%
VMT & F.P. Risk Factor	10,000 & 140%	15,000 & 75%	20,000 & 30%	3.6%	8.0%	14.0%	11.0%
Disc. Rate & F.P. Risk Factor	17.2% & 140%	12.2% & 75%	5.2% & 30%	6.0%	8.0%	13.0%	7.0%

Source: University of Michigan Transportation Research Institute

Sensitivity Results for Detroit Three

Figure 13 summarizes results for the Detroit Three and is organized in the same fashion as the table for the industry.

For the industry as a whole, the change in variable profit ranges from a drop of 1.6% to an increase of 29%. (These two values are underlined in the table.) Just as for the industry, both of these extremes for the Detroit Three occur with varying vehicle life and fuel price together.

Of the 20 alternative scenarios, there are two in which Detroit Three variable profit falls (Min. & Min. for Vehicle Life & Fuel Price and for VMT & Fuel Price), and one in which industry profit is essentially unchanged (Min. & Min. for Vehicle Life & VMT). The factors in these alternatives represent the greatest risk to Detroit Three profits.

Figure 13. Change in Detroit Three Variable Profit

	Corresponding Input Values			Output Value			
Input Variables	**Min & Min**	**Baseline**	**Max & Max**	**Min & Min**	**Baseline**	**Max & Max**	**Swing**
Vehicle Life and Fuel Price	3 & $2.00	7 & $4.00	15 & $7.00	(1.6%)	12.0%	29.0%	31.0%
VMT & Fuel Price	10,000 & $2.00	15,000 & $4.00	20,000 & $7.00	(0.1%)	12.0%	27.0%	27.0%
Discount Rate & Fuel Price	17.2% & $2.00	12.2% & $4.00	5.2% & $7.00	1.8%	12.0%	26.0%	24.0%
Vehicle Life & VMT	3 & 10,000	7 & 15,000	15 & 20,000	0.3%	12.0%	24.0%	23.0%
Discount Rate & Vehicle Life	17.2% & 3	12.2% & 7	5.2% & 15	2.9%	12.0%	26.0%	23.0%
Fuel Price & F.P. Risk Factor	$2.00 & 140%	$4.00 & 75%	$7.00 & 30%	3.0%	12.0%	26.0%	23.0%
Vehicle Life & F.P. Risk Factor	3 & 140%	7 & 75%	15 & 30%	3.5%	12.0%	22.0%	18.0%
Discount Rate & VMT	17.2% & 10,000	12.2% & 15,000	5.2% & 20,000	4.6%	12.0%	20.0%	16.0%
VMT & F.P. Risk Factor	10,000 & 140%	15,000 & 75%	20,000 & 30%	5.7%	12.0%	19.0%	14.0%

Source: University of Michigan Transportation Research Institute

Detailed Sales in the Baseline Scenario

Figure 14 reports sales of the 70 entries in the baseline scenario.

Figure 14. Sales (000's) in Baseline Scenario – 2020E

Segment	Ford	GM	Honda	Nissan	Toyota	Others	All automakers
Car - Luxury	48	151	67	142	234	769	**1,411**
Car - Midsize	565	748	450	409	638	1,287	**4,097**
Car - Small	429	131	444	241	492	1,345	**3,082**
CUV - Luxury	62	59	80	30	171	40	**442**
CUV - Midsize	275	388	171	74	166	603	**1,677**
CUV - Midsize	611	309	218	184	284	537	**2,143**
Minivan	-	-	154	-	149	445	**748**
Pickup - Large	702	761	-	40	131	255	**1,889**
Pickup - Small	-	-	-	75	145	-	**220**
SUV - Large	60	215	-	32	-	-	**307**
SUV - Luxury	13	27	-	-	33	289	**362**
SUV - Midsize	-	-	-	62	77	210	**349**
SUV - Small	-	-	-	-	-	183	**183**
Van - Large	205	125	-	28	-	29.5	**388**
All Segments	**2,970**	**2,914**	**1,584**	**1,317**	**2,520**	**5,993**	**17,298**

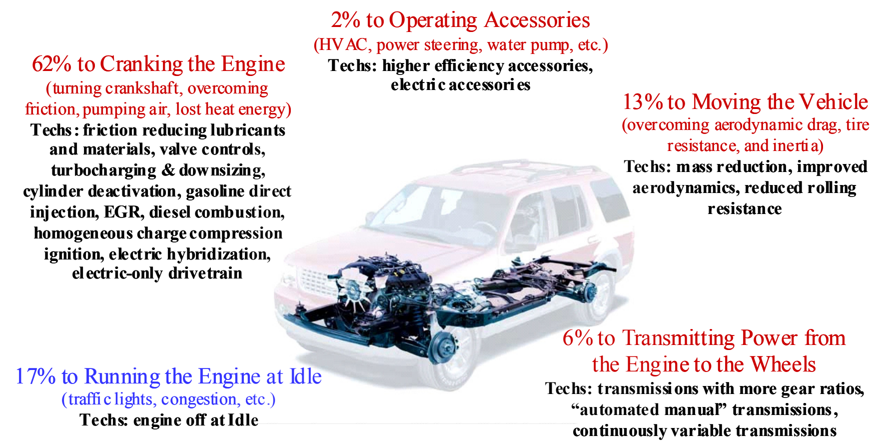
Source: University of Michigan Transportation Research Institute

Appendix B. Costs and Fuel Economy Impacts of Various Fuel Efficiency Technologies

Vehicle Efficiency Background

Although motor vehicle technology has advanced on a nearly continuous basis since the introduction of the automobile, and engine efficiency has similarly improved dramatically, a number of inefficiencies remain in the conversion of fuel energy to motive energy. Moreover, much of the potential reduction in fuel consumed per mile of travel that could have resulted from the observed increases in engine efficiency has instead been forsaken through offsetting increases in vehicle performance (most generally recognized as increased horsepower per unit engine displacement). Figure 15 presents a generalized energy consumption distribution for a vehicle driven in an urban environment, illustrating both how total fuel energy is consumed and where there is remaining room for efficiency improvement.

Figure 15. Urban Fuel Energy Breakdown



2% to Operating Accessories
(HVAC, power steering, water pump, etc.)
Techs: higher efficiency accessories, electric accessories

62% to Cranking the Engine
(turning crankshaft, overcoming friction, pumping air, lost heat energy)
Techs: friction reducing lubricants and materials, valve controls, turbocharging & downsizing, cylinder deactivation, gasoline direct injection, EGR, diesel combustion, homogeneous charge compression ignition, electric hybridization, electric-only drivetrain

13% to Moving the Vehicle
(overcoming aerodynamic drag, tire resistance, and inertia)
Techs: mass reduction, improved aerodynamics, reduced rolling resistance

6% to Transmitting Power from the Engine to the Wheels
Techs: transmissions with more gear ratios, "automated manual" transmissions, continuously variable transmissions

17% to Running the Engine at Idle
(traffic lights, congestion, etc.)
Techs: engine off at Idle

Source: Meszler Engineering Services

As one would expect, the largest energy losses are associated with converting fuel energy to mechanical energy in the engine. Such losses are reflected as heat emitted through the radiator, engine block, and exhaust system. Since vehicle engines have to be designed to operate over a wide range of speed and load conditions (from crawling along in city traffic to climbing hills to cruising along on highways, both with and without significant cargo weight) engines are designed for "worst case" operating conditions and, as a result, are seldom operating under conditions of maximum efficiency. A typical gasoline engine is only about 25% efficient on average, so 75% of fuel energy is simply "lost" as heat. Thermodynamics places a practical limit on the potential improvement of this energy conversion process, but substantial improvements into the 40% average efficiency range (before hybridization or electrification) are possible. Moreover, there are technologies that can be used to capture varying amounts of the energy otherwise discarded as waste heat.

The technologies that can be used to promote increased engine efficiency are generally designed to reduce mechanical friction, improve “breathing” (facilitating airflow through the engine), improve fuel control, or adjust the effective engine load to maximize high efficiency operations. Such technologies include the use of improved lubricants and low friction materials (to reduce mechanical resistance), improved valvetrain controls (to allow for finer air and combustion control), the increased use of turbocharging (to allow for greater performance from smaller engines), internal and cooled external exhaust gas recirculation (to reduce throttling, reduce fuel enrichment, allow additional spark advance, and allow for increased compression ratio), cylinder deactivation (to effectively change the “size” of an engine with operating conditions), gasoline direct injection (to allow for finer fuel control), dieselization (since the diesel cycle has inherent efficiency advantages relative to gasoline), homogeneous charge compression ignition (HCCI, which brings gasoline combustion efficiency closer to diesel, while retaining important gasoline emissions advantages), hybridization (to supplement heat energy with higher efficiency electrical energy), and electrification (to move the heat energy conversion processes offboard the vehicle where they *may* be accomplished by higher efficiency systems).

Energy losses also occur as energy is transmitted from the engine to the wheels or due to non-motive engine loads. In urban driving, 17% or more of energy is consumed while the vehicle is not moving and the engine is simply idling—consuming fuel but producing no motive work. Recouping this energy through technology that allows the engine to be shut off at idle can provide for significant improvements in effective driving cycle efficiency. About 2% of fuel energy is consumed to power vehicle accessories such as a power steering pump, a water pump, or an air conditioning system. Accessories that demand less energy to operate or accessories that are operated electrically can reduce this energy consumption.

About 6% of energy is lost in moving energy from the engine to the vehicle wheels through transmission and axle systems. More efficient transmission technology can both reduce these losses, as well as contribute to improved engine efficiency by allowing the engine to operate under high efficiency conditions more often. Since the load placed on an engine varies with road speed, transmissions with more (and a wider range of) gear ratios allow engine speed to adjust more frequently to road conditions and thereby maximize efficiency. The idealization of this is the continuously variable transmission (CVT) that potentially allows for infinite engine speed adjustment, although it is important to recognize that torque converter losses can result in lower overall CVT transmission efficiencies than advanced “step gear” technologies such as automated manual transmissions.

About 13% of fuel energy is actually used to move the vehicle. This energy is used to overcome a vehicle’s inertial resistance, which is a function of vehicle mass, air resistance, and the rolling resistance of vehicle tires. Thus, technologies such as high strength, low mass materials, more streamlined vehicle designs, and lower rolling resistance tires can increase vehicle fuel efficiency.

Fuel Economy Cost and Impact Estimates

Meszler Engineering Services (MES) undertook a limited meta-analysis to estimate the fuel economy and cost impacts of various vehicle efficiency technologies. While MES undertook this analysis for both individual technologies and selected packages of technologies, only the technology package estimates were used to evaluate industry impacts. This technology package approach was employed in recognition of the fact that many technologies target the same inefficiencies, so their combined application results in a lesser efficiency improvement than would be expected were their individual impacts assumed to be independent. The evaluated technology packages were selected to cover a broad range of fuel economy impacts, basically ranging from modest (around 10%) improvements due to conventional engine technology advances to large (>100%) improvements due to advanced technologies such as advanced hybrid electric, plug-in hybrid electric, and electric-only vehicle technology. It is important to recognize that the latter two technologies—plug-in hybrid electric and electric-only vehicle technology—are not necessary to meet the level of fuel economy evaluated for 2020 under this study. Nevertheless, such technology could be critical in achieving compliance with more aggressive fuel economy scenarios or additional requirements after 2020, should such requirements be implemented.

Specific studies or information sources included in the meta-analysis include NHTSA's 2011-2015 CAFE proposal and related support documents,[6] NHTSA's 2012-2016 CAFE proposal and related support documents,[7] NHTSA's 2017 -2025 CAFE proposal and related support documents,[8] a 2009 EPA report on light-duty vehicle greenhouse gas technology costs,[9] a 2004 report on greenhouse gas reduction technology from the Northeast States Center for a Clean Air Future,[10] the 2008-2010 versions of the Energy Information Administration's NEMS (National Energy Modeling System) Transportation Demand Module (which is used to support their Annual Energy Outlook forecast series),[11] the National Academy of Science's 2002 CAFE review,[12] the National Academy of Science's 2002 CAFE review,[13] currently unpublished vehicle simulation modeling results, and numerous articles in automotive trade publications such as Automotive News and Automotive Engineering International. By definition, the impact estimates reflect a compendium of work performed by others and, as such, span a rather wide range of both efficiency and cost estimates. Generally, this study reflects an effort to synthesize the various estimates and where widely ranging estimates exist, gives greater weight to more detailed and more recent studies. As is always the case when dealing with future cost impacts, some degree of subjective inference from both current knowledge and similar historic analogs is involved.

Figure 16 presents a list of the individual technologies evaluated, along with their respective fuel economy and cost impacts, while Figure 17 presents similar impacts for the selected technology packages.

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[6] See reference set 1 at the end of Appendix B.

[7] See reference set 2 at the end of Appendix B.

[8] See reference set 3 at the end of Appendix B.

[9] See reference set 4 at the end of Appendix B.

[10] See reference set 5 at the end of Appendix B.

[11] See reference set 6 at the end of Appendix B.

[12] See reference set 7 at the end of Appendix B.

[13] See reference set 8 at the end of Appendix B.

Figure 16. Fuel Economy Impact and Cost of Individual Technologies

Fuel Economy Technology	Change in CAFE mpg	Cost Basis	Cost to Vehicle Manufacturer for:					
			DOHC 14 P2 HEV	DOHC V6 P2 HEV	DOHC V8 P2 HEV	OHV V6 P2 HEV	OHV V8 2M HEV	DOHC V8 2M HEV
Conventional Evolutionary Package	6.0%	See note A	$100	$120	$140	$120	$140	$140
VVT (Variable valve timing, cam phasing)	3.0%	Dual Coupled, with EGR credit	$35	$70	$70	$35	$35	$70
VVL (Variable valve lift)	2.0%	Discrete lift technology	75	$100	$150	$100	$150	$150
VVT + VVL	5.0%		110	$170	$220	$135	$185	$220
CVA (camless valve actuation)	8.0%		$340	$565	$720	$565	$720	$720
Cylinder Deactivation (1/2 of cylinders deactivate)	6.0%	Independent system	N/A	$115	$150	$115	$150	$150
		If combined with VVL	N/A	$200	$260	$200	$260	$260
Turbocharging (with downsizing)	12.0%	Turbo, twin turbo for V8-to-V6	$360	$380	$600	$380	$600	$600
		Downsizing credit	$0	($550)	($260)	($550)	($260)	($260)
		OHV to DOHC conversion	$0	$0	$0	$420	$460	$0
		Net cost	$360	($170)	$340	$250	$800	$340
Gasoline Direct Injection	10.0%	GDI system cost	$190	$275	$315	$275	$275	$315
		After-treatment cost	$0	$0	$0	$0	$0	$0
		Net cost	$190	$275	$315	$275	$275	$315
Cooled Boosted EGR (includes trubocharging, downsizing, and gasoline direct injection)	30.0%	EGR system cost	$200	$200	$200	$200	$200	$200
		Turbo/GDI cost	$550	$105	$655	$525	$1,075	$655
		Net cost	$750	$305	$855	$725	$1,275	$855
Diesel Direct Injection (relative to MPFI gasoline, V6-to-I4, V8-to-I6)	45.0%	2020 HSDI from 2010 MPFI	$1,200	$600	$1,200	$1,100	$1,400	$1,200
		After-treatment cost	$500	$600	$1,000	$600	$1,000	$1,000
		Net cost	$1,700	$1,200	$2,200	$1,700	$2,400	$2,200
12V Idle Off	3.0%		$200	N/A	N/A	N/A	N/A	N/A
42V ISG - Idle Off/Regen Braking/Launch Assist	10.0%	System cost	$280	$320	$350	$320	$350	$350
		Electrical system upgrade	$70	$70	$70	$70	$70	$70
		Net cost	$350	$390	$420	$390	$420	$420
Mass Reduction (per % reduction in mass, PRM)	0.7%	Per pound reduced	Cost per pound = -0.05(PRM) + 8.5(PRM)(PRM)					
Drag Reduction (per % reduction in drag)	0.2%	Per % reduction	$5	$5	$5	$5	$5	$5
Electric Power Steering	1.0%		$20	$40	$40	$40	$40	$40
Transmission Transition from:								
A4 to A6	5.0%		$50	$75	$80	$75	$80	$80
A4 to A7	6.5%		$75	$110	$120	$110	$120	$120
A4 to A8	8.0%		$110	$160	$170	$160	$170	$170
A5 to A6	2.0%		$20	$20	$20	$20	$20	$20
A5 to A7	3.5%		$45	$55	$60	$55	$60	$60
A5 to A8	5.0%		$80	$105	$110	$105	$110	$110
A6 to A7	1.5%		$25	$35	$40	$35	$40	$40
A6 to A8	3.0%		$60	$85	$90	$85	$90	$90
A4 to CVT	8.0%		$150	$175	$200	$175	N/A	N/A
A5 to CVT	5.0%		$120	$120	$140	$120	N/A	N/A
A6 to CVT	3.0%		$100	$100	$120	$100	N/A	N/A
A4 to AMT6dry	10.0%		($90)	($65)	($60)	($65)	N/A	N/A
A4 to AMT6wet	9.0%		($45)	($20)	($15)	($20)	($15)	($15)
A4 to AMT8dry	13.0%		($30)	$20	$30	$20	N/A	N/A
A4 to AMT8wet	12.0%		$15	$65	$75	$65	$75	$75
P2 HEV (incremental to conventional advances)	30.0%		$1,500	$2,200	$2,200	$2,200	N/A	N/A
2-Mode HEV (incremental to conventional advances)	20.0%		N/A	N/A	N/A	N/A	$3,200	$3,200
PHEV20 (incremental to HEV)	72.0%	See note B	$3,900	$4,800	$4,800	N/A	N/A	N/A
PHEV40 (incremental to HEV)			$5,300	$6,450	$6,450	N/A	N/A	N/A
EV75 (incremental to HEV)	495.0%	See note C	$4,250	$5,250	$5,250	N/A	N/A	N/A
EV100 (incremental to HEV)			$5,700	$7,000	$7,000	N/A	N/A	N/A
EV150 (incremental to HEV)			$8,800	$10,750	$10,750	N/A	N/A	N/A

Notes: mpg = miles per gallon, DOHC = dual overhead cam engine, OHV = overhead valve engine, EGR = exhaust gas recirculation, MPFI = multiport fuel injection, HSDI = high speed direct injection, ISG = integrated starter/generator, Regen = regenerative, PRM = percent reduction in mass, CVT = continuously variable transmission, AMT = dual clutch automated manual transmission, HEV = hybrid electric vehicle, PHEV = plug in HEV, EV = electric only vehicle

Note A. Includes technology such as low friction lubes, engine friction reduction, aggressive shift logic, and low rolling resistance tires.

Note B. Assumes CAFE is based on current 50/50 duel fuel criteria and EV multipliers for EV mode. Overall CAFE impact based on fleet average consumption of 0.23 kW hr/mi in EV mode and 60 mpg in HEV mode. Percentage changes only apply to the calculations presented in this section as platform specific consumption data were used for the industry analysis (see Figure 18). CAFE impact data are identical regardless of EV only ranges as current CAFE rules apply a 50/50 split to any dual fuel vehicle.

Note C. Assumes no change to current CAFE AFV multiplier (6.67) for EVs. Overall CAFE impact based on fleet average consumption of 0.23 kW hr/mi relative to 60 mpg HEV. Percentage changes only apply to the calculations presented in this section as platform specific consumption data were used for the industry analysis (see Figure 18). CAFE impact data is identical regardless of EV only ranges as current CAFE rules make no range adjustments. For this reason, only data for the EV150 are considered in the analysis reported in this section.

Source: Meszler Engineering Services

Figure 17. Fuel Economy Impact and Cost of Technology Packages

Fuel Economy Technology		Change in CAFE mpg	Cost to Vehicle Manufacturer for:					
			DOHC 14 P2 HEV	DOHC V6 P2 HEV	DOHC V8 P2 HEV	OHV V6 P2 HEV	OHV V8 2M HEV	DOHC V8 2M HEV
Base Weight (pounds)			3,029	4,005	3,939	4,128	4,872	5,158
Assumed Mass Reduction			10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Assumed Drag Reduction			5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
VVT + EPS + MD + CEP	AMT8dry	34.0%	$249	$407	$487	$373	N/A	N/A
	AMT8wet	33.0%	N/A	N/A	N/A	N/A	$504	$541
VVTL + DeAct + EPS + MD + CEP	AMT8dry	41.0%	N/A	$507	$597	$473	N/A	N/A
	AMT8wet	40.0%	N/A	N/A	N/A	N/A	$614	$651
VVT + Turbo + EPS + MD + CEP	AMT8dry	46.0%	$534	$137	$677	$523	N/A	N/A
	AMT8wet	45.0%	N/A	N/A	N/A	N/A	$1,154	$731
VVT + Turbo + GDI + EPS + MD + CEP	AMT8dry	58.0%	$724	$412	$992	$798	N/A	N/A
	AMT8wet	56.0%	N/A	N/A	N/A	N/A	$1,429	$1,046
VVT + Turbo + GDI + ISG + EPS + MD + CEP	AMT8dry	68.0%	$1,074	$802	$1,412	$1,188	N/A	N/A
	AMT8wet	66.0%	N/A	N/A	N/A	N/A	$1,849	$1,466
VVTL + DeAct + ISG +EPS + MD + CEP	AMT8dry	50.0%	N/A	$897	$1,017	$863	N/A	N/A
	AMT8wet	49.0%	N/A	N/A	N/A	N/A	$1,034	$1,071
VVTL + DeAct + GDI + ISG + EPS + MD + CEP	AMT8dry	62.0%	N/A	$1,087	$1,292	$1,178	N/A	N/A
	AMT8wet	60.0%	N/A	N/A	N/A	N/A	$1,309	$1,346
VVTL + tGDI/cbEGR + EPS + MD + CEP	AMT8dry	72.0%	$999	$712	$1,342	$1,098	N/A	N/A
	AMT8wet	71.0%	N/A	N/A	N/A	N/A	$1,779	$1,396
VVTL + tGDI/cbEGR + ISG + EPS + MD + CEP	AMT8dry	83.0%	$1,349	$1,102	$1,762	$1,488	N/A	N/A
	AMT8wet	82.0%	N/A	N/A	N/A	N/A	$2,199	$1,816
DDI + EPS + MD + CEP	AMT8dry	85.0%	$1,839	$1,437	$2,467	$1,938	N/A	N/A
	AMT8wet	83.0%	N/A	N/A	N/A	N/A	$2,719	$2,521
DDI + ISG + EPS + MD + CEP	AMT8dry	96.0%	$2,189	$1,827	$2,887	$2,328	N/A	N/A
	AMT8wet	95.0%	N/A	N/A	N/A	N/A	$3,139	$2,941
HEV (with Turbo + GDI, but without cbEGR)	P2 HEV	108.0%	$2,299	$2,712	$3,342	$3,098	N/A	N/A
	2-Mode HEV	91.0%	N/A	N/A	N/A	N/A	$4,779	$4,396
HEV (with Turbo + GDI + cbEGR)	P2 HEV	124.0%	$2,499	$2,912	$3,542	$3,298	N/A	N/A
	2-Mode HEV	105.0%	N/A	N/A	N/A	N/A	$4,979	$4,596
PHEV (with Turbo + GDI, but without cbEGR) -- see Note A	PHEV 20	258.0%	$6,199	$7,512	$8,142	N/A	N/A	N/A
	PHEV 40	258.0%	$7,599	$9,162	$9,792	N/A	N/A	N/A
PHEV (with Turbo + GDI + cbEGR) -- see Note B	PHEV 20	285.0%	$6,399	$7,712	$8,342	N/A	N/A	N/A
	PHEV 40	285.0%	$7,799	$9,362	$9,992	N/A	N/A	N/A
EV -- see Note C	EV75	1185.0%	$6,649	$8,062	$8,692	N/A	N/A	N/A
	EV100	1185.0%	$8,099	$9,812	$10,442	N/A	N/A	N/A
	EV150	1185.0%	$11,199	$13,562	$14,192	N/A	N/A	N/A

All impacts are relative to a gasoline multiport fuel injected, 4 speed automatic transmission base technology.

mpg = miles per gallon, DOHC = dual overhead cam engine, OHV = overhead valve engine, EGR = exhaust gas recirculation, VVTL = variable valve timing and lift, VVT = variable valve timing injection, EPS = electric power steering, MD = mass and drag effects, CEP = conventional evolutionary package, Turbo = turbocharging, GDI = gasoline direct injection, tGDI = turbocharged GDI, ISG = integrated starter/generator,

DeAct = cylinder deactivation, cbEGR = cooled and boosted EGR, DDI = diesel direct injection, AMT = dual clutch automated manual transmission, HEV = hybrid electric vehicle, PHEV = plug in HEV, EV = electric only vehicle.

Note A. Assumes CAFE is based on current 50/50 duel fuel criteria and EV multipliers for EV mode. Overall CAFE impact based on fleet average consumption of 0.23 kW hr/mi in EV mode, 58 mpg in HEV mode, and a 27.8 mpg baseline. percentage changes only apply to the calculations presented in this section as platform specific consumption data were used for the industry analysis (see Figure 18). CAFE impact data are identical regardless of EV only ranges as current CAFE rules apply a 50/50 split to any dual fuel vehicle.

Note B. Assumes CAFE is based on current 50/50 duel fuel criteria and EV multipliers for EV mode. Overall CAFE impact based on fleet average consumption of 0.23 kW hr/mi in EV mode, 63 mpg in HEV mode, and a 27.8 mpg baseline. percentage changes only apply to the calculations presented in this section as platform specific consumption data were used for the industry analysis (see Figure 18). CAFE impact data are identical regardless of EV only ranges as current CAFE rules apply a 50/50 split to any dual fuel vehicle.

Note C. Assumes no change to current CAFE AFV multiplier (6.67) for EVs. Overall CAFE impact based on fleet average consumption of 0.23 kW hr/mi relative to a 27.8 mpg baseline. Percentage changes only apply to the calculations presented in this section as platform specific consumption data were used for the industry analysis (see Figure 18). CAFE impact data are identical regardless of EV only ranges as current CAFE rules make no range adjustments. For this reason, only data for the EV150 are considered in the analysis reported in this section.

Source: Meszler Engineering Services

Figure 18. EV and PHEV CAFE Fuel Economy

Vehicle Type	EV CAFE mpg	PHEV EV Mode CAFE MPG
A Car	467.0	N/A
B Car	435.0	411.3
C Car	402.8	380.4
E Car	N/A	312.1
Sports Car	379.1	358.0
Full-size Pickup	292.9	276.7
Mid-size Crossover	366.2	345.8
Small Crossover	385.9	364.5
Small Van	315.9	298.4

Note: Estimates were developed for the full size pickup, but it was recommended that no PHEVs or EVs be forecasted for this class.

Overall fuel economy for PHEVs is equal to: 1/((0.5/HEV Mode CAFE)+(0.5/EV Mode CAFE)), with HEV mode CAFE calculated in accordance with forecasted technology introduction and impacts.

Source: Meszler Engineering Services

Generally, the technology packages included in the analysis were intended to reflect the lowest cost technologies available to support a broad range of fuel economy improvements. Moreover, these packages generally reflect technologies that are or will be market ready within the next few vehicle model years. Technologies such as fuel cells and hydrogen internal combustion engines that either require further development or supporting (e.g. refueling) infrastructure establishment before being viable on a high volume basis are not considered, as the driver of this study is technology expected to be used to support CAFE compliance through the 2020 timeframe. The exceptions to this approach are plug-in hybrid electric and electric only technologies, which have been included as they have started to enter the automotive market. Rather aggressive battery system cost reductions have been assumed between now and 2020 for both technologies, but such assumptions have virtually no impact on analysis results as neither technology is required to meet the established 2020 CAFE target. Nevertheless, the reader should consider such assumptions when viewing the time- and target-independent vehicle price and marginal cost charts that appear later in this section as the upper ranges of these charts do incorporate the aggressive cost reduction assumptions for plug-in hybrid electric and electric only technology.

Due to differences in costs (and, in some cases, cost savings) for engines of different sizes and designs, the data were analyzed for the design combinations depicted in Figure 19 individually.

Figure 19. Design Combinations

Design Configuration	Market Share
DOHC I4 Engine (with P2 hybrid when hybridized)	41.3%
DOHC V6 Engine (with P2 hybrid when hybridized)	38.9%
DOHC V8 Engine (with P2 hybrid when hybridized)	2.9%
OHV V6 Engine (with P2 hybrid when hybridized)	6.9%
OHV V8 Engine (with 2-Mode hybrid when hybridzed)	6.1%
DOHC V8 Engine (with 2-Mode hybrid when hybridized)	3.9%

Source: Meszler Engineering Services

The design combinations that utilize the 2-Mode hybrid (when hybridized) are generally intended to reflect applications requiring traditional towing capacity. To avoid confusion in the charts that follow, analysis data have been aggregated to the fleet level using the indicated market shares. It is important to recognize, however, that these market shares *only* apply to the charts in this section. The independent market forecast that is an integral component of the larger analysis makes no use of the market shares presented and used in this section.

Finally, when considering the costs presented in Figures 16 & 17, it is critical to understand that:

- The estimates reflect costs to the vehicle manufacturer. No retail price markup has been applied. Manufacturer-specific markups are applied to the tabulated costs as an integral component of the market analysis documented in the other sections of this report.
- The estimates reflect future year costs (generally reflective of the 2016-2020 timeframe) and thus assume varying (technology-dependent) levels of cost reduction due to learning and volume production.
- Given the extensive lead time associated with the 2020 CAFE target, the estimates do not include retooling costs that might be incurred during any associated platform redesign. It is assumed that any required redesign will be integrated into the normal platform redesign process and the associated schedule will be unaffected by the 2020 target.

Thus, the tabulated costs are, in some cases, substantially lower than the costs that would be incurred if such technologies were implemented today.

The specific technologies considered include:

Variable valve timing (or cam phasing) – Valves are used to allow air and exhaust gases to respectively enter (intake valves) and exit (exhaust valves) the combustion chambers (cylinders) of the internal combustion engines that currently power the vehicle fleet. Traditional valve opening and closing is controlled by fixed cams located on one or more camshafts that are driven by the rotation of the engine crankshaft, limiting the ability to tailor either intake or exhaust performance to specific engine operating conditions. Variable valve timing technology allows the timing of intake and/or exhaust valve openings to vary in accordance with engine speed and load. This allows for improved breathing (intake air and exhaust gas movement) and more efficient combustion.

Variable valve lift – Variable valve lift is an adjunct to variable valve timing technology, which allows valve opening height (and duration) to also vary with engine speed and load. This further improves breathing and combustion efficiency.

Camless valve actuation – Camless valve actuation allows for valve functionality that is fully independent of crankshaft and/or cam operation. Electromechanical actuators allow valve operation to be continuously varied in accordance with engine speed and load, so that breathing and combustion efficiency can be optimized. In addition, the elimination of mechanical camshafts and actuators reduces engine load and friction. Camless valve actuation is not included in the technology packages evaluated for this analysis due to current costs that outweigh the additional efficiency potential relative to less expensive variable valve timing and lift systems.

Cylinder deactivation – Cylinder deactivation technology effectively "shuts off" engine cylinders under operating conditions where their output is not necessary for performance purposes. This essentially creates a smaller displacement engine that operates closer to its optimum efficiency speed and load conditions. When the smaller displacement configuration is not adequate for demanded performance, the deactivated cylinders are "turned back on" and the performance capacity of the larger displacement engine is restored. For this analysis, it is assumed that cylinder deactivation technology can be effectively applied to engines of 6 or more cylinders, but that 4-cylinder engines are not viable technology candidates.

Turbocharging – Turbocharger technology utilizes some of the energy that leaves engine cylinders in the form of exhaust heat to drive a compressor in the engine air intake manifold. This compressor increases the quantity of air delivered to the combustion chambers, and this increased change density allows for greater engine power (than would be delivered by the same size non-turbocharged, or naturally aspirated, engine). This higher specific-power allows for a smaller (and more efficient) engine to be used for a given level of performance. For certain engines (e.g., DOHC V6 engines), the cost savings associated with engine downsizing can offset the incremental cost of the turbocharger. However, the savings are reduced if 2-valve-per-cylinder OHV engines are simultaneously converted to 4-valve-per-cylinder DOHC configurations. For this analysis, it is assumed that there is no significant cost savings associated with downsizing a 4-cylinder engine (as the downsized engine will retain all cylinders, valves, camshafts, etc.).

Gasoline direct injection – "Conventional" gasoline engine fueling is accomplished through relatively low-pressure fuel injection outside (at the air intake ports) of the engine cylinders. This currently conventional multiport fuel injection technology allows for significantly enhanced fueling (and efficiency gains) relative to the predecessor carburetion technology, but even greater advantages can be attained through higher pressure fuel injection directly into the engine cylinders. This so-called gasoline direct injection (GDI) technology allows for much more precise fuel control, higher compression, increased exhaust gas recirculation (EGR), and stratified lean burn (more air/less fuel per unit of power than conventional non-stratified combustion) under certain operating conditions. For this analysis, it is assumed that stratified operations would be avoided (i.e. the GDI system benefits assume stoichiometric operation) so that no additional exhaust gas after-treatment costs are incurred.

Cooled and Boosted Exhaust Gas Recirculation (EGR) – Modest levels of EGR have been used in conventional gasoline engines for decades, primarily as a method of controlling engine-out emissions. However, higher levels of EGR can result in significant efficiency synergies. Low load pumping losses can be reduced by allowing stoichiometry to be maintained with less throttling. At higher loads, cooled EGR allows for reduced pre-ignition (which allows for both increased compression ratio and increased spark advance) and lower combustion temperatures (which alleviates the need for enriching fueling ratios to control exhaust temperatures). Such systems are particularly synergistic with turbocharging technology, which by design pushes engine operation into higher load regimes.

Direct injection diesel engines – Direct injection diesel engine technology is well established and offers considerable efficiency benefits relative to current gasoline engines, primarily through high compression throttle-less lean burn combustion characteristics. About one-half of all vehicles currently sold in the EU are diesel powered, but more stringent emissions requirements as well as continuing (but no longer justified) stigmas of noise, soot, etc. and a higher fuel price must be overcome in the U.S. market. The cost impacts assumed in this analysis include both downsizing credits for 6- and 8-cylinder engines and additional exhaust after-treatment costs for all diesel applications.

Transmission technology – Increasing the number of steps between the lowest and highest transmission gear ratios allows the engine to operate in the region of greatest efficiency more often. For this reason, significant movement from four-speed toward five- and six-speed automatic transmissions is already underway, and seven- and eight-speed automatic transmissions have entered the market. Continuously variable transmission (CVT) technology, which provides an essentially “infinite” range of gear ratios, allows the engine to operate in the region of greatest efficiency most often. Historically, torque limitations have hindered the widespread application of CVT technology, but improved technology has extended potential application to most light-duty vehicles. The most significant advance expected over the mid term is, however, the adoption of automated manual transmission technology, which combines the efficiency of manual transmissions with automatic transmission convenience. This technology essentially electronically automates transmission shifting, allowing for the elimination of the automatic transmission torque converter (and its associated losses).

12-volt idle-off technology – Considerable fuel energy is used during engine idle operations in typical urban driving environments. Turning the engine off during these operations would improve the overall driving cycle average fuel efficiency of the vehicle. A 12-volt belt-driven alternator/starter (BAS) system can offer a relatively simple solution, allowing automatic engine shutdown and automatic, fast, and reliable restart (upon brake release). For this analysis, it is assumed that BAS systems are not sufficiently able to control larger 6- and 8-cylinder engines, but are reliably able to control engine-off at idle operations for 4-cylinder engines.

42-volt integrated starter/generator (ISG) – A step up from the 12-volt BAS, the 42-volt ISG is a small, high performance electric motor that is either integrated into the driveline of a vehicle (generally referred to as a flywheel alternator/starter or FAS) or belt-driven like the 12-volt BAS. Like the 12-volt BAS, the technology allows the vehicle engine to be turned off at idle and instantaneously restarted (both automatically) and accessories to be powered electrically during the engine off period. However, the higher system voltage also allows for regenerative braking (where braking energy is captured and stored for later use) and a modest level of launch assist (where electrical energy is used to supplement internal combustion engine performance). Sometimes termed a “mild hybrid” as a result of these features, the 42-volt ISG system is capable of controlling all light duty engines. The costs estimated for this analysis include an associated electrical system upgrade.

Improved aerodynamics – In urban driving, 20% to 30% of motive energy is expended in overcoming air resistance, 50% to 65% at highway speeds. More streamlined designs that allow for less turbulent airflow reduce fuel use.

Reduced rolling resistance – 30% to 40% of motive force is expended overcoming the resistive torque of tires. Improved tire designs (and reduced vehicle weight) can reduce this force, but tradeoffs in traction, etc. are limiting.

Reduced vehicle weight – Vehicle weight affects both the force required to overcome rolling resistance and the force required to induce a given motion. Generally, each 10% weight reduction reduces fuel use by about 7%. However, the efficiency advantages of weight reduction must be considered in conjunction with possible safety concerns.

Advanced power steering – Electric and electrohydraulic power steering systems offer improved efficiency over conventional hydraulic systems. Conventional hydraulic power steering systems rely on a pump that is connected to the engine via a belt, and this pump places a continuous load on the engine. Conversely, the electric and electrohydraulic power steering systems are operated electronically on an as-needed basis, resulting in improved engine efficiency through the elimination of the continuous load otherwise placed on the engine by a conventional power steering pump.

Electric hybrid powertrains – Two hybrid electric designs were evaluated as part of the technology packages included in this analysis. Since hybridization facilitates several complementary technologies, simple hybridization of the engine was not evaluated in isolation, but instead included as a supplementary technology for conventional engine improvements. For most vehicles, “P2” HEV technology was assumed due to benefits that rival those of the more complex Prius-type “power split” technology, but at a significantly reduced cost. The P2 system allows for both electric-only and combined engine/motor operation using a single electric machine integrated into the driveline of a vehicle. For vehicles requiring conventional type towing capability, 2-mode HEV technology was assumed. The 2-mode system, with two electric machines, is a higher cost approach with reduced efficiency benefits commensurate with the increased reliance on the conventional engine to provide extended power and towing capability on demand.

Plug-in hybrid electric powertrains – Plug-in hybrid electric technology was considered in the analysis, but is not required to meet the evaluated 2020 CAFE target. This technology essentially consists of hybrid electric technology combined with a larger storage system (e.g. battery) to allow for an extended electric only driving range. Combined with offboard recharging capability, such vehicles can substantially reduce conventional engine usage for certain (short range) driving patterns. However, the added battery capacity leads to both higher costs and reduced conventional engine efficiency (relative to onboard-only hybrids) due to the increased battery weight. Although both 20- and 40-mile electric-only range plug-in hybrids were included in the analysis (PHEV20 and PHEV40 respectively), the CAFE values were assumed to be identical for both. This is because the CAFE procedures for plug-in hybrids are still under development and current CAFE requirements would treat such vehicles as dual fuel (electric and conventional) vehicles, basing net vehicle CAFE on a 50/50 weighting of CAFE determined independently for each fuel. Since the weighting is fixed, regardless of the electric-only range of the vehicle, CAFE is independent of that range. It is likely that this will change over time, but since such vehicles are not critical to the attainment of the 2020 CAFE target evaluated in this analysis, no attempt was made to hypothesize what such change will entail.

Electric-only powertrains – Electric-only technology was considered in the analysis, but is not required to meet the evaluated 2020 CAFE target. This technology consists of an electric-only drivetrain combined with a battery system of sufficient capacity to allow for an extended driving range. The necessary battery capacity leads to significantly higher costs. Although the analysis ostensibly included electric-only technology with 75, 100, and 150 miles driving ranges (EV75, EV100, and EV150 respectively), only the latter was included in determining system cost-effectiveness. Since no "penalty" is assumed for the reduced driving range relative to that of conventional vehicles, only the highest range vehicle was considered. Further refinement of this approach is appropriate before the cost-effectiveness of CAFE targets that require electric-only technology for compliance can be accurately determined. That does not mean that such vehicles will not be introduced between now and 2020, but simply that such introduction will not be necessitated by a CAFE target of the magnitude evaluated in this study (although CAFE benefits will nevertheless accrue to the associated manufacturer, albeit in a cost inefficient manner).

Societal Cost-Effectiveness

As indicated in Figure 17, the evaluated technology packages (excluding plug-in hybrid and electric-only technology) are estimated to be capable of increasing CAFE fuel economy by as much as 125%. However, since expenditures increase with fuel economy impact, it is important to understand variation in the cost-effectiveness of potential fuel economy increases. Figure 20 shows the fleet average fuel economy technology cost curve for the six basic engine configurations evaluated. As one would expect, costs increase more rapidly with each successive gallon of fuel saved.[14] The underlying analysis for the presented curve is based on the parameters presented in Figure 22.[15]

Figure 21 presents these same data in terms of marginal cost (expressed on a retail price increase basis) per discounted gallon of fuel saved versus specific levels of CAFE fuel economy.

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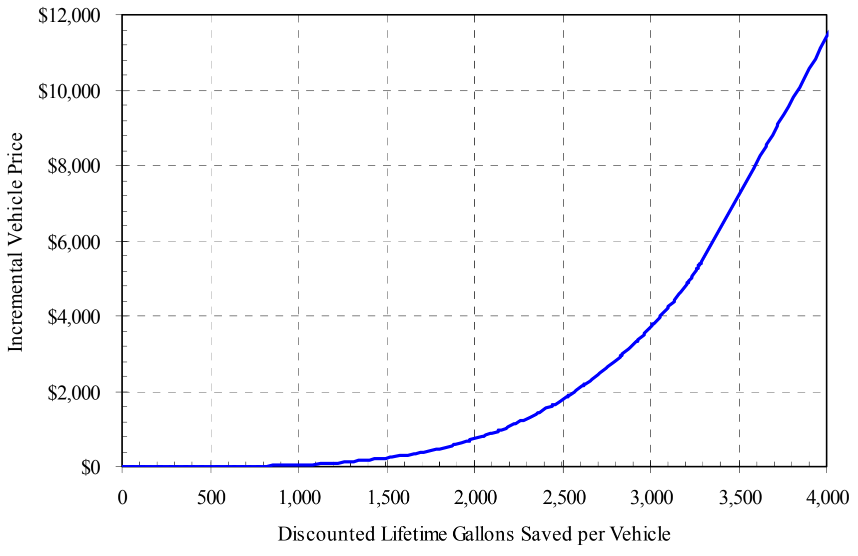
[14] It is important to recognize that due to the AFV credits awarded to electric-only drivetrain technology, there is a significant data "gap" between HEV, PHEV, and EV CAFE fuel economy. To avoid having the PHEV and EV data points overly influence the constructed marginal cost curve, the curve is developed in a piecewise fashion. The "lower" portion of the curve is developed for all data through HEV technology and joined with an "upper" curve that is constructed using PHEV and EV data. Due to the limited number of data points, the "upper" curve region approaches linearity.

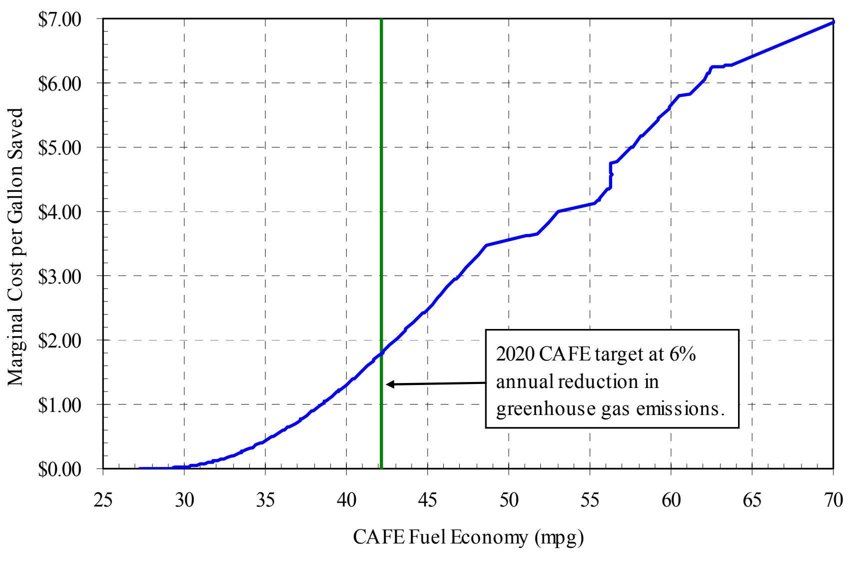
[15] It is important to note that the analysis, figures, and cost-effectiveness estimates presented in this section are independent of the larger industry analysis discussed in this report. The cost estimates provided for the larger industry analysis are expressed in terms of incremental costs to the vehicle manufacturer, and all associated manufacturer markups are introduced as a component of the larger industry analysis, with associated sales, revenue, and profit estimates based on expected consumer responses to those price increases relative to the price of fuel. The limited estimates presented in this section reflect a *societal* cost-effectiveness analysis, wherein fuel savings are valued over the full lifetime of the vehicle (albeit on a discounted basis).

Figure 20. Fuel Economy Technology Cost Curve for 2020



Source: Meszler Engineering Services

Figure 21. Marginal Fuel Economy Cost in 2020 by CAFE Level



Source: Meszler Engineering Services

Figure 22. Cost Effectiveness Analysis Assumptions

Analysis Parameter	
Discount Rate	8%

	Cars	Trucks
Lifetime Mileage (see Note A)	197,579	231,856
Lifetime Discount Factor	0.646	0.608

	Gasoline (per gallon)	Electricity (per kW-hr delivered)	Electricity (per gge delivered)	Electricity (per gge consumed)
Fuel Price (see Note B)	$ 3.00	$ 0.15	$ 5.056	$ 1.846

	SI	CI	HEV	PHEV20	PHEV40	EV
Retail Markup Factor	1.25	1.25	1.51	1.70	1.70	1.70
In-Use/Consumer-Oriented CAFE Fuel Economy	0.80	0.80	0.75	0.70	0.70	0.70
Consumer-Oriented CAFE/NHTSA CAFE (see Note C)	1.00	0.91	1.00	0.83	0.83	0.41
Fuel Economy Price Adjustment Factor	1.00	1.00	1.00	1.21	1.37	1.63
Fraction of VMT in EV Mode	0%	0%	0%	34%	59%	100%

	DOHC I4 P2 HEV	DOHC V6 P2 HEV	DOHC V8 P2 HEV	OHV V6 P2 HEV	OHV V8 2M HEV	DOHC V8 2M HEV
Base CAFE Fuel Economy (mpg)	34.1	25.3	22.9	24.7	20.3	18.8
Cars as a % of Segment	0.90	0.54	1.00	0.50	0.12	-
Lifetime Mileage (see Note A)	200,840	213,389	197,579	214,562	227,759	231,856
Lifetime Discount Factor	0.642	0.628	0.646	0.627	0.613	0.608

Note: kW hr = kilowatt hour, gge = gasoline gallon equivalent (energy basis), SI = spark ignition, CI = compression ignition, HEV = hybrid electric vehicle,

PHEV = plug in HEV, EV = electric only vehicle, VMT = vehicle miles of travel, mpg = miles per gallon, DOHC = dual overhead cam engine,

OHV = overhead valve engine.

Note A. Annual mileage functions developed by NHTSA. While not depicted, annual mileage declines with age as reflected by the tabulated discount factors.

Note B. Gasoline and electricity prices are used in the analysis only to derive a fuel price adjustment factor for PHEVs and EVs. Otherwise, the analysis is independent of fuel price in that it predicts cost effectiveness in terms of cost per gallon saved.

Note C. CAFE for EVs (and PHEVs in EV mode) includes both upstream “correction factors” and an “AFV” (alternative fueled vehicle) multiplier. The CAFE correction factors tabulated here "undo" these corrections in order to adjust EV (and PHEV) CAFE to a consumer perspective.

Source: Meszler Engineering Services

It is perhaps important to briefly explain the discontinuities in the curve. As presented in Figure 21, the basic cost-effectiveness curve is constructed in terms of “price adjusted” gallons of fuel saved, and is thus based on “in-use” fuel economy—i.e. the level of fuel economy which a consumer would actually be expected to achieve during actual vehicle use. For PHEV and EV technology, there is also a price adjustment factor that is intended to place a gallon of gasoline and an “energy equivalent gallon” of electricity on comparable price terms, as any price differential would either accrue or be assessed to the consumer. For example, if electricity were half the price of gasoline (using an energy equivalent comparison), then the cost equivalent of one gallon of gasoline is saved for every gallon used, and a correction for this is included in the marginal cost analysis (using the factors presented in Figure 22). There is also an assumed differential between in-use fuel economy and CAFE fuel economy, and this factor varies by technology type. For PHEV and EV technology, there are also alternative-fuel vehicle “credits” that are granted to manufacturers of such vehicles. As a result of these latter two factors, discontinuities are introduced as one moves from in-use fuel economy to equivalent CAFE fuel economy.

In effect, as one moves from left to right along the fuel savings cost curve (real world, in-use fuel savings), one reaches points where fundamental technology shifts become necessary to achieve the associated fuel savings. When these shifts involve moving from a technology with one relationship between in-use and CAFE fuel economy to a technology with a different relationship (e.g. conventional engines to HEVs, HEVs to PHEVs, PHEVs to EVs), then there is a step change associated with, what would otherwise be, "neighboring" CAFE values. There is, in effect, a CAFE "windfall" relative to the level of associated in-use fuel savings. It is these "windfalls" that lead to the discontinuities depicted in Figure 21.

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Appendix C. Acronyms

CAFE	U.S. Corporate Average Fuel Economy
EPA	U.S. Environmental Protection Agency
NHTSA	National Highway Traffic Safety Administration
CARB	California Air Resources Board
GHG	greenhouse gas
ICE	internal combustion engine
EV	electric-only vehicle
BEV	battery electric vehicle
HEV	hybrid electric vehicle
PHEV	plug-in hybrid electric vehicle
CUV	crossover utility vehicle
SUV	sport utility vehicle
MPG	miles per gallon

Appendix A-1

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