

Equities

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U.S. Autos & Auto Parts

Fuel Economy Focus: Industry Perspectives on 2020

■ Industry Overview

- **What's New?** — In collaboration with Ceres and the Investor Network on Climate Risk, we, along with Oakland University's School of Business Administration, Baum and Associates, and Meszler Engineering Services evaluated the impact that the proposed U.S. Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emissions program might have on the industry in 2020. The analysis is meant to provide investors with a framework for evaluating this important, yet fluid, long-term theme. Since analyzing this dynamic subject involves making numerous assumptions that can meaningfully sway outcomes, we have also provided key sensitivities in the report.
- **Regulatory Timeline Update** — In May 2010, a secondary phase of the National Program (CAFE/GHG vehicle standards for model years 2017-2025) was proposed and enacted by EPA and NHTSA. After considering a range of standards (as set forth in the 2010 Joint Notice of Intent), last December the agencies proposed a standard of 49.6 miles per gallon and 163 grams of CO₂ per mile by 2025 (equivalent to 54.5 mpg). The final rule is expected in mid-2012.
- **OEM Simulation Takeaways** — The report updates OEM product plans, an overview of key technologies and potential penetration rates. Simulating the long-term sales & profit impact to automakers is highly dynamic and involves several debatable assumptions. Our baseline simulation suggests that an opportunity exists for aggregate industry sales and profits to actually increase as fuel economy improves. This is based on assumptions that we deem reasonable, however, we also recognize and present scenarios where industry profits would suffer from tightening regulations. The report does not seek to endorse one set of assumptions over another or form a view on the merits of industry regulations, but rather provide investors with a framework for modeling this important and inevitable trend. Under our baseline simulation, Detroit 3 profits gain vs. the industry due to: (1) Narrowing the historical gap between D-3 fuel economy and competitors; and (2) Light trucks and larger cars, in which the D-3 sport a greater share, have greater potential to add consumer value, and since full-size trucks tend to be used for commercial purposes, this is actually an advantage to the D-3.
- **Suppliers of Fuel Economy Technologies to 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), Delphi (DLPH) 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. Delphi stands to gain from its position in Powertrain technologies and electronic distribution systems (weight reduction). JCI sports a leading position in the growing start-stop hybrid market.

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

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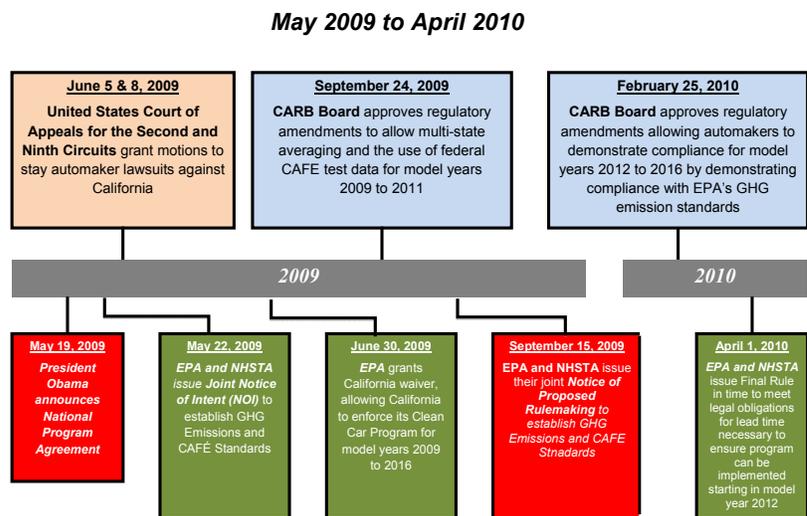
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Fuel Economy Focus: Perspectives on 2020

In collaboration with Ceres and the Investor Network on Climate Risk, we, along with Oakland University's School of Business Administration, Baum and Associates, and Meszler Engineering Services simulated the impact that the proposed U.S. Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emissions program might have on the industry in 2020. The analysis is meant to provide investors with a framework for evaluating the potential industry impact from tightening regulations. Since analyzing this dynamic subject involves making numerous assumptions around uncertain factors, we have provided key sensitivities.

Phase I of the National Program: 2012-2016

Figure 1. National Program MY2012-2016 Timeline



Source: U.S. EPA, California Air Resources Board, and Natural Resources Defense Council

In May 2009, 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 was announced. This program grew out of an agreement between the automakers, the state of California, and the U.S. Executive Office. EPA and NHTSA adopted the final rule in April 2010.

The adoption of Phase I of the National Program was noteworthy because it represented the first U.S. regulation of GHG emissions for any source (the result of the 2007 Supreme Court case *Massachusetts v. EPA*), as well as the first update to fuel economy standards in decades.

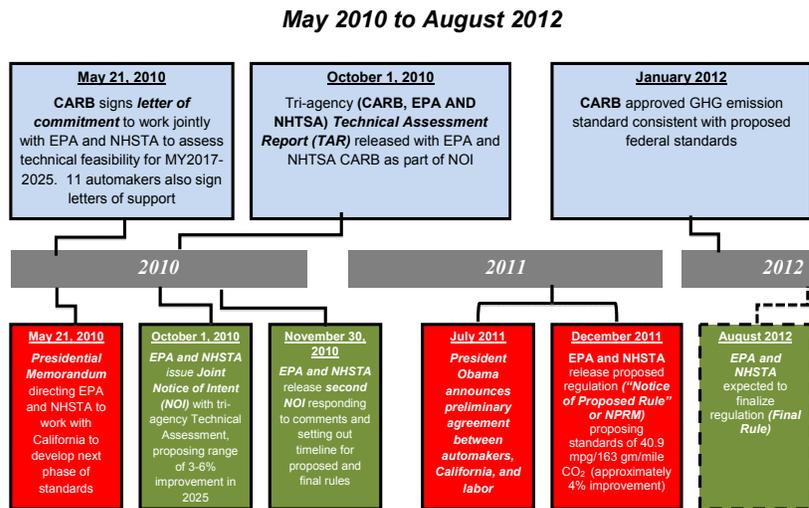
The National Program was also significant in that it provided for consistency between federal and state CAFE and GHG emission standards, which was a critical component from the perspective of automakers. Under section 209 of the Clean Air Act, California is empowered to set its own vehicle emission standards, provided that they are at least as stringent as federal standards, and EPA provides a waiver to California. Under section 177 of the Clean Air Act, once California receives a waiver, other states are permitted to adopt California's standards as well.¹

¹ Thirteen states and the District of Columbia, comprising 40% of the national light-duty vehicle market, adopted California's GHG standards for 2009-2016.

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, which requires an estimated fleetwide average of 34.1 mpg and 250 grams of CO₂ per mile by 2016. Thus, for the first time, there was effectively one national standard for fuel economy and GHG emissions.

Phase II of the National Program: 2017-2025

Figure 2. National Program MY2017-2025 Timeline, Phase II of National Program



Source: U.S. EPA, California Air Resources Board, and Natural Resources Defense Council

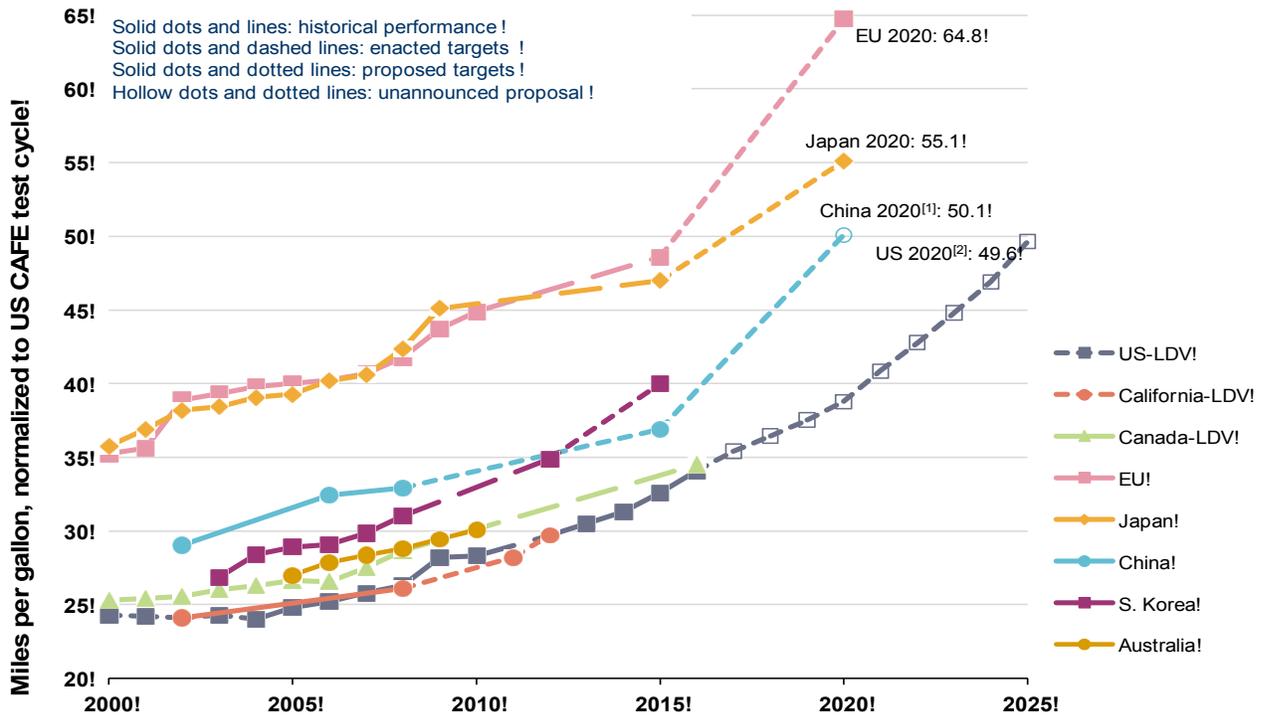
In May 2010, EPA and NHTSA began to work with California to develop the next phase of the National Program (for model years 2017-2025). In October 2010, EPA and NHTSA issued a Joint Notice of Intent (NOI), with an Interim Joint Technical Assessment Report (TAR) authored by CARB, NHTSA and EPA, followed by a Supplemental NOI in November 2010. The TAR found that scenarios ranging from 3-6% annual increases in stringency would be technically feasible. After a period of extensive discussions between federal agencies, California, automakers, and other stakeholders, a preliminary agreement was announced in July 2011. In December 2011, the proposed federal rule setting standards in 2025 of 40.9 mpg/163 gm/mile of CO₂ (roughly equivalent to 54.5 mpg), was published, and in January 2012, CARB approved a GHG emissions standard consistent with the proposed federal standards.

The rules provide for a mid-term evaluation by both agencies of the standards from 2022-2025 (NHTSA is statutorily required to conduct a separate rulemaking for those years). Like Phase I of the National Program, the standards are based on the vehicle footprint; hence smaller vehicles are subject to more stringent standards while larger vehicles are subject to less stringent standards. Combined with the Phase I of the National Program, by 2025 the proposed regulations would nearly double the fuel economy and halve the GHG emissions associated with MY 2010 vehicles.

Comparison of U.S. and International Standards

The proposed federal standards would be less stringent than many foreign standards; however, as shown in Figure 3 below, they are beginning to converge.

Figure 3. Historical Fleet Fuel Economy Performance and Current or Proposed Standards



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be higher.
 [2] US and Canada light-duty vehicles include light-commercial vehicles.

Source: Global Comparison of Light-Duty Vehicle Fuel Economy/GHG Emissions Standards (ICCT), August 2011

Market Analysis

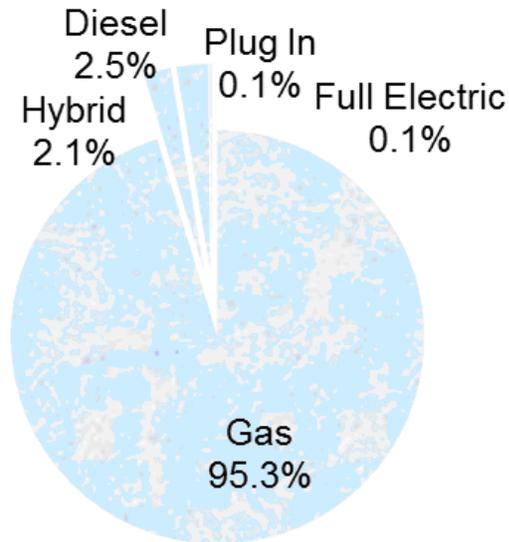
The Role of Alternative Fuel Vehicles

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). Other manufacturers are increasing diesel share and going beyond the large pickups, which have been their historical stronghold. Differences in emissions standards between the U.S. and other nations (particularly those in Western Europe) have slowed the deployment of diesel engines in the U.S., however, there appears to be some harmonization forthcoming, which may reduce the cost of emissions reduction (by spreading costs across higher volumes) and therefore reduce the cost and increase the utilization of these powertrains.

The figures below present a conservative view of the share of U.S. sales among the various powertrain types. These figures are based upon the minimum expected projections of alternative fuel vehicles. However, it is likely that consumer demand and automaker goals will increase shares beyond those shown. 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) will enable hybrids (including lower cost mild hybrids), plug-ins, and electrics (as well as diesels) to coexist.

Figure 4. U.S. Sales by Powertrain Type in 2011



Source: Baum and Associates

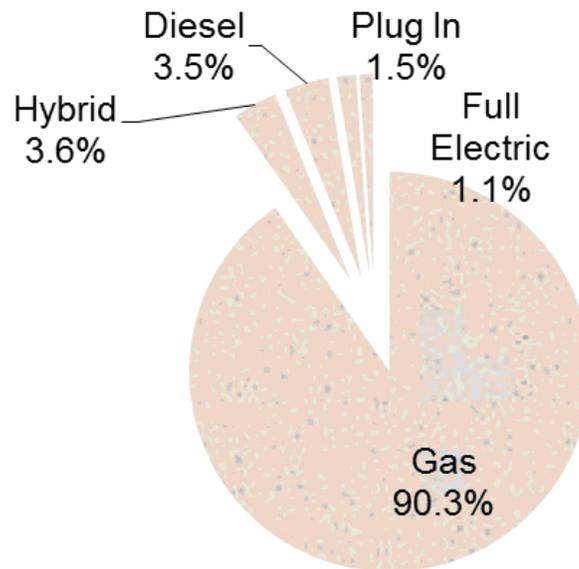
In 2011, hybrids represented 2.1% of the market that was affected by a shortage of product due to the Japan earthquake and tsunami (which affected both vehicles built in Japan as well as key components that were provided by Japan-based suppliers). The importance of Toyota in the hybrid market (with the 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 2011. Over the next several years, a large number of new entries, the increasing price of gasoline, and overall growth in the vehicle market should 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 should enable increased market share going forward. The following table illustrates the large number of vehicles offered to U.S. consumers, although volumes on many of these products will be modest by 2015.

Figure 5. Alternative Vehicles Available to U.S. Consumers

Vehicle Type	# of Entries
Regular hybrid	Over 50
Full electric	Over 30
Plug-in electric	Over 25

Source: Baum and Associates

Figure 6. U.S. Sales by Powertrain Type in 2015

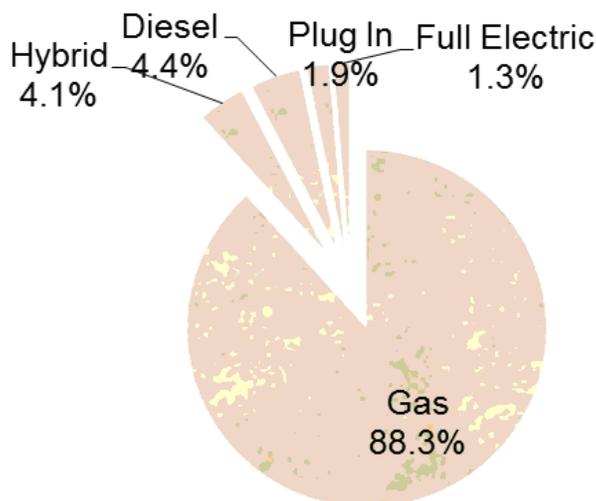


Source: Baum and Associates

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

- Gas prices in line with current levels (adjusted for inflation).
- Modest or no consumer purchase incentives.
- Modest or no manufacturer incentives.
- 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.

Figure 7. U.S. Sales by Powertrain Type in 2020



Source: Baum and Associates

General Motors

GM is taking a number of approaches to enhance fuel economy. While there is no particular advantage in meeting these standards by increasing the sale of small cars, GM is using this strategy with the forthcoming Chevrolet Spark and Cadillac ATS and the ongoing sales of the Chevrolet Cruze. Volumes of the Chevy Sonic and Buick Verano should continue to grow. The ATS is the first Cadillac small car since the Cimarron, but this car is designed on a new platform with appropriate Cadillac content and performance aimed at the heart of the entry luxury market.

GM is taking a leadership role in the introduction of mild hybrids, which includes a small lithium ion battery, belt driven electric motor/generator, regenerative braking, start/stop technology, low rolling resistance tires, and aerodynamic improvements. The technology appears on the Buick Lacrosse and Regal and Chevrolet Malibu, with other vehicles coming soon. The technology carries the appeal of a low-cost, high-return strategy, particularly compared to other approaches such as battery electric vehicles.

Sales of the Volt in 2011 were somewhat behind plan. However, GM has launched a marketing campaign to spur sales (March 2012 sales were stronger) and the Volt technology is likely to be used in a number of vehicles in order to spread costs and provide additional volume. The Volt has already served as a "halo" technology and attracted customers who purchased other vehicles such as the Chevrolet Cruze and Malibu.

GM is expected to continue leveraging its global resources for vehicles and powertrains (and associated technologies) including from its Opel division, which can contribute diesel engines and small internal combustion engines.

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. These include 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).

Ford

Unlike some of its competitors, Ford has placed greater emphasis on smaller vehicles and smaller engines. This is a high risk/high return strategy, but it is consistent with the requirement to meet higher fuel economy and has so far worked well. While Ford gained 10bp of U.S. market share in 2011 and was solidly profitable. New products launching in 2012 (Fusion and Escape, as well as the Lincoln MKZ) should provide volume growth and improvements in fuel economy.

Customers moving from larger vehicles are often unwilling to give up content to which they have become accustomed, and are willing to pay for these options (in part because of the lower cost of the smaller vehicles relative to the larger vehicles they are leaving). In particular, Ford has enhanced its small car range with a new Focus (offered almost identically worldwide), Fiesta, and smaller crossover utility vehicles (CUVs).

Beyond modifying its product line (now more diverse due to its greater focus on global platforms), 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 F-150, Edge, Escape, Explorer, Flex, MKT, MKS, and Taurus, and soon the Fiesta, Focus, and Fusion. Ford plans to offer the EcoBoost as an option on 90% of its U.S. products within a year or two.

Ford's strategy is to use EcoBoost to reduce the displacement of its engines and provide performance and fuel economy that customers are 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.

Besides being a technically advanced product, Ford's marketing of the EcoBoost has been effective and consumer recognition of the technology is very high. On the F-150, the EcoBoost has exceeded expectations with a 40% take rate, which was only constrained by engine availability. Besides charging a premium for the engine, Ford also packages additional content with many of these sales, thus further increasing profitability.

The redesigned 2013 Fusion is scheduled to launch this fall and the engine choices include a standard four cylinder engine, two EcoBoost four cylinder engines, a regular hybrid, and a plug in hybrid. This is significant, because the Fusion is a high volume vehicle and at the center of Ford's product line. The forthcoming 2013 Escape will be offered with the same four cylinder engine options as the Fusion. These powertrain options will make a strong contribution to Ford's fuel economy improvement efforts.

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 and/or accelerates. The technology is relatively inexpensive, can improve fuel economy from 4% to 10% and is particularly useful in city driving. The technology is common in hybrids (and even more prevalent across the fleet in Europe), but Ford should lead the field in widespread use of the feature on smaller vehicles with internal combustion engines. The feature will likely spread to most vehicles except

large trucks, and we expect most automakers to incorporate the product. A credit has been included in the current fuel economy regulations to encourage the use of start-stop technology (as the current EPA test cycle did not give credit for the fuel improvement offered by this technology).

Ford will be offering products across multiple electric vehicle technologies. Hybrids either exist or are planned on the C-Max, Fusion, and MKZ, while Ford manages plug-in versions of the Focus, C-Max, and Fusion, and battery electric technologies on the Focus. In this way, Ford 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.

Chrysler

With respect to powertrain, Chrysler's existing I4 engine family has been upgraded (and is now known as the Tiger Shark) and its new V6 Pentastar engine represents substantial improvement from prior products in terms of performance and fuel efficiency. Fiat's MultiAir technology has been and is being added to many of these products in order to improve emissions and fuel economy. In addition, one high-speed transmission, in partnership with ZF, has launched and another is forthcoming and will be offered in high volume with production at Chrysler's facilities in Kokomo, Indiana.

Chrysler is moving conservatively in the area of hybrids and electric vehicles. The company plans to offer a regular hybrid in the 300 and plans to include an electric powertrain for the Fiat 500. Before its link with Fiat, Chrysler had shown several versions of alternative powertrain vehicles, but these have been scrapped in favor of Fiat's broader plans for the company.

Chrysler could make a mark in diesel technology, given that Fiat is a global leader. Chrysler has offered diesel engines on some of its sport utilities in the past, but current usage is limited to vehicles sold outside the U.S. The Grand Cherokee and Durango will soon offer a diesel, and the Liberty is expected to follow suit.

Honda

Honda's fuel economy has always been among the best in the industry given its heritage as an engine company.

The Civic, CR-Z, and Insight hybrids remain available and sell relatively well and a number of Acura vehicles will soon offer hybrid powertrains. Further, an Accord plug in hybrid is on the way. Honda is also developing a low-volume full electric Fit and continues to develop the FCX Clarity, a vehicle powered by fuel cells.

Additionally, fuel economy requirements led Honda to cancel the introduction of larger engines and a rear wheel drive platform for its Acura brand. Six speed transmissions and a CVT are forthcoming, as Honda seeks to close the gap it currently has in transmission technology.

Nissan

Nissan weathered last year's devastating earthquake better than its competitors and has gained share, although that may be difficult to maintain as its competitors recover. The Altima, Pathfinder, and Sentra are newly redesigned this year, and plant expansion in Mexico will provide additional capacity as more products are sited in North America (thereby increasing product availability).

Nissan was a latecomer to alternative engine technology, but has raised its profile with the all-electric Leaf. The technology will be offered in a number of other Nissan, Infiniti, and Renault products. Production is planned in three locations worldwide, which should ensure adequate supply of the Leaf (with U.S. production of the vehicle and its batteries beginning late this year).

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.

Toyota

Toyota is clearly the industry leader in regular hybrids and it will continue to leverage this leadership, with an entire range of products now available. U.S. sales of the Prius since its launch in 2000 have surpassed 1 million units and sales should grow significantly in 2012 with the launch of new products. The “regular” Prius has been joined by a larger wagon-like vehicle (known as the “V”), a smaller vehicle known as the “C” and a plug in version, which can run in all-electric mode for short distances. In addition, the new Camry has spawned an updated hybrid version with improved fuel economy (although falling short of the forthcoming Ford Fusion hybrid). Additional hybrid products are forthcoming or continuing, including the Lexus RX and Toyota Highlander (with production planned to move to the U.S. next year).

Toyota is also launching a RAV4 electric vehicle, with design assistance and battery provided by Tesla. The Prius plug in and the RAV4 electric are examples of Toyota’s diversification efforts, although regular hybrids remain its central focus.

It is important to note that the cost of the Prius and related products is declining, as Toyota has improved its products and reduced its manufacturing costs. By 2014, the Prius will be in its fourth generation, with further improvements in performance and pricing. Over the years, the success of Toyota’s products and strong marketing of its fuel-efficient products have been a major competitive advantage for the company. However, the industry will likely narrow the gap as more stringent CAFE regulations create a more level playing field over the coming years.

Hyundai/Kia

Hyundai and its affiliate Kia have gained significant market share with strong marketing, improved products, and a number of powertrain innovations. The Sonata was ahead of a trend in midsize sedans by offering only four cylinder engines, including a high mileage four cylinder turbo for those desiring higher performance. This design allowed for less weight in the vehicle frame and a number of other fuel saving characteristics.

A hybrid version is also offered, and the same option is available on the Kia Optima. The company is using lithium polymer batteries as opposed to the apparent 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.

The company has attracted attention by attaining high levels of fuel economy in a number of its internal combustion engine-powered products, breaking the 40 mile per gallon milestone (which translates into a much higher level under the test cycle used to determine CAFE compliance).

Fuel Economy Impacts on Suppliers

The following section focuses on key technologies and components driving the improvement in fuel economy and highlights some of the companies most likely to be impacted. Our focus is on public companies as they offer a more direct opportunity for investment, although there are clearly some smaller companies that, if successful, may also offer investment opportunities.

Internal Combustion Engine Technologies

The importance of the internal combustion engine in meeting fuel economy requirements means that volumes for components that meet this challenge will be significant. Many of these products are based upon components that are standard on most vehicles and are modified to improve fuel economy. This is important because it reduces the development cost and piece price given high volume production that allows for amortization of what otherwise might be higher costs.

The “workhorse” suite of technologies that form the core of the low-cost/high-return approach to fuel economy contains a number of key components including:

- Direct injection.
- Electric power steering.
- Exhaust gas recirculation.
- Low rolling resistance tires.
- Turbocharging.
- Variable valve lift and timing.

Figure 8. “Workhorse” Technologies

Product	Companies
Direct injection	Bosch, Continental, Delphi, Siemens
Electric power steering	Denso, JTEKT, Mando, Nexteer, NSK, NTN, TRW, ZF
Exhaust gas recirculation components	BorgWarner, Metaldyne, Senior Flexonics
Low rolling resistance tires	Bridgestone, Continental, Goodyear, Michelin, Yokohama
Turbochargers	ABB, BorgWarner, Bosch, Continental, Eaton, Honeywell
Variable valve lift and timing	Aisin, BorgWarner, Delphi, Eaton

Source: Meszler Engineering Services

Transmissions

Advances in transmission technology are critical to the improvement in fuel economy for internal combustion engines. Transmission technology provides a strong improvement in fuel economy and is relatively well understood by consumers (more speeds are better than fewer!). There has been some concern with the “feel” provided by dual clutch transmissions and automakers need to be attentive to American drivers and their comfort level with these newer products. Continuously variable transmissions are also important as their market share has increased, and in the past some have performed better than others. Again, automakers have taken notice and current products are being designed to perform at a higher level.

While consumers will not dismiss a product due to its transmission specifications, advanced transmissions and higher fuel economy are highly correlated and are therefore valued by consumers.

Figure 9. Transmission Technologies

Product	Companies
Automated manual transmissions	Aisin, BorgWarner
Automatic - high speed (6 or more)	Aisin, ZF
Continuously variable transmissions	Aisin, JATCO
Dual clutch transmissions	Aisin, BorgWarner, Getrag, ZF

Source: Meszler Engineering Services

Other Components

Components that require power from the vehicle's engine works against fuel economy. As a result, items like electric power steering are growing in popularity as they result in less "assistance" from the engine. HVAC has historically required "power" from the engine to operate and alternative systems are gaining share. Other items such as LED lighting are growing in popularity as their use of energy is far less than standard lighting systems. Companies such as Cree and Osram Sylvania are among those pushing the technology.

While many of the products described in the previous section are offered by larger, usually first tier suppliers (some of which are identified here), the opportunity is not limited to suppliers that make these well-known parts. Far-reaching approaches that facilitate improved fuel economy include mass reduction, drag reduction, low friction materials, and downsizing.

These "approaches" are available to any supplier and offer suppliers an opportunity to solve problems for their customers, which gives them the ability to at least argue that their products are not commodities and that they should therefore not be subject to continuous cost reduction. Of course, the competitive nature of the industry makes such an approach challenging, but certainly not impossible.

Hybrid and Electric Vehicle Technologies

While the share of vehicles offered as hybrid or electric vehicles by 2020 is much smaller than vehicles powered by the internal combustion engine (and as illustrated above, a modest share will be needed to meet the fuel economy requirements), the share will be significant and is expected to rise over time. There are a number of unique components that are required and include the following:

- Batteries.
- Battery cooling systems.
- Battery materials.
- Electric motors.
- Electronic content including controllers and electronic control modules.
- Infrastructure such as charging stations.
- Inverters.
- Power splitters.
- Start/stop systems (also available on internal combustion engine powered vehicles).
- Wiring including harnesses and advanced controls.

Volume for these products will vary (some could be sold across models, while others will be more vehicle specific) and may require significant product development and sales effort. While volumes might be modest in the short term, contracts in this growing area may be rewarded with growing volume in the future. Experience gained in this period may be very useful in reducing production costs and winning new business as volumes grow in later years.

Figure 10. Hybrid and EV Technologies

Product	Companies
Batteries	A123, ABB, BWA, Bosch, BYD, Compact Power (LG Chem), CON, Dow Kokam, Electrovaya, Yuasa, Hitachi, HON, JCI, NEC, Panasonic, Samsung, Sanyo, Tesla, Toshiba
Battery cooling systems	Behr, Visteon
Battery materials	3M, Applied Materials, BASF, Celgard (Polypore), Chemetall Foote, Dow, DuPont, Holingsworth and Vose, HON, Mitsubishi, Novolyte Technologies, Superior Graphite, Toda
Electric motors	Brose, CON, Hitachi, Remy
Electronic content including controllers and electronic control modules	Bosch, CON, DanaHER, DLPH, Denso, Intersil, MGA, Maxim, NEC, Rohm, Sanyo, Texas Instruments, TRW
Infrastructure such as charging stations	Aerovironment, Coulomb Technologies, Eaton, ECOtality, GE, GridPoint, LEA, Leviton
Inverters	Denso
Power splitters	Delphi Electronics
Start/stop systems	Bosch, CON, Denso
Wiring: harnesses and advanced controls	Inteva Products, LEA, Leoni, Sumitomo Electric, Yazaki

Source: Meszler Engineering Services

Material Opportunities

The enemy of fuel economy is weight. As a result, we are seeing growing content in traditional materials such as aluminum, plastics, and magnesium. Other less traditional materials include high-strength steel and in more extreme circumstances, carbon fiber.

Simulated OEM Implications of 2020 Standards

Impacts on Sales and Profits in 2020

Our simulation suggest that improving fuel economy could have a positive impact on sales units and variable profits for the U.S. auto industry, where variable profit rises by 5.3% (Detroit 3 +6.3%), according to the baseline analysis. Please note that this simulation is intended to assist investors with framing this evolving topic; as the sensitivities show, profit outcomes can vary greatly (and even result in losses) depending on the assumptions. The purpose of the simulation isn't to argue for one set of assumptions over another, but rather to illustrate the model under various assumptions.

In the baseline scenario, the Detroit Three gained relative to the industry as a whole. We have identified several reasons that drove this outcome. Historically, and in our initial forecast, the Detroit Three lag behind the Japan Three (Honda, Nissan and Toyota) in average fuel economy and the response to 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.

In the baseline scenario, we assumed an industry-wide standard in 2020 of approximately 40 mpg, and a regular unleaded gasoline price of \$3.50 per gallon. 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 – 2020E

We chose to focus on the year 2020 due to our opinion about the limits of plausibility of detailed long-term forecasts. In addition, the fuel economy regulations for the period 2022-2025 are subject to a mid-term review in 2018 and therefore may change from the levels in the current rule. 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 (vehicle, drivetrain, and powertrain) through 2017. This included electrified vehicles (hybrid, plug-in, and all-electric) as well as conventional gasoline-powered and diesel-powered vehicles.

In the second step, we organized the 2017 vehicle configurations into aggregates by segment 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 approximately 40 mpg, is shown in Figure 11 below.

Figure 11. 2020 Sales Forecast (Thousands): Prior to Impacts of Higher Fuel Economy (to approx. 40.0 mpg)

Segment	Chrysler	Ford	GM	Honda	Nissan	Toyota	Others	All automakers
Car - Luxury	37	52	162	53	87	145	670	1,204
Car - Midsize	304	567	708	434	373	654	989	4,030
Car - Small	98	409	563	512	399	372	746	3,098
CUV - Luxury	-	37	56	64	16	134	40	347
CUV - Midsize	99	342	281	185	74	204	394	1,579
CUV - Midsize	88	415	367	303	177	263	270	1,883
Minivan	175	-	-	145	11	148	50	528
Pickup - Large	258	600	591	-	33	98	-	1,580
Pickup - Small	18	-	43	-	56	139	-	257
SUV - Large Luxury	-	33	18	-	-	16	71	139
SUV - Large	-	43	181	-	21	-	-	245
SUV - Midsize	241	-	-	-	47	58	8	354
SUV - Midsize Luxury	-	-	-	-	13	-	195	208
SUV - Small	122	-	-	-	-	-	28	150
Van - Large	-	104	69	-	12	-	18	202
All Segments	1,440	2,601	3,038	1,696	1,319	2,230	3,479	15,802

Source: Baum and Associates and Oakland University, School of Business Administration

In our subsequent analysis, we held these 74 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”).

Chrysler and Ford each have ten entries, while General Motors has eleven entries, based on our vehicle segmentation. Honda has only seven entries (owing to a more limited product line, while Nissan has thirteen entries and Toyota has eleven. The “Other” category (based on actual product offerings) has twelve entries.

Econometric Model

The econometric model used to simulate the industry impacts of higher fuel economy is based on a 74 by 74 matrix of price elasticities and cross-price elasticities. 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 future fuel costs of the entry itself and the prices and future fuel costs of all 73 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 + (Present Value of Fuel Costs) x (Consumer Trade-off Between Price and Future Fuel Costs)

Present Value of Future Fuel Costs is a function of the Relevant Life of the Vehicle, Expected Future Fuel Prices, Future Vehicle Miles Traveled (VMT), and the Net Consumer Discount Rate.

The Net Consumer Discount Rate = Real Discount Rate + Rate at which Annual Vehicle Miles Traveled (VMT) Fall as the Vehicle Ages – Expected Rate of Inflation in Fuel Prices

All of the elements in these definitions, except the purchase price, are subjective and depend on consumer preferences. We examine the impacts of a range of subjective values for these factors in the sensitivity analysis of Appendix A.

The consumer trade-off between price and future fuel costs measures the rate at which consumers are willing to trade reductions in future fuel costs for increases in current 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 which results in reducing by \$1 the present value of fuel costs.

The consumer discount rate is the rate at which consumers discount future fuel costs. It has three elements. The real discount rate measures the time value of money. VMT falls as the life of the vehicle increases due to vehicle retirements and vehicle aging. The expected rate of inflation in fuel prices reflects expectations of consumers about future inflation in fuel prices over and above overall economic inflation in all prices.

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 74 alternative entries. Some observers have claimed that consumers consider only the first three years, while others have claimed that consumers consider many more years.

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.

Variable Profit

The 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 sales, price, variable cost, and variable profit for 74 segments by manufacturer market entries to 2020. Variable profit is the difference between revenue and variable cost. Thus to estimate or forecast variable profit, we need to estimate or forecast revenue (sales times price) and variable cost. The following definitions, all at the market entry level, may be helpful.

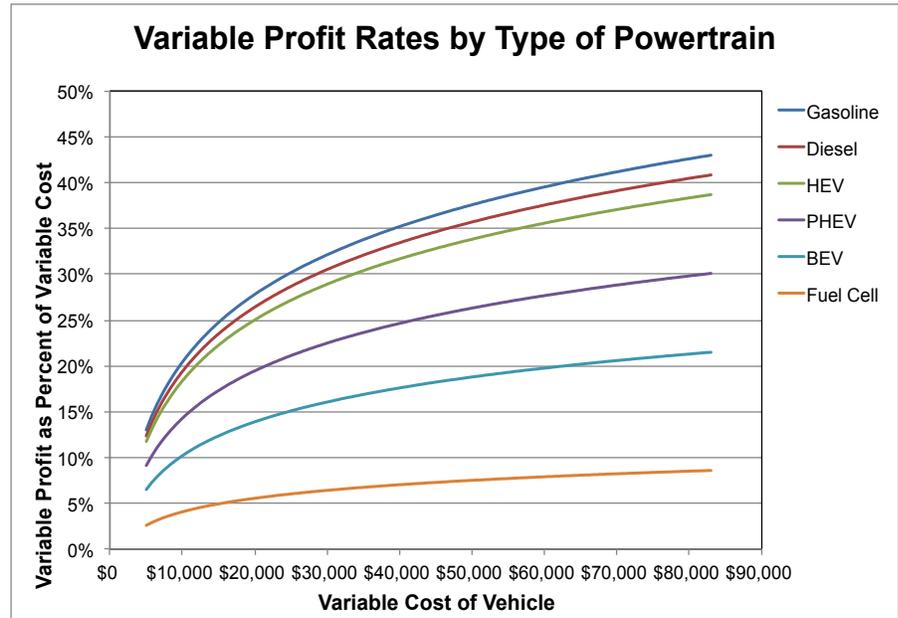
- **Price** = Revenue per Unit Sold.
- **Variable Cost** = Base Variable Cost + Cost of MPG Improvements (Base Variable Cost is our estimate of the variable cost per unit prior to the MPG improvements needed to meet the 2020 target).
- **Variable Profit (per unit)** = Price – Variable Cost (per unit).
- **Variable Profit Rate** = (Variable Profit) / (Variable Cost).

Note that our current definition of the variable profit rate is defined in terms of variable profit as a percent of variable cost. In previous studies we have used price rather than variable cost as the denominator for the variable profit rate. The choice of denominator does not affect the analysis and conclusions drawn from it. Profit rates denominated in terms of costs are numerically higher than are profit rates denominated in terms of price.

We projected variable profit rates (variable profit as a percent of variable cost) for the 74 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 variable cost, with the variable profit rate increasing with variable cost but at a diminishing rate.

Conventional gasoline-powered vehicles are likely to have the highest variable profit rates at a given variable cost. Conventional diesel-powered vehicles are expected to have a slightly lower profit rate than that of conventional gasoline-powered vehicles. 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 variable cost. We expect hydrogen fuel cell vehicles to have the lowest variable profit rate for a given variable cost. Figure 12 is a graphical representation summarizing our expectations.

Figure 12. Variable Profit Rates by Type of Powertrain



Source: Oakland University, School of Business Administration

Base Scenario: Technology-Driven Improvements in MPG

In our baseline scenario, we developed technology packages that would improve industry-wide average fuel economy to approximately 40 mpg and applied them to the 74 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 (vehicle purchase price plus future fuel costs of operation) using our mainstream assumptions about the variables in Figure 13.

Figure 13. Baseline Scenario Assumptions

Consumer net discount rate		9.2%
= Real discount rate	4.0%	
+ Rate of change in annual VMT	5.2%	
- Future inflation in fuel price	0.0%	
Consumer relevant life of the vehicle		7 years
Beginning annual vehicle miles traveled (VMT)		14,000
Consumer fuel price risk factor		90%
Expected future price of fuel (\$/gal Regular gas)	\$	3.50

Source: Oakland University, School of Business Administration

For each of the 74 entries, we computed the resulting percentage change in full price. The percentage change in sales units for all 74 entries was then determined by applying the elasticity matrix to the set of 74 percentage changes in full price. We then calculated the sales units of each of the 74 entries by applying these percentage changes in sales. The variable profit analysis was performed by applying our estimated variable profit rates to variable cost before and after the changes in fuel economy.

Fuel Efficiency Technologies and Costs

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.

Appendices

Appendix A. Sensitivity Analysis

We assessed the sensitivity of our results to alternative assumptions about the costs of meeting the 2020 target MPG and about consumer preference and expectations. Figure 14 shows the values we examined for each of these uncertainties. For each uncertain factor we developed a range of values intended to represent 90% confidence intervals. In the table, the alternative values are arranged in three columns: Unfavorable, Baseline, and Favorable. We varied the factors detailed in Figure 14 two at a time for the alternative values, generating 288 additional scenarios (including our baseline). Unfavorable profit outcomes occurred in 25 of the scenarios.

Figure 14. Uncertainties in Consumer Preferences & Expectations and in Compliance Cost

	Unfavorable	Baseline	Favorable
Consumer net discount rate	17.2%	9.2%	1.2%
= Real discount rate	8.0%	4.0%	0.0%
+ Rate of change in annual VMT	7.2%	5.2%	3.2%
- Future inflation in fuel price	-2.0%	0.0%	2.0%
Consumer relevant life of the vehicle	3 years	7 years	15 years
Beginning annual vehicle miles traveled (VMT)	9,000	14,000	19,000
Consumer trade-off between future fuel cost and vehicle price	70%	90%	120%
Expected future price of fuel (\$/gal Regular gas)	\$ 1.50	\$ 3.50	\$ 6.50
Compliance cost (multiple of baseline estimate)	3.00	1.00	1.00
Variable profit on new equipment for compliance (multiplier)	(1.00)	1.00	1.00

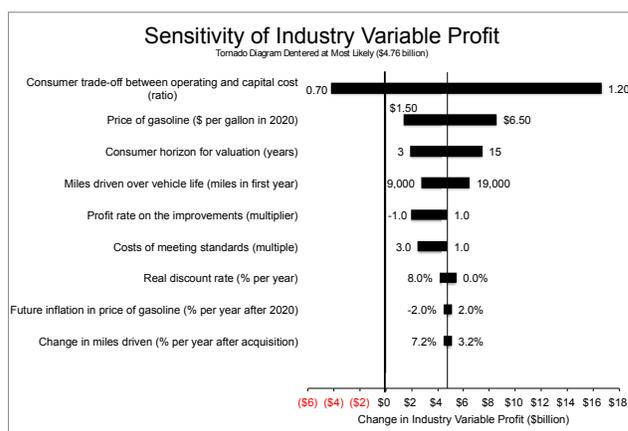
Source: Oakland University, School of Business Administration

Figure 15. Baseline Scenario Impacts on Sales and Variable Profits

\$ billions			
	Forecast	Change	% Change
Industry variable profit	\$ 89.78	\$ 4.76	5%
Detroit Three variable profit	\$ 38.76	\$ 2.44	6%
Non-Detroit Three variable profit	\$ 51.02	\$ 2.31	5%

\$ millions			
	Forecast	Change	% Change
Industry sales	15.8	0.6	4%
Detroit Three sales	7.1	0.3	4%
Non-Detroit Three sales	8.7	0.3	3%

Figure 16. Sensitivity of Industry Variable Profit



Source: Oakland University, School of Business Administration

Source: Oakland University, School of Business Administration

The Consumer Net Discount Rate, as explained in the body of the report, is a combination of three elements: the Real Discount Rate PLUS the Rate of Change in Annual VMT MINUS expected Future (post-2020) Inflation in Fuel Price. In the sensitivity analysis, each of these elements is varied separately. Note that the Unfavorable value for expected Future Inflation in Fuel Price, -2.0%, indicates that deflation is expected in fuel price. Subtracting a negative value for Future Inflation in Fuel Price results in a higher Net Consumer Discount Rate.

The other uncertain factors related to consumer preferences and expectations are Consumer Relevant Life of the Vehicle, Beginning Annual Vehicle Miles Traveled

(VMT), Consumer Trade-off Between Future Fuel Costs and Vehicle Price, and Expected Future (in 2020) Price of Fuel (\$/gal Regular Gasoline).

In addition to examining the impact on sales and variable profit of alternative assumptions about consumer preferences and expectations, we also examined the impact of different assumptions about the costs of complying with the 2020 standards. Specifically, we examined the impact on sales and profits of compliance costs three times larger than our baseline estimates. This factor is Compliance Cost, which is measured as a multiple of our baseline estimate. We did not explicitly examine the impact on sales and variable profit of compliance costs lower than our baseline.

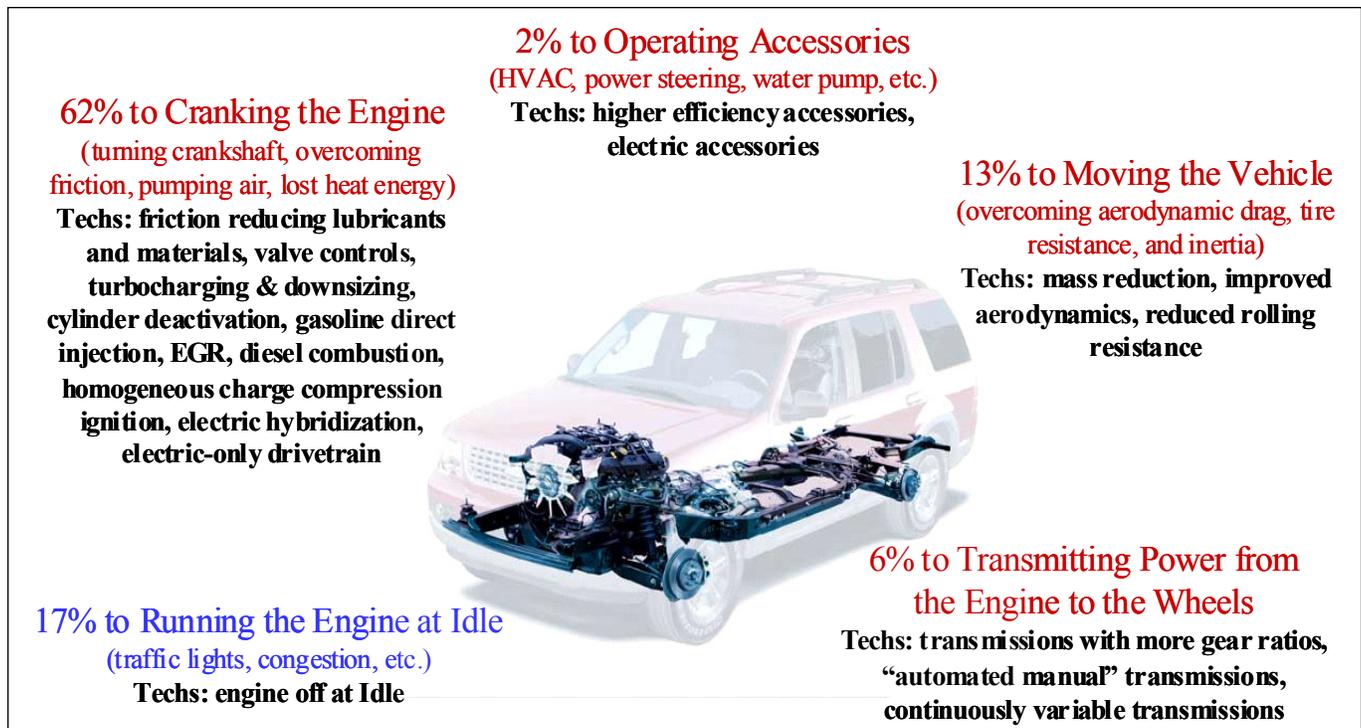
Finally, we examined the impact of a different variable profit rate on our conclusions. The uncertainty here is a multiplier, set equal to 1 or -1, and multiplied by variable profit on the new equipment the automakers add for compliance. In our baseline assumption, we assume that the new equipment garners variable profit at the same rate as the vehicle. In the downside, we assume that the equipment generates a loss rather than a profit. For example, if the variable profit rate were 30%, then in our baseline, the new equipment would earn profits of 30%, but in the downside it would generate losses of -30%.

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 17 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 17. Urban Fuel Energy Breakdown



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, NHTSA's 2012-2016 CAFE proposal and related support documents, NHTSA's 2017-2025 CAFE proposal and related support documents, a 2009 EPA report on light duty vehicle greenhouse gas technology costs, a 2004 report on greenhouse gas reduction technology from the Northeast States Center for a Clean Air Future, 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), the National Academy of Science's 2002 CAFE review, the National Academy of Science's 2010 CAFE review, 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 18 presents a list of the individual technologies evaluated, along with their respective fuel economy and cost impacts, while Figure 19 presents similar impacts for the selected technology packages.

Figure 18. 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	5.0%	See note A	\$55	\$55	\$55	\$55	\$55	\$55
VVT (Variable valve timing, cam phasing)	5.0%	Dual Coupled, no downsizing Dual Coupled, with downsizing	\$35 \$35	\$70 \$35	\$70 \$70	\$35 \$35	\$35 \$35	\$70 \$70
VVL (Variable valve lift)	3.5%	Discrete lift, no downsizing Discrete lift, with downsizing	\$100 \$100	\$150 \$100	\$150 \$150	\$200 \$100	\$200 \$150	\$150 \$150
VVT + VVL	8.5%	No downsizing With downsizing	\$135 135	\$220 \$135	\$220 \$220	\$235 \$135	\$235 \$185	\$220 \$220
Cylinder Deactivation (1/2 of cylinders deactivate)	6.0% 9.0%	Independent system With VVT + VVL	N/A N/A	\$115 \$225	\$150 \$260	\$115 \$230	\$150 \$270	\$150 \$260
Turbocharged (downsized) Gasoline Direct Injection 24 bar boost pressure, OHV converted to DOHC	25.0%	Turbo, twin turbo for V8-to-V6 Downsizing credit GDI cost Net cost	\$500 (\$50) \$150 \$600	\$500 (\$450) \$250 \$300	\$850 (\$250) \$300 \$900	\$500 \$50 \$250 \$800	\$850 \$300 \$300 \$1,450	\$850 (\$250) \$300 \$900
	30.0%	Net cost, with VVT + VVL	\$735	\$435	\$1,120	\$935	\$1,635	\$1,120
Cooled Boosted EGR (includes turbocharged, downsized GDI, 24 bar boost pressure)	30.0%	EGR system Turbo GDI Net Cost	\$200 \$600 \$800	\$200 \$300 \$500	\$200 \$900 \$1,100	\$200 \$800 \$1,000	\$200 \$1,450 \$1,650	\$200 \$900 \$1,100
	34.0%	Net cost, with VVT + VVL	\$935	\$635	\$1,320	\$1,135	\$1,835	\$1,320
Diesel Direct Injection (relative to MPFI gasoline, V6-to-I4, V8-to-I6)	42.0%	2020 HSDI from 2010 MPFI After-treatment cost Net cost	\$1,200 \$700 \$1,900	\$1,200 \$1,000 \$2,200	\$1,200 \$1,200 \$2,400	\$1,200 \$1,000 \$2,200	\$1,200 \$1,200 \$2,400	\$1,200 \$1,200 \$2,400
12V Idle Off	5.0%		\$250	\$300	\$350	\$300	\$350	\$350
42V ISG - Idle Off/Regen Braking/Launch Assist	11.0%		\$550	\$620	\$650	\$620	\$650	\$650
Mass Reduction (per % reduction in mass, PRM)	0.7%	Per pound reduced	Cost per pound = 0.045 x % change in mass					
Drag Reduction (per % reduction in drag)	0.2%	Per % reduction	\$5	\$5	\$5	\$5	\$5	\$5
Electric Power Steering	1.5%		\$80	\$80	\$80	\$80	\$80	\$80
Transmission Transition from:								
A4 to A6	5.0%		\$0	\$0	\$0	\$0	\$0	\$0
A4 to A8	9.0%		\$50	\$50	\$50	\$50	\$50	\$50
A6 to A8	4.0%		\$50	\$50	\$50	\$50	\$50	\$50
A4 to CVT	10.0%		\$150	\$175	\$200	\$175	N/A	N/A
A6 to CVT	5.0%		\$150	\$175	\$200	\$175	N/A	N/A
A4 to AMT6 dry clutch	10.0%		(\$200)	(\$200)	(\$200)	(\$200)	N/A	N/A
A4 to AMT6 wet clutch	9.0%		(\$140)	(\$140)	(\$140)	(\$140)	(\$140)	(\$140)
A4 to AMT8 dry clutch	16.0%		(\$30)	(\$30)	(\$30)	(\$30)	N/A	N/A
A4 to AMT8 wet clutch	15.0%		\$30	\$30	\$30	\$30	\$30	\$30
P2 HEV (incremental to conventional advances)	40.0%		\$2,100	\$2,400	\$2,400	\$2,500	N/A	N/A
2-Mode HEV (incremental to conventional advances)	20.0%		N/A	N/A	N/A	N/A	\$3,700	\$3,700
PHEV20 (incremental to HEV)	72.0%	See note B	\$5,000	\$6,100	\$6,100	N/A	N/A	N/A
PHEV40 (incremental to HEV)			\$6,700	\$8,600	\$8,600	N/A	N/A	N/A
EV75 (incremental to HEV)			\$6,600	\$7,900	\$7,900	N/A	N/A	N/A
EV100 (incremental to HEV)			\$8,000	\$9,300	\$9,300	N/A	N/A	N/A
EV150 (incremental to HEV)	495.0%	See note C	\$11,500	\$14,000	\$14,000	N/A	N/A	N/A

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, 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, aggressive shift logic, and low rolling resistance tires.

Note B. Assumes CAFE is based on current 50/50 dual 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 17). CAFE impact data are identical regardless of EV only range 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 17). CAFE impact data are identical regardless of EV only range 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 19. Fuel Economy Impact and Cost of Technology Packages

Fuel Economy Technology	Change in CAFE mpg	Cost to Vehicle Manufacturer for:						
		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 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 AMT8wet	39.0% 38.0%	\$401 N/A	\$530 N/A	\$527 N/A	\$551 N/A	N/A \$644	N/A \$642
VVTL + DeAct + EPS + MD + CEP	AMT8dry AMT8wet	39.0% 39.0%	N/A N/A	\$535 N/A	\$567 N/A	\$546 N/A	N/A \$679	N/A \$682
VVT + Turbo + GDI + EPS + MD + CEP	AMT8dry AMT8wet	66.0% 65.0%	\$1,001 N/A	\$745 N/A	\$1,427 N/A	\$1,251 N/A	N/A \$2,044	N/A \$1,542
VVT + Turbo + GDI + 12VSS + EPS + MD + CEP	AMT8dry AMT8wet	75.0% 73.0%	\$1,251 N/A	\$1,045 N/A	\$1,777 N/A	\$1,551 N/A	N/A \$2,394	N/A \$1,892
VVT + Turbo + GDI + ISG + EPS + MD + CEP	AMT8dry AMT8wet	85.0% 83.0%	\$1,551 N/A	\$1,365 N/A	\$2,077 N/A	\$1,871 N/A	N/A \$2,694	N/A \$2,192
VVTL + DeAct + 12VSS + EPS + MD + CEP	AMT8dry AMT8wet	46.0% 45.0%	N/A N/A	\$835 N/A	\$917 N/A	\$846 N/A	N/A \$1,029	N/A \$1,032
VVTL + DeAct + ISG + EPS + MD + CEP	AMT8dry AMT8wet	55.0% 54.0%	N/A N/A	\$1,155 N/A	\$1,217 N/A	\$1,166 N/A	N/A \$1,329	N/A \$1,332
VVTL + tGDI/cbEGR + EPS + MD + CEP	AMT8dry AMT8wet	71.0% 70.0%	\$1,201 N/A	\$945 N/A	\$1,627 N/A	\$1,451 N/A	N/A \$2,244	N/A \$1,742
VVTL + tGDI/cbEGR + 12VSS + EPS + MD + CEP	AMT8dry AMT8wet	80.0% 79.0%	\$1,451 N/A	\$1,245 N/A	\$1,977 N/A	\$1,751 N/A	N/A \$2,594	N/A \$2,092
VVTL + tGDI/cbEGR + ISG + EPS + MD + CEP	AMT8dry AMT8wet	90.0% 89.0%	\$1,751 N/A	\$1,565 N/A	\$2,277 N/A	\$2,071 N/A	N/A \$2,894	N/A \$2,392
DDI + EPS + MD + CEP	AMT8dry AMT8wet	82.0% 80.0%	\$2,166 N/A	\$2,510 N/A	\$2,707 N/A	\$2,516 N/A	N/A \$2,809	N/A \$2,822
DDI + 12VSS + EPS + MD + CEP	AMT8dry AMT8wet	91.0% 89.0%	\$2,416 N/A	\$2,810 N/A	\$3,057 N/A	\$2,816 N/A	N/A \$3,159	N/A \$3,172
DDI + ISG + EPS + MD + CEP	AMT8dry AMT8wet	102.0% 100.0%	\$2,716 N/A	\$3,130 N/A	\$3,357 N/A	\$3,136 N/A	N/A \$3,459	N/A \$3,472
HEV (with Turbo + GDI, but without cbEGR)	P2 2-Mode	133.0% 98.0%	\$3,101 N/A	\$3,145 N/A	\$3,827 N/A	\$3,751 N/A	N/A \$5,744	N/A \$5,242
HEV (with Turbo + GDI + cbEGR)	P2 2-Mode	140.0% 104.0%	\$3,301 N/A	\$3,345 N/A	\$4,027 N/A	\$3,951 N/A	N/A \$5,944	N/A \$5,442
PHEV (with Turbo + GDI, but without cbEGR) -- see Note A	PHEV 20 PHEV 40	300.0% 300.0%	\$8,101 \$9,801	\$9,245 \$11,745	\$9,927 \$12,427	N/A N/A	N/A N/A	N/A N/A
PHEV (with Turbo + GDI + cbEGR) -- see Note B	PHEV 20 PHEV 40	313.0% 313.0%	\$8,301 \$10,001	\$9,445 \$11,945	\$10,127 \$12,627	N/A N/A	N/A N/A	N/A N/A
EV -- see Note C	EV75 EV100 EV150	1306.0% 1306.0% 1306.0%	\$9,801 \$11,201 \$14,701	\$11,145 \$12,545 \$17,245	\$11,827 \$13,227 \$17,927	N/A N/A N/A	N/A N/A N/A	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, 12VSS = 12 volt start-stop system, 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 dual 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 range as current CAFE rules apply

Note B. Assumes CAFE is based on current 50/50 dual 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 range 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 Table 11). CAFE impact data are identical regardless of EV only range 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 20. 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: $1/((0.5/HEV \text{ Mode CAFE})+(0.5/EV \text{ Mode CAFE}))$ 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 because 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 proposed 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 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 21 individually.

Figure 21. 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 hybridized)	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 18 and 19, 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.

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 charge 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. Cost savings associated with downsizing a 4 cylinder engine is substantially less than the savings for 6 and 8 cylinder V block engines (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 aftertreatment 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 aftertreatment 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).

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

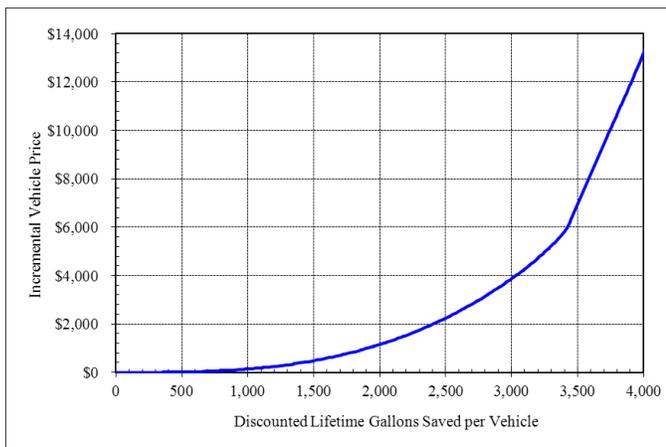
As indicated in Figure 19, the evaluated technology packages (excluding plug in hybrid and electric only technology) are estimated to be capable of increasing CAFE fuel economy by as much as 140%. However, since expenditures increase with fuel

economy impact, it is important to understand variation in the cost effectiveness of potential fuel economy increases. Figure 22 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. The underlying analysis for the presented curve is based on the parameters presented in Figure 24.

Figure 23 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. While not critical for understanding the implications of the presented marginal cost curve, it is perhaps important to briefly explain the discontinuities in the curve. As presented in Figure 22, 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 24). 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.

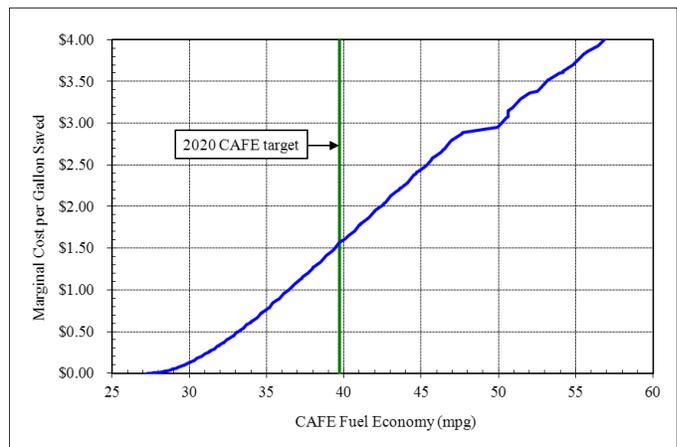
In effect, as one moves from left to right along the fuel savings cost curve (real world, in use fuel savings), one reaches points where fundamental technology shifts become necessary to achieve the associated fuel savings. When these shifts involve moving from a technology with one relationship between 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 23.

Figure 22. Fuel Economy Technology Cost Curve for 2020



Source: Meszler Engineering Services

Figure 23. Marginal Fuel Economy Cost in 2020 by CAFE Level



Source: Meszler Engineering Services

Figure 24. 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	1.40	1.40	1.60	1.80	1.80	1.80
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

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

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Appendix C. Acronyms

Figure 25. Acronyms Used in Report

Acronym	Stands for...
CARB	California Air Resources Board
EPS	U.S. Environmental Protection Agency
NHTSA	National Highway Traffic Safety Administration
UWA	United Automobile, Aerospace, and Agricultural Implement Workers of America
CAFE	U.S. Corporate Average Fuel Economy
GHG	Greenhouse gas
MPG/mpg	Miles per gallon
BEV	Battery electric vehicle
CUV	Crossover utility vehicle
EV	Electric-only vehicle
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
PHEV	Plug-in hybrid electric vehicle
SUV	Sport utility vehicle

Source: Citi Investment Research and Analysis

Appendix D. Companies Mentioned

Figure 26. Companies Mentioned

Company	RIC	Rating	Currency	Target Price	Share Price	
Nissan	7201.T	1	JPY	1290.00	899.00	
Toyota	7203.T	2	JPY	3990.00	3585.00	
Honda	7267.T	2	JPY	3530.00	3195.00	
Borg Warner	BWA.N	2	USD	85.00	85.07	
Delphi	DLP.N	1	USD	36.00	31.27	
Ford Motor	F.N	1	H	USD	15.00	12.64
General Motors Co	GM.N	1	H	USD	36.00	25.54
Johnson Controls	JCI.N	2	USD	34.00	32.60	

Source: Citi Investment Research and Analysis

Appendix A-1

Analyst Certification

The research analyst(s) primarily responsible for the preparation and content of this research report are named in bold text in the author block at the front of the product except for those sections where an analyst's name appears in bold alongside content which is attributable to that analyst. Each of these analyst(s) certify, with respect to the section(s) of the report for which they are responsible, that the views expressed therein accurately reflect their personal views about each issuer and security referenced and were prepared in an independent manner, including with respect to Citigroup Global Markets Inc and its affiliates. No part of the research analyst's compensation was, is, or will be, directly or indirectly, related to the specific recommendation(s) or view(s) expressed by that research analyst in this report.

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