

No. 18
SUMMER 2014

MERCATUS GRADUATE POLICY ESSAY

PAVING THE PATH TO FUEL EFFICIENCY: HOW FEDERAL
POLICIES AND THE MARKET ADDRESS GASOLINE USE IN
THE UNITED STATES

by Michelle Wei



The opinions expressed in this Graduate Policy Essay are the author's and do not represent official positions of the Mercatus Center or George Mason University.

ABSTRACT

Since gasoline is one of the most popular transportation fuel sources worldwide, policymakers are interested in using the tools available to them to alter their citizens' demand. Policymakers believe that without regulations, car companies will not develop and adopt technology that reduces gasoline use. The most common motivations behind policy are to discourage gasoline consumption for environmental externality issues or reduced foreign reliance. In order to predict policy results, consumer response to changes in price and vehicle attributes must be accurately known. Automobile manufacturers similarly attempt to understand consumer demand in order to reach their preferences. This paper utilizes market process theory, public choice, and the dynamics of intervention theory to analyze the predicted and actual consumer responses to policies by looking at how successful the fuel efficiency policies have been at achieving their goals. Specifically the ability of Corporate Average Fuel Economy Standards and Renewable Fuel Standard to achieve reduction in fuel use is reviewed. The market mechanisms of consumer preferences and price feedback are then examined as to how they can achieve the same goals. This paper highlights the racing industry as a testing ground for new and better technology which can spillover to production cars. This happens, to some extent, apart from government policy influence.



AUTHOR BIO

Michelle Wei is an alumna of the Mercatus Center MA Fellowship at George Mason University. Prior to graduate school, she has worked as an Earth Day Network Public Policy Programs Intern and in the University of Delaware College of Agriculture and Natural Resources. Michelle received a BS in Resource Economics from the University of Delaware.

COMMITTEE MEMBERS

Patrick McLaughlin, senior research fellow, Mercatus Center at George Mason University

Jerry Ellig, senior research fellow, Mercatus Center at George Mason University

Stefanie Haeffele-Balch, associate director, Graduate Student Programs, Mercatus Center at George Mason University

Mercatus MA Fellows may select the Mercatus Graduate Policy Essay option in fulfillment of their requirement to conduct a significant research project. Mercatus Graduate Policy Essays offer a novel application of a well-defined economic theoretical framework to an underexplored topic in policy. Essays offer an in-depth literature review of the theoretical frame being employed, present original findings and/or analysis and conclude with policy recommendations. The views expressed here are not necessarily the views of the Mercatus Center or Mercatus Center Graduate Student Programs.

Acknowledgements

I would like to thank my committee chair, Dr. Patrick McLaughlin, as well as my committee members, Stefanie Haeffele-Balch and Dr. Jerry Ellig, for their valuable comments and insights regarding my essay. I would like to acknowledge the resources and financial support from the Mercatus Center and George Mason University, which has allowed me to complete this essay and provided me with invaluable education and work experience. Any errors are my own.

Contents

Introduction	2
Economic Theory	3
The Economics of Consumer Response	4
Government Policy	6
CAFE Standards	6
Car Manufacturers' Response to CAFE Standards	8
Effects of CAFE Standards	9
Renewable Fuel Standard	13
Effects of Renewable Fuel Standard	15
Interaction between Government Policies	18
Government Policies Effect on the Market	18
Markets and the Racing Industry	19
Car Company Involvement in Racing	20
Gasoline-Powered Cars	21
Future Transfer: Electric Cars and Racing	22
Formula E	25
Other Electric Vehicle Series and Electric Racing Developments	26
Beyond Electric: Hydrogen Fuel Developments	27
Conclusion	28
Appendix 1: Alternative Fuel Vehicles in Use through 2010	30
Appendix 2: Alternative Vehicles for Sale	31
Appendix 3: CAFE Standards over Time	35
Appendix 4: Timeline of New Technologies to Reduce Emissions and Improve Fuel Economy	36
Appendix 5: Annual Costs of CAFE Standards to Achieve 10% Reduction in Gasoline Consumption	38
Appendix 6: EISA 2007 Expansion of the Renewable Fuel Standard (in billions of gallons)	39
Appendix 7: The Current Automobile Production Market	41
Appendix 8: Formula E Teams and Cities	44
2014 Inaugural Race Season Calendar	44
Ten Teams	44

Introduction

Gasoline has long been a popular topic because of Americans' love of cars, which allow people the freedom to travel privately whenever they want. With almost no refueling time and extensive availability, gasoline is currently the most convenient form of fuel available. Out of over 250 million registered cars, only 1,191,786 used alternative fuels in 2011.¹ Gasoline fuel costs have become integrated into consumer budgets as a necessity. Gasoline use benefits Americans, but the quantity of fuel consumed despite fluctuating prices is concerning to some.

As such, some US policymakers aim to reduce gasoline use for two main reasons: to address environmental quality and to ensure domestic security. Air quality is a classic tragedy of the commons problem, and the government is viewed as the traditional solution.² Air pollution is seen as a tragedy of the air commons since no incentive exists for an individual to reduce emissions when their neighbor will still burn gasoline and emit greenhouse gasses. Consuming domestic fuel sources reduces the country's reliance on foreign sources of oil with the eventual goal of energy independence. Due to the high importation volume and perceived risk associated with reliance on other countries, bipartisan political support exists to reduce fuel importation, produce more domestic fuel, and reduce overall fuel consumption. Consumers may likewise be concerned about gasoline use for these reasons, but their main concern is fluctuating price.

Policymakers think consumers do not adequately internalize the externality costs of burning gasoline. When deciding to refuel, the price per gallon is the biggest cost that consumers face, not the amount of pollution emitted or money going to foreign governments. As a result, consumers do not alter demand to the consumption level that policymakers believe reflects the costs associated with these externalities. The suppliers in the oil market observe these consumer preferences and provide them with the amount of gasoline they demand. Meanwhile, the car manufacturer market supposedly faces no reason to innovate in fuel efficiency technology since consumers continue to purchase large amounts of gasoline.

These consequences of choosing to follow consumer preferences present various environmental impact challenges during the long process required to manufacture a car. Designing a vehicle requires forecasting what a consumer will want at least a few years in advance. This presents a particular challenge with consumer fuel efficiency technology demands since gasoline demand changes slowly over time. Renato Orsato and Peter Wells point to this as support for regulatory pressure encouraging fuel efficient innovation³ since consumer demand for the technology will take a few years to reach the manufacturers. Once car manufacturers understand there is consumer demand, they can begin to alter the car's design or research new technology. However, upfront costs associated with developing technology are high. Car manufacturers would like to integrate the technology into their mass-produced vehicles in order to start seeing a return on the investment as soon as possible. This is a riskier investment strategy for companies because they are not guaranteed to develop successful fuel efficient technology, and are more hesitant to invest in something that may not pay off in the short term. The hesitation of car manufacturers to pour

¹ "How Many Alternative Fuel and Hybrid Vehicles Are There in the US?" Frequently Asked Questions. US Energy Information Administration, 2011. <<http://www.eia.gov/tools/faqs/faq.cfm?id=93&t=4>>.

See appendix 1 for graph for data up to 2010.

² The tragedy of the commons is an economic theory developed by economist Garrett Hardin. The theory states that depletion of a shared resource, or commons, arises due to each individual's self-interest in using as much of the resource as quickly as possible. This happens even if the individuals understand that this behavior does not foster long-term sustainability, since not taking advantage of consuming the resource means someone else will.

See: Hardin, Garrett. "The Tragedy of the Commons." *Science* 162.3859 (1968): 1243-1248.

³ Orsato, Renato J., and Peter Wells. "U-turn: the rise and demise of the automobile industry." *Journal of Cleaner Production* 15.11 (2007): 994-1006.

money into fuel efficient technology development is often cited as a reason why the market will not innovate without government support.⁴

A Brookings Institute paper points to the ability of the government to direct innovation as the only way to make American car manufacturers competitive globally in the production of fuel efficient technology.⁵ Regulations with mandates enforced by fines let policymakers incentivize development of fuel efficient technology and reduction in gasoline consumption at a level they deem appropriate. One such policy, Corporate Average Fuel Economy (CAFE) Standards, imposes a fine unless a specific vehicle fuel efficiency target is met. This is seen as a way to encourage car companies to invest in research and technology that can provide for the next generation of fuel efficient technology, yielding long-term fuel efficiency improvements. However, long-term research and development projects can be undertaken apart from consumer demand for fuel efficiency. With the structure of the car industry and an alternative development outlet—racing—opportunities exist to provide advanced fuel efficiency technology for production cars without government policies.

The purpose of this paper is to explore responses to the concerns about the large volume of gasoline consumption in the United States. First, this paper reviews the literature on consumer response to price and other concerns surrounding gasoline, as well as the economic theory of market process, the dynamics of interventionism, and public choice to analyze fuel efficiency goals and policies. This is the main framework of the paper, because consumer response in the market is primarily to price, influenced by both market and policy decisions. Next, the successes of policies that alter consumer behavior are examined. Specifically, CAFE standards and Renewable Fuel Standard (RFS) are analyzed. While established literature analyzes both of these policies, recent legislative changes warrant an updated analysis. Lastly, the paper examines how the market, through prices and technology development, can address consumer responses to gasoline. Specifically, this paper examines how the technology developments and innovations within racing can provide positive spillover to the consumer industry. This is the paper's main contribution, since market mechanisms that lend themselves to transferring fuel efficiency from racing technology are absent in policy debate.

Economic Theory

Market process is an economic theory that studies how individual actors satisfy their demands through exchange, and the institutions within which these transactions happen.⁶ One major tenant of market process theory is that consumers are the ultimate directors of the market, or consumer sovereignty.⁷ When a consumer buys a service or good, they are communicating to the producer that they value it at that price. The decision to buy is made on individual levels, with different subjective values leading to different marginal utilities for the same product.⁸ Producers have hundreds of transactions and are able to see trends of preferences and willingness to pay for their products, and plan to produce more goods and services according to consumer desires. Furthermore, entrepreneurship is rewarded with profit when a new or better product is produced that consumers want, and disciplined by losses when innovations do not meet consumer demand.

⁴ Ettl, John E., and Albert H. Rubenstein. "Stimulating the flow of innovations to the US automotive industry." *Technological Forecasting and Social Change* 19.1 (1981): 33-55.

⁵ Klier, Thomas and Christopher Sands. "The Federal Role in Supporting Auto Sector Innovation." Metropolitan Policy Program at Brookings, October 2010. <<http://www.hudson.org/research/7385-the-federal-role-in-supporting-auto-sector-innovation>>.

⁶ Ikeda, Sanford. "Market-process theory and" dynamic" theories of the market." *Southern Economic Journal* (1990): 75-92.

⁷ Hutt, William H. "The concept of consumers' sovereignty." *The Economic Journal* (1940): 66-77.

⁸ For more discussion about marginal utility see Menger, Carl. *Principles of economics*. Ludwig von Mises Institute, 1981.

The dynamics of interventionism is the economic exploration of how government processes affect the market process. Interventions normally affect the production side of the market, either through explicit payments or a variety of policies that give economic benefit to certain producers over others. This includes generous insurance policies, lower interest rates, tax breaks, import or export quotas, and more. All of these are subsidies because they give an economic advantage to qualifying producers, making it more difficult for unqualified producers to compete in the market. Subsidies and artificial changes in competition mean the feedback in prices no longer fully reflect consumer demand. The self-regulation of profit and loss through the price feedback mechanism no longer works since the government is also a source of profit and loss.⁹

Public choice theory applies the tools of economics to government action, mainly that individuals pursue actions in their interest. Public choice explores the incentives that government workers—both elected officials and bureaucrats—face while doing their jobs. Gordon Tullock and James Buchanan are two of this theory’s best-known authors whose scholarly work focuses on “politics without romance.”¹⁰ Actions that seem contradictory make sense once they are analyzed through the lens of public choice. For example, government agencies have an incentive to spend their entire allotted budgets—even on unnecessary or inefficient programs—because spending the money makes their mission seem important, while saving the money earns no reward. Instead their budget is cut since Congress sees no reason to give the agency as much money.¹¹

To supplement the economic theories this paper utilizes to analyze policies, the literature on consumer response in the auto industry gives insight into the specific market the policies attempt to affect. Global factors drive market conditions in the auto industry, while consumers face different decision-making timelines. A car is an expensive durable good whereas the gasoline to power the car is a lower-cost everyday expense. By analyzing the economic literature that examines how these differences affect consumer decisions, the regulatory policies to alter such consumer response can be more accurately assessed.

The Economics of Consumer Response

Prices are the largest driver in altering consumer demand in gasoline consumption. This is because gasoline purchases are necessary for many people’s basic mobility. Consumers respond to prices and demand fuel economy. Since gasoline is an inelastically demanded product, the most common immediate behavioral adjustments to higher gasoline prices are reducing the amount of driving, planning multi-stop trips, or carpooling. In the long run, consumers respond to consistently high gasoline prices by purchasing more fuel-efficient cars.

However, consumer preferences for characteristics such as vehicle speed, power, style, or brand name also influence gasoline consumption. Some alter their gasoline consumption based on preferences like where the fuel is produced or the environmental impact of burning gasoline. Since these characteristics matter in a different way to each consumer, specific decision-making behavior is difficult to identify for policymakers and economists alike. But the strong correlation between the price of gasoline and consumer behavior remains. Because it is a complex issue, extensive academic literature explores all aspects of the demand and supply sides in an attempt understand the actual workings of the market.

Consumer response to fuel efficiency is a well-researched facet of the demand side of the oil market. No matter the current price of fuel, a vehicle has a set range of achievable fuel efficiency. This

⁹ See for compilation of individual case studies: Kurrild-Klitgaard, Peter. *The Dynamics of Intervention: Regulation and Redistribution in the Mixed Economy*. Vol. 8. Amsterdam: Elsevier JAI, 2005.

¹⁰ For example see Buchanan, James M., and Gordon Tullock. *The Calculus of Consent: Logical Foundations of Constitutional Democracy*. Ann Arbor: University of Michigan Press, 1962.

¹¹ Shughart II, William F. “Public Choice.” *The Concise Encyclopedia of Economics*. September 6, 2014. <<http://www.econlib.org/library/Enc/PublicChoice.html>>.

leads some consumers to alter their travel behavior to adjust to gasoline prices, while others demand more fuel-efficient vehicles. Automotive manufacturers attempt to predict the amount of fuel efficiency, in the form of technology and vehicle weight, which consumers will demand in the next generation of car models. Policymakers also aim to predict the amount of fuel efficiency consumers will demand, and what automotive manufacturers will supply. This is necessary to forecast in order to accurately alter incentives to achieve their policy goals. For CAFE standards the goal is to increase fuel efficiency above what they calculate the market will provide in the name of externalities, public goods, and health welfare.

A 2009 literature review by Gloria Helfand and Ann Wolverton¹² surveys vehicle choice models and consumer evaluations between the cost of purchasing additional fuel economy and the expected fuel savings. The review's main question concerns an apparent gap between the amount consumers are willing to pay and the amount automakers provide. One methodological issue associated with modeling vehicle choice is that there might be endogeneity of some of the explanatory variables, such as vehicle price, if characteristics which aren't observed are the ones causing changes in consumer response to that variable. Models that use instrumental variable methods to correct for the endogeneity get different results than full models do. Another methodological issue is omitted variable bias, since many vehicle characteristics are strongly correlated with each other, and inclusion of all the characteristics can make the results difficult to interpret. This reflects the overall difficulty of isolating specific characteristics when car manufacturers offer them in packages. Errors also arose from using approximations of the attributes that actually interested consumers, though some studies used instruments for regressors to address this issue. The actual influence of vehicle regulations is also difficult to isolate, or is simply not included in models.

The choice in data source similarly can influence the scope of the interpretation and implications the model can have with a complete micro-level dataset ideal but often unattainable. This leads to one of the main things the literature lacks—direct reporting of willingness to pay for fuel economy, likely achieved through original surveying and data collection. Most models assume consumers make the best choices for their own welfare and individual situations, leading to an assumed efficient market for fuel economy minus externalities. Helfand and Wolverton point out that if this is true, then new requirements and regulations will make most consumers worse-off since they are already paying their efficient amount. Also, data and models generally rely on historical data, so they are not well suited to predict large scale changes in vehicle fleet composition. The authors recommend that major policy changes based on econometric models therefore, should be undertaken with serious caution.

The energy paradox, how models find that consumers buy less energy efficiency than a simple present value calculation finds, is explained in the literature by “consumers who put little weight on the future; consumer disinterest in fuel economy; bundling of fuel economy with other attributes; consumer difficulty calculating expected fuel savings; uncertain fuel savings contrasted with certain and immediate increased costs; consumer heterogeneity; and the role of vehicles and fuel economy in signaling a consumer's social status.”¹³ Evidence supporting some of the explanations is notably absent despite the constant citations in the literature. Possible explanations for the lack of supply of fuel economy is that manufacturers may not invest in something not clearly demanded by consumers, that they bundle attributes and choose to provide other characteristics over fuel efficiency, or the vehicle design and development takes years and are difficult to change once started.¹⁴

The literature review concludes that “[e]ven with the ability to model vehicle choice, the literature still leaves open the question of how consumers value fuel economy, and why their willingness to pay for more of it may not equal the expected value of the fuel savings. From a public policy perspective, it is an open question whether these problems justify additional fuel economy

¹² Helfand, Gloria, and Ann Wolverton. “Evaluating the consumer response to fuel economy: A review of the literature.” *National Center for Environmental Economics*. Working Paper (2009): 09-04.

¹³ Id 28

¹⁴ Id; see pages 43-47 for a more in-depth discussion.

requirements.”¹⁵ The literature review stresses that prolonged high gasoline prices lead to consumer choices to reduce fuel use and purchase fuel-efficient vehicles. However, not all the literature agrees upon the valuation of externalities associated with gasoline use and why and when consumer calculation leads to this long-term behavior. It is notable that studies focusing on other countries found this to be true as well. This is important to keep in mind since approximate behavioral responses for specific populations can be forecasted, but there are serious issues if policy is designed to elicit responses according to results found from studying nonnative populations.

Helfand and Wolverton’s extensive literature review is not all-inclusive, but it shows research has produced no clear answers that can be used to create foolproof policies. Academics have a basic idea of how consumers respond and the correlation and relationship of the elasticities. However, due to the complicated market and specific attributes that consumers may value differently, one cannot accurately isolate any one effect.

The framework of public choice and market process theory can help explain why consumer response is so difficult to predict even with advancements in academic tools. Observable market trends are the result of individuals making decisions based on the knowledge available to them at that time. Producers pick up on these trends through the feedback mechanisms of profit and loss. Academics and regulators cannot determine the exact policies that will optimize fuel efficiency and gasoline consumption, since the market is constantly changing and made up of consumers with different preferences, budgets, and utility functions. Even if the exact monetary amount of a gasoline tax, electric vehicles rebates, or gas guzzler tax is known, they are individual policies in a complex marketplace that alone may fail to alter an individual consumer’s choices. Furthermore, government policies affect both the knowledge and incentives that face consumers and producers, which can lead to unintended consequences that often prompt regulators to introduce further corrective policies.

Government Policy

CAFE standards, RFS, and the Energy Independence and Security Act of 2007 (EISA) are major federal policies that affect the car market. Their stated goals are to increase energy independence and environmental quality, but voters, special interests, politicians, and agencies ultimately shape government policy.¹⁶

CAFE Standards

The Energy Policy and Conservation Act (EPCA) of 1975¹⁷ originally established CAFE standards as a direct response to the 1973 oil embargo. In 1973 the Arab members of the Organization of Petroleum Exporting Countries (OPEC) imposed an embargo against the United States and other countries in retaliation for aiding Israel in the 1973 Arab-Israeli War.¹⁸ The embargo significantly impacted the world’s economy because the resulting increased price of oil coincided with the devaluation of the US dollar. CAFE standards sought to increase national security and protect the domestic economy by not having to rely on oil from OPEC.

CAFE standards set target fleet fuel efficiency by mandate and impose fines on any car manufacturers who fail to meet the standards. A manufacturer’s fleet is separated into domestic and

¹⁵ Id 49.

¹⁶ The field of public choice discusses this more see <http://www.econlib.org/library/Enc/PublicChoice.html> for more information.

¹⁷ “S. 622 (94th): Energy Policy and Conservation Act.” GovTrack.us. <<https://www.govtrack.us/congress/bills/94/s622>>.

¹⁸ “Oil Embargo, 1973-1973.” Milestones: 1969-1976. US Department of State Office of the Historian, 31 Oct. 2013. <<http://history.state.gov/milestones/1969-1976/oil-embargo>>.

imported, with each fleet having to meet the standards separately. A car is considered domestically produced if it contains at least 75% US, Canadian, or Mexican parts. The legislation includes scheduled increases in target fleet fuel economy up to 27.5 miles per gallon (mpg), implemented from 1978-1985. The National Highway Traffic Safety Administration (NHTSA) has authority to implement the targets with discretion, in particular the authority to propose standards above 27.5 mpg that formerly were subject to a veto by the US Senate. Court cases have since ruled that a “one-house veto” power is unconstitutional, forcing NHTSA to use the rulemaking process¹⁹ to change the standard or methods of implementation. Alternatively, the standards can be changed by legislation passed in the US Congress.

CAFE standards had automatic increases in mpg requirement until 1980, specified in the law. After this, the standard was only changed legislatively three times during the period of 1986-2010 due to the political process associated with changing the program. Partly this was because Congress froze the standard²⁰ from 1994-2000 by forbidding allocated budget funds from being used to enforce it. From 2011 on, the standard has been determined by a harmonic mean formula based on the car’s total “footprint,” a product of the wheelbase and track dimensions. Cars with a larger footprint have a lower fuel economy standard to meet, while smaller footprint cars have a higher fuel economy standard. In addition to these individual model standards, there is a minimum standard for the entire manufacturer’s vehicle fleet. The fleet standard is the higher of 27.5 mpg or 92% of the projected average fuel economy for all automobile fleets.²¹

Fines are determined by a formula of \$5.50 per automobile for every 0.1 mpg short of the average of each manufacturer’s fleet attribute standard,²² with enforcement taking two years to implement. Mercedes-Benz of North America and Bavarian Motor Works (BMW) of North America have been the largest CAFE standards violators; however they are both luxury car manufacturers which can easily afford to pay fines since consumers are willing to pay more for the signaling value of the brand name.²³

The average fleet fuel efficiency has increased over time as graphed below, and in accordance to the scheduled target increases. The current target recently announced by the Environmental Protection Agency (EPA) and the Department of Transportation (DOT) is 54.5 mpg by 2025.²⁴

¹⁹ For more information, see *A Guide to the Rulemaking Process*, Prepared by the Office of the Federal Register.

²⁰ Bamberger, Robert. “Automobile and Light Truck Fuel Economy: The CAFE Standards.” *Almanac of Policy Issues*. N.p., September 25, 2002. <http://www.policyalmanac.org/environment/archive/crs_cafe_standards.shtml>. See appendix 1 for a table of CAFE standards targets over time.

²¹ Specifically, the alternative to 27.5 mpg is “92% of the average fuel economy projected by the Secretary [of the Department of Transportation] for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year.” See <http://www.law.cornell.edu/uscode/text/49/32902>.

²² “6.10. Corporate Average Fuel Economy (Cafe) Standards.” US EPA National Center for Environmental Economics, 14 Dec. 2013. Web. <<http://yosemite.epa.gov/ee/epa/eed.nsf/fa6512c6e51c4a208525766200639df2/f422a65d47e7cea18525777d000cbcd0!OpenDocument>>.

²³ “Summary of CAFE Fines.” Fuel Economy. National Highway Traffic Safety Administration, April 2013. Web. <<http://www.nhtsa.gov/fuel-economy>>.

²⁴ “Obama Administration Finalizes Historic 54.5 MPG Fuel Efficiency Standards.” The White House. 28 Aug. 2012. Web. <<http://www.whitehouse.gov/the-press-office/2012/08/28/obama-administration-finalizes-historic-545-mpg-fuel-efficiency-standard>>.

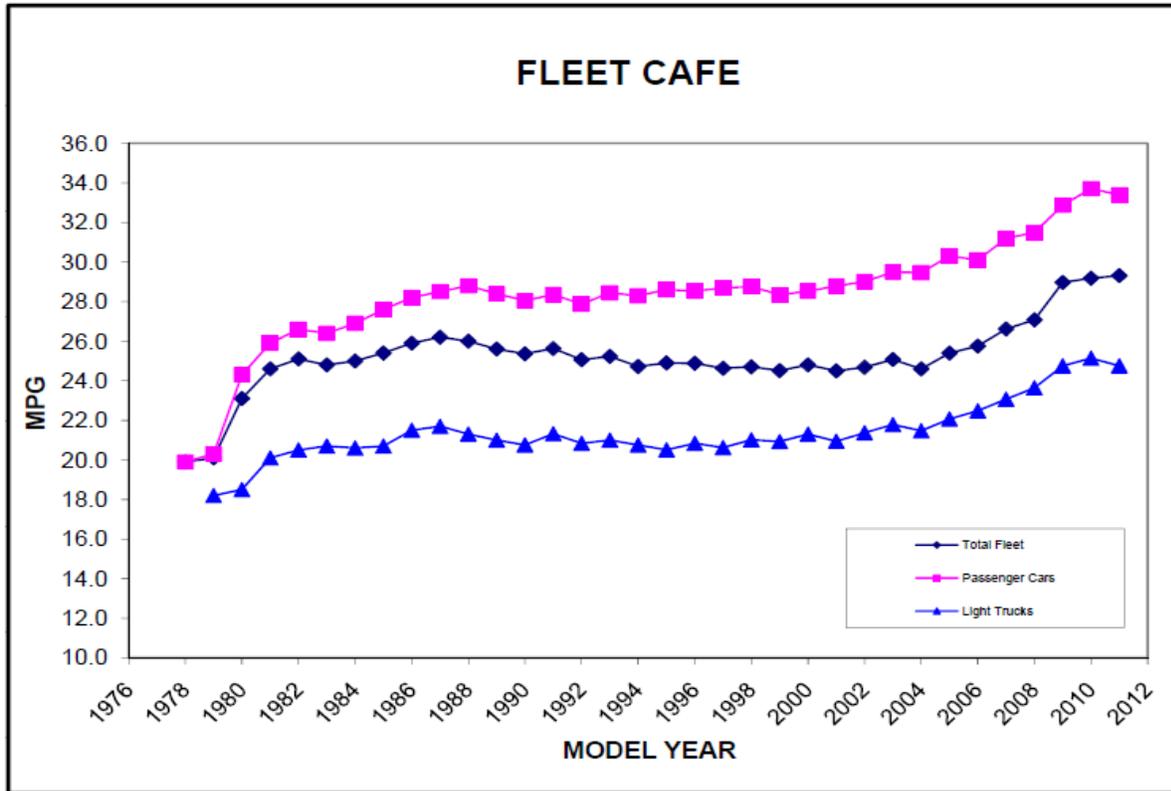


Figure 1: Fleet Fuel Economy
 Source: Summary of Fuel Economy Performance (Public Version). US DOT NHTSA. April 28, 2011

The EISA was the first legislative change to the CAFE standards since they were established. It established a credit trading provision. Credits are generated by finding the difference between required CAFE standards and actual fleet fuel economy, multiplied by ten times the number of cars in production.²⁵ Credits, equivalent to 1/10 of the difference between the standard mpg and actual mpg for each vehicle in the fleet, last up to five years and can be traded between the manufacturers’ own categories or sold to other manufacturers. This is not applicable to the fleet minimum standard but the attribute-based individual model standard, which is aggregated to become the fleet fuel economy.²⁶ Other changes include having a legislatively set goal for an average fleet fuel economy of 35 mpg by 2020 and extending requirements of the standards to all passenger vehicles, including “light trucks.” The light truck category includes pickup trucks, sport utility vehicles (SUV) and minivans. This is the first time CAFE standards have been applied to these popular vehicles.²⁷ These changes became effective in 2011.

Car Manufacturers’ Response to CAFE Standards

²⁵ The equation is as follows: Credits = (Actual fuel efficiency - CAFEStandard) * Production * 10.
²⁶ “CAFE Credit Status.” National Highway Traffic Safety Administration. <http://www.nhtsa.gov/Laws & Regulations/CAFE - Fuel Economy/CAFE_credit_status>.
²⁷ “New Light Truck Economy Standards to Save 10.7 Billion Gallons of Fuel, Include Largest SUVs for First Time Ever, Transportation Secretary Mineta Announces.” National Highway Traffic Safety Administration, 29 Mar. 2006. <<http://www.nhtsa.gov/About+NHTSA/Press+Releases/2006/New+Light+Truck+Economy+Standards+to+Save+10.7+Billion+Gallons+of+Fuel,+Include+Largest+SUVs+for+First+Time+Ever,+Transportation+Secretary+Mineta+Announces>>.

In 2009 during President Barack Obama's announcement of a policy agreement to reach 35.5 mpg fleet fuel economy by 2016, supported by Ford, Toyota, GM, Honda, Chrysler, BMW, Nissan, Mercedes Benz, Mazda, and Volkswagen.²⁸ In 2011 when President Obama announced a 54.5 mpg standard with the new CAFE standards' changes, Ford, GM, Chrysler, BMW, Honda, Hyundai, Jaguar, Land Rover, Kia, Mazda, Mitsubishi, Nissan and Volvo backed him.²⁹ These car manufacturers are happier with the flexibility the new formula gives to larger vehicles while the companies try to reach higher fuel economy. A flexible but singular policy that covers all vehicles leads to less regulatory uncertainty and easier compliance for the car manufacturers, contrasting with the previous compliance measures with multiple agencies and standards.

Despite supporting the 2009 efforts, Volkswagen dislikes the new standard due to the perception that it disadvantages diesel fuel by not incentivizing its use.³⁰ Volkswagen offers several models that consume diesel fuel, with some achieving up to 43 mpg. Other similarly fuel efficient types of engines and fuels get special considerations and incentives under CAFE standards. Since the "footprint"-based formula imposes lighter standards on larger vehicles, it does not benefit manufacturers that already focused on smaller vehicles.

Effects of CAFE Standards

CAFE standards change the incentives that automobile manufacturers face when supplying cars. Some car companies simply pay the fine and do not alter their behavior. In order to avoid fines, car companies must produce lighter, more fuel-efficient cars regardless of actual consumer demand. Companies change the type of cars offered and adopt advanced technology including engine downsizing and supercharging, direct-injection gasoline or diesel engines, automatic shift/manual transmission, integrated starter/generators, camless valve actuation, and vehicle weight reduction.³¹ One main concern is that this expensive technology raises the price of vehicles and can cause economic deadweight loss. In 2010 NHTSA estimated an increase in fuel economy to 33.3 mpg in 2012 and to 37.8 mpg in 2016 will cost manufacturers about \$695 per car.³² The NHTSA regulatory impact analysis for the CAFE standards affecting the 2017-2025 year production vehicles is estimated to cost consumers an extra \$1,885 per car in 2025 car models with \$151.40 of technology costs.³³ The difference between total cost and technology costs is because NHTSA assumes that the cost of fines will be passed directly on to the consumer. NHTSA's analysis included over 35 different technologies, which can help raise mpg including

²⁸ "Remarks by the President on National Fuel Efficiency Standards." The White House. May 19, 2009. <<http://www.whitehouse.gov/the-press-office/remarks-president-national-fuel-efficiency-standards>>.

²⁹ "President Obama Announces Historic 54.5 Mpg Fuel Efficiency Standard." The White House, 29 July 2011. Web. <<http://www.whitehouse.gov/the-press-office/2011/07/29/president-obama-announces-historic-545-mpg-fuel-efficiency-standard>>.

³⁰ Mihalascu, Dan. "VW Attacks Proposed CAFE Standards, Goes to White House." In Auto News, 17 Nov. 2011. Web. <<http://www.inautonews.com/vw-attacks-proposed-cafe-standards-goes-to-white-house#.Uv5LeoVvCSp>>.

³¹ National Research Council. "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards." National Academy of Sciences, 2002. (Subsequently referred to as "NRC CAFE Report 2002.")

It is notable that due to safety requirements a weight increase is associated with a 3-4% decrease in fuel consumption improvement. See appendix 2 for detailed tables and information.

³² National Highway Traffic Safety Administration. Office of Regulatory Analysis and Evaluation. National Center for Statistics and Analysis. *Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012–MY 2016 Passenger Cars and Light Trucks*, March 2010. (Subsequently referred to as "NHTSA CAFE RIA 2012.")

³³ National Highway Traffic Safety Administration. Office of Regulatory Analysis and Evaluation. National Center for Statistics and Analysis. *Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2017–MY 2025 Passenger Cars and Light Trucks*, August 2012. (Subsequently referred to as "NHTSA CAFE RIA 2017.") See page 54 table 15, Cumulative impacts of all fuel economy standards from MY 2011–2025.

turbocharging, diesel engines, high-efficiency gearboxes, aerodynamic drag reduction and various electrification or hybridization technologies.³⁴

The NHTSA analysis concludes that the consumer fuel savings benefits alone outweigh the costs, with environmental benefits as purely extra. NHTSA includes theories as to why the outcome is in the analysis but not observed in real life,³⁵ and why the regulation is needed to achieve these observations. It first points to classic market failure issues, specifically an uncompetitive market and incomplete or imperfect information. It also states that consumer time preferences for the long-term are incorrect when calculating fuel efficiency, leading to them not valuing and capturing the benefits. Other combinations of consumer preferences are affected by the changes manufacturers have to implement to comply with the standards, which may reduce overall consumer welfare if it limits or alters choices available. NHTSA argues that consumer uncertainty with the amount of fuel cost savings may lead to an undervaluation of fuel savings. The agency also admits that the values it has used may be incorrect due to underlying assumptions. Manufacturers now must pursue research strategies in order to direct funding toward fuel efficiency advances instead of other vehicle attributes. This can lead to forgone attributes that lower the value of the vehicle more than the agency has considered. It similarly considers that it may have underestimated the costs of research and development of fuel-efficient technologies, and that the policy may be more expensive to implement.

The idea of an uncompetitive market seems highly unlikely given the large variety of cars available. Competition exists between new and old versions of the same model vehicle, manufacturers, level of luxury, and generally with every type of attribute in a vehicle. The NHTSA analysis does not attempt to analyze the amount of competition in the market. While this could explain a lack of fuel efficiency, there is little evidence that it would be a main cause. Incomplete information as a market failure seems unlikely to be a main cause as well since fuel economy labels include an estimated annual fuel cost and savings. If a consumer sees this and still chooses to purchase a less fuel-efficient car, then it simply is not crucial in their personal decision-making process.

The explanations NHTSA gives for the difference in the real versus theoretical world stem from the difficulty of creating accurate models, where incorrect assumptions can impact the results. A few assumptions in particular have altered the analysis substantially. NHTSA assumes a static supply side of the market where each car manufacturer will have the same amount of market share throughout the entire analysis, and higher-priced luxury cars are similarly static in their prices. All gasoline taxes are omitted from the cost-benefit analysis because they are viewed as a transfer payment since they are correcting an externality issue. The cost of gasoline throughout the analysis is \$0.40 a gallon lower than what consumers face at the pump.³⁶ This reduces the amount of consumer response to price in the model. The ultimate effect is that consumers look like they do not respond to and value fuel efficiency as strongly. NHTSA estimated economic cost of security dependence of \$.17 per gallon is added to the price of gasoline, but the estimated price of gasoline is still lower than in real life.³⁷

The model represents a theoretical average consumer with preferences based on aggregated real-market data. This explanation for the existence of the paradox reveals just how difficult it is to predict what a real consumer would want or the costs an individual manufacturer faces. The analysis attempts to utilize the most complete and realistic data available, but aggregating real data points into an accurate economy-wide model can never capture everything that goes into each individual's action. For example, NHTSA assumes that the anticipated static luxury car prices will lead to proportional substitution in consumer purchases of lower class and smaller cars from the same company.³⁸ This makes the calculation easier, but does not reflect the highly competitive market between manufacturers and brand loyalty.

³⁴Id 211-217.

³⁵ NHTSA CAFE RIA 2012, 421-428.

³⁶ In 2007 dollars.

³⁷ NHTSA CAFE RIA 2012, 380-383.

³⁸ NHTSA CAFE RIA 2012, 27.

Another major concern is that car manufacturers will compromise safety for fuel efficiency. Downsizing and lightening cars is a cheap way to improve fuel efficiency to meet CAFE standards. From 1975 to 1988, a significant part of increased fuel economy is directly attributable to downsizing due to the simultaneous decline in both car weight and length.³⁹ Historically, larger and heavier cars were safer in crashes than smaller, lighter vehicles. This is because heavier cars are more likely to move an object, causing slower deceleration and lower risk of injury during a crash. The larger the car, the more distance there is between a passenger and the hard structure of the vehicle. Robert Crandall and John Graham were some of the first academics to point out this shift to lighter cars to meet CAFE standards.⁴⁰ NHTSA acknowledges that “safety-tradeoffs associated with fuel economy increases have occurred in the past”⁴¹ for this very reason. However, the existence of a statistical correlation between car weight and accident severity does not necessarily imply lighter cars result in an increased likelihood of an accident becoming deadly. Proponents of CAFE standards make this case and point to recent engineering designs leading to better safety, deemphasizing the importance of the vehicle’s weight,⁴² including testimony before the US Congress.⁴³ In 2005 the Insurance Institute for Highway Safety found that heavier cars such as SUV’s are actually more dangerous to passengers in crashes.⁴⁴ The Institute also found that the crash scores of small cars depend on the engineering design itself, independent of its size.⁴⁵ However, other evidence concludes that CAFE standards did have a negative impact on the amount of road fatalities. The National Research Council Transportation Research Board study concludes that the CAFE standards “probably resulted in an additional 1,300 to 2,600 traffic fatalities,”⁴⁶ 13,000 to 26,000 incapacitating injuries, and 97,000 to 195,000 total injuries in 1993.⁴⁷ The 1989 study by Robert Crandall and John Graham found that it led to an even higher death rate of 2,200-3,900 per year.⁴⁸ In 2007 the Insurance Institute for Highway Safety found a correlation of 250-500 deaths per year per mpg reduced.⁴⁹ The issue has eluded a definitive conclusion, but it remains a fact that mass and weight reduction is a low-cost technique to improve fuel efficiency. Car manufacturers have indicated that they plan on pursuing weight and mass reduction as a way to achieve compliance,⁵⁰ so at the very least the possibility that this could cause more injuries and deadly accidents cannot be ignored.

The policy also alters consumer incentives. Improved fuel economy makes it cheaper to drive, encouraging additional driving. This “rebound effect” mitigates the benefits to the environment and energy independence, undermining the policy’s purpose. This behavioral adjustment is included in most analyses, with an average increase of 10-30% in vehicle miles traveled.⁵¹ The National Research Council

³⁹ NRC CAFE Report 2002, 24.

⁴⁰ Crandall, Robert W. and John D. Graham, “The Effect of Fuel Economy Standards on Automobile Safety,” *Journal of Law and Economics* 32, no. 1 (1989): 97 – 118, <<http://www.jstor.org/stable/725381>>.

⁴¹ NHTSA CAFE RIA 2012, 435.

⁴² Wenzel, Tom and Marc Ross. “Increasing the Fuel Economy and Safety of New Light-Duty Vehicles.” Lawrence Berkeley National Laboratory, 18, September 2006.

⁴³ Chelimsky, Eleanor. “Automobile Weight and Safety,” Testimony, April 11, 1991, before the US Senate Committee on Commerce, Science, and Transportation. Available on the US Government Accountability Office website.

⁴⁴ “In Collisions with Cars, SUVs are Incompatible.” *Safety Status Report* 42 (4): 1–8. Insurance Institute of Highway, April 28, 2005.

⁴⁵ “Minicars First Test Results.” *Status Report* 41 (10): 1–8. Insurance Institute of Highway Safety, December 19, 2006.

⁴⁶ NRC CAFE Report 2002, 3.

⁴⁷ NRC CAFE Report 2002, 27.

⁴⁸ Crandall and Graham. “The Effect of Fuel Economy Standards on Automobile Safety,” 115.

⁴⁹ “Driver Deaths by Make and Model.” *Status Report* 42 (4): 1–8. Insurance Institute of Highway Safety, April 19, 2007.

⁵⁰ NHTSA CAFE RIA 2012, 435.

⁵¹ Greening, Lorna A., David L. Greene, and Carmen Difiglio. “Energy efficiency and consumption—the rebound effect—a survey.” *Energy Policy* 28.6: 389-401. 2000.

found a 1-2% increase in vehicle travel for every 10% increase in fuel economy, leading to approximately a 7% total reduction of all US greenhouse gas (GHG) emissions.⁵² Some economists estimate higher overall emissions because it is cheaper to drive.⁵³ The policy's effect on a consumer's choice of cars can also cause higher emissions. The Congressional Budget Office (CBO) found that higher CAFE standards impose an extra \$153 per car to consumers and \$2.4 billion total.⁵⁴ The overall extra costs to the cars vary per model, and could be high enough for a person to choose not to purchase a new car. Discouraging new clean fuel efficient car purchases means that older dirtier cars will be in use longer.

Even more importantly, CAFE standards seem to be cost-ineffective. Studies conducted soon after the standards were enacted found them to be effective—at a high cost. The CBO found that due to the 14-year period necessary to reach maximum gasoline reduction with CAFE standards, a gasoline tax would be more cost-effective in reducing emissions.⁵⁵ The National Research Council study finds that CAFE standards “clearly contributed to increased fuel economy of the nation’s light-duty vehicle fleet during the past 22 years,” adding that it has had the effect of keeping fuel economy higher than it would have been when gasoline prices started to decline—at monetary and human life costs.⁵⁶ It also diverted investments and resources to improving fuel economy,⁵⁷ an effect that NHTSA acknowledges. While the National Research Council’s report finds that CAFE standards have been effective for the time period, they find that other policies can accomplish the same reduction in fuel consumption at a lower cost. Alternative policies include taxing vehicles achieving less and rebating vehicles achieving higher than the average fuel economy, higher fuel taxes, tradable credits for fuel economy improvements, and standards based on vehicle attributes like weight or size.⁵⁸ These last two suggestions have been incorporated into the recently proposed CAFE standards, and the gas-guzzler tax is similar to a penalty for low fuel economy. The report is optimistic overall about government involvement in this issue if these and other changes are implemented.

One main hurdle the National Research Council states will exist no matter what changes the government may make is that many advanced technologies that could really impact fuel economy have issues and are prohibitively expensive for widespread use. Another issue is that the mass adoption of a new fuel technology is slow due to the lack of a well-developed infrastructure of alternative refueling stations. While the National Resource Council report is from 2002, the infrastructure barrier is still very real for cars powered by electricity, hydrogen, and natural gas. Besides home charging options, only 7720 electric charging stations exist in the United States⁵⁹ for the 66,409 electric and hybrid vehicles on the road.⁶⁰ There are 672 compressed natural gas stations and 51 liquefied natural gas stations⁶¹ for

⁵² NRC CAFE Report 2002, 19-20.

⁵³ Espey, Molly. “Pollution Control and Energy Conservation: Complements or Antagonists? A Study of Gasoline Taxes and Automobile Fuel Economy Standards,” *Journal of Energy* 18, no. 2: 23–28. 1997. <<http://ideas.repec.org/a/aen/journal/1997v18-02-a02.html>>.

⁵⁴ Austin, David and Terry Dinan. “Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes,” *Journal of Environmental Economics and Management*, Elsevier, vol. 50(3), pages 562-582, November 2005.

See appendix 3 for full chart of costs from the paper.

⁵⁵ Id 44.

⁵⁶ NRC CAFE Report 2002, 3.

⁵⁷ NRC CAFE Report 2002, 20.

⁵⁸ NRC CAFE Report 2002, 5.

⁵⁹ As of March 17, 2014. See: http://www.afdc.energy.gov/fuels/electricity_locations.html.

The number of existing electricity charging stations do not make up an adequate charging infrastructure, but is worse when the type of charging equipment is taken into account. One type of charging level only gives the user 2-5 miles of range per hour of charging, with the next level only providing 10-20 miles of range per hour of charging. For more information see http://www.afdc.energy.gov/fuels/electricity_infrastructure.html.

⁶⁰ “How Many Alternative Fuel and Hybrid Vehicles Are There in the US?” US Energy Information Administration, 2011. Data is for light duty alternative fuel vehicles in use for the year 2011.

approximately 112,000 natural gas vehicles; 2407 ethanol stations⁶² for 819,133 flex-fuel vehicles,⁶³ and 10 hydrogen refueling stations⁶⁴ for the 425 light-duty hydrogen vehicles in use. No hydrogen fuel cell vehicles are commercially available from automotive manufacturers yet, but they are in development.⁶⁵ To put these numbers in context, there were approximately 168,000 gasoline stations in 2004⁶⁶ for 248 million gasoline-powered vehicles.⁶⁷ In his 2014 State of the Union speech, President Obama stated that he would support congressional action to encourage natural gas vehicles with a more extensive fueling station network.⁶⁸ No specifics were given as to how this would be achieved, but this was an interesting choice of fuel to support given that only four light-duty natural gas powered vehicles exist for purchase.

Overall the CBO study estimated that long-term gasoline consumption has decreased only by 10%, assuming a 3.8 mpg increase in CAFE standards. The maximum gasoline savings are only realized in 14 years, after all existing vehicles are replaced.⁶⁹

CAFE standards were enacted in order to improve domestic security and environmental quality. Despite the best efforts of policymakers, policy implementation has been costly and ineffective at reaching their original goals. The amount of knowledge required to account for all consumer behavior and responses to incentives in this global market are impossible for experts to know. F.A. Hayek shows that is because knowledge is diffused throughout the entire market, with each individual having knowledge about local conditions in a way that no single person could ever have.⁷⁰ As a result, CAFE standards can be used as a blunt instrument to try to induce a general consumer trend, but the exact impact cannot be identified ex ante and is difficult to disentangle from other influencing factors ex post.

Even if adequate expertise could be housed within agencies, they do not operate in a vacuum. Outside pressure from politicians and private actors affect the policymaking process. Car companies support the efforts of the CAFE standards when it benefits their business models to do so, but when it does not they publically go against it like Volkswagen has. Businesses support government intervention in the market because minimum product standards set actions that must be met and make it harder for competitors to enter the market. Businesses are rewarded for behavior they were already doing with incentives like earning credits for having a higher fuel economy than required. These incentives reward those who have already completed these actions and induces other businesses to move in that direction at research and development costs.

Renewable Fuel Standard

⁶¹ As of March 17, 2014. See http://www.afdc.energy.gov/fuels/natural_gas_locations.html.

⁶² As of March 17, 2014. See http://www.afdc.energy.gov/fuels/ethanol_locations.html.

⁶³ Id footnote 2 data is for light duty vehicles in use in 2011.

⁶⁴ As of March 17, 2014. See http://www.afdc.energy.gov/fuels/hydrogen_locations.html.

⁶⁵ As of March 17, 2014. See http://www.afdc.energy.gov/vehicles/fuel_cell_availability.html.

⁶⁶ “How Many Gas Stations Are There in the US?” US Department of Energy (DOE), Web. 03 Aug. 2014. <<http://www.fueleconomy.gov/feg/quizzes/answerQuiz16.shtml>>.

⁶⁷ “How Many Alternative Fuel and Hybrid Vehicles Are There in the US?” US Energy Information Administration, 2011.

The number is calculated by subtracting the number of alternative fuel vehicles from the number of registered vehicles. This does mean that diesel powered fuels are included, but that diesel fueling stations are normally paired with the gasoline ones so the difference should be negligible.

⁶⁸ “President Barack Obama State of the Union 2014 Speech (full Text, Video).” *Politico*. January 28, 2014. <<http://www.politico.com/story/2014/01/state-of-the-union-2014-speech-transcript-text-video-102763.html>>.

⁶⁹ Austin, David and Terry Dinan. “Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes”, 1.

This paper assumes that the firms would not voluntarily use the new technologies to boost fuel economy, and that this is consistent with observed behavior.

⁷⁰ Hayek, Friedrich August. “The use of knowledge in society.” *The American Economic Review* (1945): 519-530.

RFS, established by the Energy Policy Act of 2005 (EPAct), mandates that renewable fuel sources be blended into gasoline sold at the pump. The goal behind the policy is two-fold: to encourage domestic sources of energy to be consumed over foreign sources, and to burn cleaner fuels. The EPAct mandates 4 billion gallons of biofuel to be mixed with gasoline by 2006, 6.1 billion gallons by 2009, and 7.5 billion gallons by 2012.⁷¹ The Congressional Research Service estimates that 2012 US biofuel consumption is only 5.75% of total transportation fuel consumption.⁷²

The EPA implements the program and new rules to alter RFS. The EPA published the final rule establishing the first version of the renewable fuel program (RFS1) in April 2007. To determine which fuels and biomass qualify as a renewable fuel, the EPA took into account GHG emissions, type of feedstock converted into fuel, and changes in land use in other countries due to more US land being used to produce fuel instead of food. One of the most controversial aspects of RFS1 was the indirect land use changes that altered the categorization of some renewable fuels. Academics and industries alike questioned the accuracy of the EPA’s calculations and methodology.⁷³

The EISA altered RFS by 1) expanding the total gallons targeted to be blended to 36 billion gallons by 2022, 2) expanding the program to now apply to diesel fuel, 3) applying lifecycle greenhouse gas performance threshold standards to ensure the renewable fuel emits fewer greenhouse gasses than the petroleum fuel it replaces, and 4) establishing new categories of renewable fuel and setting separate volume requirements for each one.⁷⁴

RFS2, the revised version of RFS1, is a result of the EISA legislation. It provides support for the biofuels market by requiring blended fuel regardless of market prices. Biofuels are separated by the following categories: advance biofuels, cellulosic and agricultural waste-based biofuel, biomass-based biodiesel, and total renewable fuels.⁷⁵ RFS2 includes the expanded gallons blended target and GHG lifecycle thresholds from the EISA. The GHG lifecycle thresholds are based on a 2005 baseline average of gasoline or diesel GHG emissions. Pre-2007 facilities or facilities under construction before 2010 are grandfathered into the program and do not need to comply. The requirements are as follows:

Table 1: EISA-Mandated Reductions in Lifecycle GHG Emissions by Biofuel Category
(Percent reduction from 2005 baseline for gasoline or diesel fuel)

Biofuels category	Threshold reduction
Renewable fuel*	20%
Advanced biofuels	50%
Biomass-based diesel	50%
Cellulosic biofuel	60%

Source: “Regulatory Announcement: EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010,” EPA-420-F-10-007, Office of Transportation and Air Quality, EPA, February 3, 2010.

⁷¹ (Title XV-Ethanol and Motor Fuels) (Subtitle A) (Sec 1501. Renewable Content of Gasoline) (o) (2) (B) (i) “Energy Policy Act of 2005” (PL 109, Aug. 8, 2005). 119 Stat 1069 (2005). Print.

⁷² Schnepf, Randy, and Brent D. Yacobucci. “Renewable Fuel Standard (RFS): Overview and Issues.” 2010.

⁷³ Yacobucci, Brent D., and Kelsi S. Braemort. “Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard.” Congressional Research Service, June 25, 2009. <<https://openncrs.com/document/R40460/>>.

⁷⁴ “Renewable Fuel Standard (RFS).” Environmental Protection Agency, December 10, 2013. <<http://www.epa.gov/OTAQ/fuels/renewablefuels/>>.

⁷⁵ See appendix 3 for a chart of all the requirements broken down further by fuel type.

*The 20% criterion applies to renewable fuel from facilities that commenced construction after December 19, 2007, the date EISA was signed into law.

Source: Schnepf, Randy, and Brent D. Yacobucci. "Renewable Fuel Standard (RFS): Overview and Issues." (2010). Table 2.

The other major change to the program was the revised definitions of renewable biomass feedstock that becomes biofuel. The definitions were changed to address the difficulty of calculating indirect land use changes. The exact amount of mandated blended renewable fuel is determined by looking at the projected total US transportation fuel use from the US Energy Information Administration and applying the percent ratio of each category of renewable fuel.

In the regulatory impact analysis of the RFS2 program, the EPA found reduced dependence on foreign sources of crude oil, reduced price of domestic transportation fuels, reduced GHG emissions, increased US farm income, decreased corn and soybean exports, increased cost of food in the United States, decreased emissions of carbon monoxide and benzene, and increased emissions of hydrocarbons, nitrogen oxides, acetaldehyde, and ethanol.⁷⁶ A survey conducted by Ronald Steenblik estimated that the effect of all federal policies, including RFS, amounted to almost a \$1 per gallon subsidy for biofuel produced in the United States.⁷⁷

Effects of Renewable Fuel Standard

RFS has large implications for the supply side of the market. One of the main goals is increasing production of domestic biomass-based fuels. While some crops currently produced will be redirected to fuel use, farmed acreage will increase since it is now more profitable to grow crops to turn into fuel. Expansion of farm production has a number of environmental consequences to consider. Land brought into production may be wildlife habitat, wetlands, and low-productivity land. Low-productivity land yields less agricultural product per acre due to soil conditions being less conducive to the crop being planted. This could be for many reasons, but it is normally due to a lack of ideal amounts of nutrients for a given crop. Monoculture farming techniques are a common cause of low-nutrient soil because only one crop is planted without adequate crop rotation and rest periods to allow for soil nutrient replenishment. The increase in farming, particularly on low-productivity land, will lead to an increase in fertilizer and other chemical use to boost yield productivity. This can result in worse water quality issues due to agricultural runoff. Water resource use also increases with more water redirected to farming and processing plants, putting more pressure on a diminishing water supply.⁷⁸

Renewable fuels are mandated in different volume amounts, with certain fuels getting preferential treatment through higher required volumes. This affects a farmer's choice in what crops to plant since the mandate provides guaranteed demand, and may lead to substitution of a traditional crop for the higher profit biomass feedstock crop. Some biofuels, including cellulosic and biodiesel from algae, are expensive to produce and blend, but due to regulatory requirements, their inclusion leads to higher gasoline prices. Incentives exist to import renewable fuels from countries that can fill production gaps between domestic

⁷⁶ US Environmental Protection Agency. Office of Transportation and Air Quality Assessment and Standards Division. "Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis." EPA-420-R-10-006, February 2010.

⁷⁷ Koplou, Doug. "Biofuels—At What Cost? Government Support for Ethanol and Biodiesel in the United States," Global Subsidies Initiative of the International Institute for Sustainable Development, Geneva, Switzerland, September 2007. 37.

⁷⁸ These concerns have been echoed in many publications including the Congressional Research Service's RFS Overview, National Academy of Sciences review of the RFS, and various academic and policy papers.

producers and the mandated blend requirements,⁷⁹ defeating the purpose of a policy goal of energy independence.

Renewable fuels still emit GHG throughout the entire production process, so the lifecycle GHG emissions are a concern to ensure that they are truly less polluting than petroleum. The resulting findings by the EPA for RFS2 GHG lifecycle emissions are as follows:

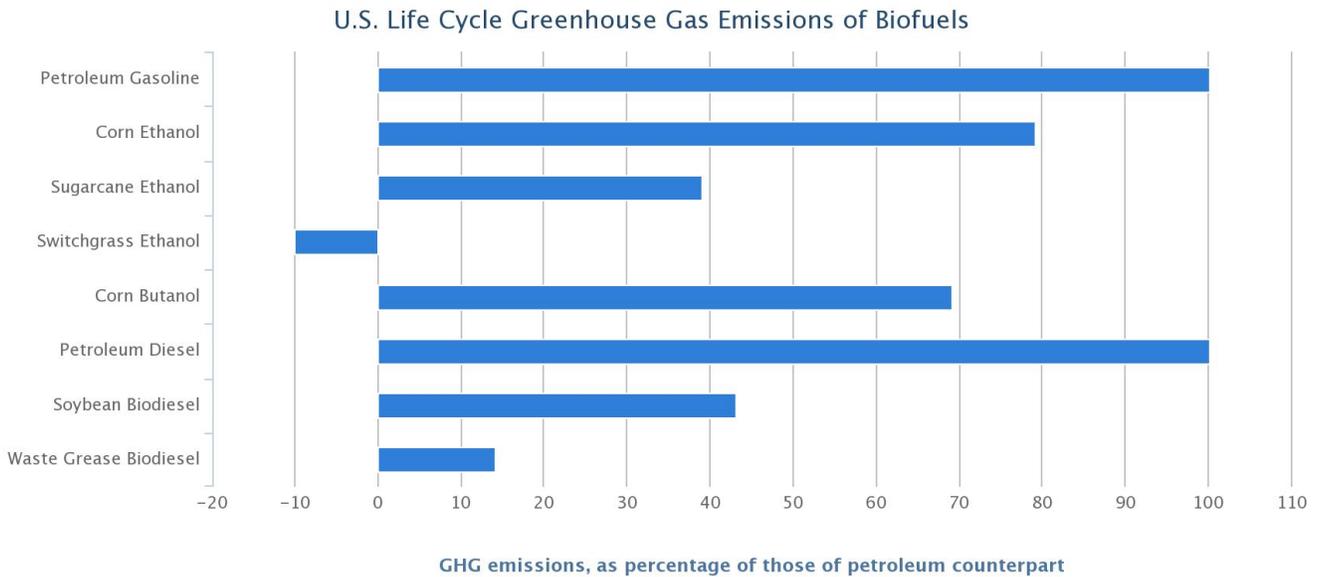


Figure 2: US Life Cycle Greenhouse Gas Emissions of Biofuels
 Source: RFS2 Regulatory Impact Analysis, <http://www.afdc.energy.gov/data/10328>

Corn-based ethanol has been the policy-favored feedstock. In 2012, about 40% of total US corn crop was used for ethanol, while accounting for only 7% of gasoline consumption based on energy equivalency.⁸⁰ One major issue with corn is that it incentivizes food be turned into fuel.⁸¹ As stated previously, the EPA determined that biofuel policies will raise the price of food. This became a major criticism of the program in 2012 due to a major drought during the summer. 60% of farms experienced drought, with a total of 43% experiencing extreme drought in August.⁸² This led to increased crop, feed, fuel, and food prices, and calls to alter the RFS requirements to avoid further negative economic effects.

There are issues with the content of the renewable fuel itself, in particular ethanol blended into gasoline. A blend of 10% ethanol and 90% oil, or E10, is currently used at gasoline pumps across the United States. Ethanol is corrosive,⁸³ and can potentially cause issues with existing pipe and storage fuel infrastructure. The EPA does not approve of its use in motorcycles, off-road vehicles, and off-road

⁷⁹ Yacobucci, Brent D., and Kelsi S. Bracmort. "Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard."4.

⁸⁰ Id 26.

⁸¹ This is applicable to other feedstock used for either human or livestock purposes as well. Soybeans are another major concern for the food system since this is a common feedstock for livestock farmers and ingredient in food.

⁸² "US Drought 2012: Farm and Food Impacts." USDA Economic Research Service, July 26, 2013. <<http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx>>.

⁸³ Allen, Mike. "Can E15 Gasoline Really Damage Your Engine?" Popular Mechanics. December 21, 2010. <<http://www.popularmechanics.com/cars/alternative-fuel/biofuels/e15-gasoline-damage-engine>>.

equipment.⁸⁴ It can also harm cars produced before 1998, including valuable collector classic cars.⁸⁵ There is a current policy push to increase the blend to 15% ethanol, or E15, although it is not mandated. The EPA has approved its use only for model year 2001 and up,⁸⁶ which was approximately 62% of passenger vehicles at the end of 2010.⁸⁷ This higher level blend is still not approved for use in any vehicle or equipment for which E10 is not deemed safe. While the EPA has cleared the use of E15, car manufacturers are suing the EPA and do not honor warranties for cars using E15, saying it causes damage for which they are not responsible.⁸⁸ In order to ensure that a warranty is honored, E15 can only be used in a flex-fuel vehicle.

One of the more serious effects of RFS is the negative health impacts, including an increase in premature deaths. This is due to the increased release of toxins from the fuels that the policy provides. The major toxins are particulate matter and ozone. Particulate matter has health effects of mortality, low birth weight, and asthma. Ozone's health effects include mortality, chronic respiratory damage, and premature aging of the lungs. In the RFS2 regulatory impact analysis, the EPA estimates that each year it is in effect, the policy will cause 110-270 premature deaths due to particulate matter and 54-250 additional premature deaths due to increased ozone.⁸⁹ In the regulatory impact analysis, the EPA valued these deaths at only \$11,320,000 of maximum yearly monetary loss. However, if you multiply the lowest estimated number of deaths by the value of a statistical life that the EPA is supposed to use (\$8.76 million in 2014 dollars)⁹⁰, the total monetized cost of lost lives is \$1,436,640,000 per year. The amount of ozone and particulate matter depends on what controversial type of renewable fuel is used the most—some being more polluting than others. Monetizing the cost of a life lost prematurely is very difficult and widely debated, and it leads to different estimated costs of a policy. But there is nonetheless the consequence that the mandated renewable fuels release pollutants that have health effects including death.

Brazil, a pioneer and leader in adopting ethanol fuel, has seen an increase in clean air quality after reducing the use of high blends of ethanol in gasoline. During 2009-2011 the price of ethanol varied widely with the price of sugarcane. Consumers who drive flex-fuel vehicles responded by decreasing the purchases of pure ethanol and high blends such as E85 when prices increased. In Sao Paulo, switching to using lower ethanol content gasoline led to a decrease in ozone. The authors of that study caution that there was an increase in nitrous oxide and carbon oxides during the same time period.⁹¹ This is the first study to use real data points of air quality and ethanol vs gasoline use, mostly because the necessary fluctuations between the two fuels were never observed in a natural dataset before Sao Paulo.

Looking at effects as simple as ozone emissions would ideally happen in a controlled situation before encouraging the use of certain fuels over others. A holistic analysis and evaluation of a fuel policy,

⁸⁴ The EPA has updated their website to reflect the approvals for E15 and no longer lists E10 separately; however, anything not approved for E15 use is also not approved for E10 use. "E15: Frequently Asked Questions." Environmental Protection Agency, March 29, 2013. <<http://www.epa.gov/otaq/regs/fuels/additive/e15/e15-faq.htm>>.

⁸⁵ "E10 Ethanol: Recommended Engine Precautions." Fuel Tester. <http://www.fuel-testers.com/ethanol_engine_precautions.html>.

⁸⁶ "E15 Approved for Use in 2001 and Newer Vehicles." Alternative Fuels Data Center. US DOE, February 11, 2011. <http://www.afdc.energy.gov/technology_bulletin_1210.html>.

⁸⁷ "E15 Decision Opens Blend to 2 Out of 3 Vehicles; More Work Yet to be Done," Renewable Fuels Association news release, January 21, 2011.

⁸⁸ "Warranties Void on Cars Burning E15, Say Automakers." Consumer Reports, July 7, 2011. Web. <<http://www.consumerreports.org/cro/news/2011/07/warranties-void-on-cars-burning-e15-say-automakers/index.htm>>.

⁸⁹ "Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis," 928-933.

⁹⁰ Adjusted for 2014 dollars, see:

<http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html#whatisvsl>

⁹¹ Salvo, Alberto, and Franz M. Geiger. "Reduction in local ozone levels in urban Sao Paulo due to a shift from ethanol to gasoline use." *Nature Geoscience*, 2014.

especially one aimed at improving the environment, should be conducted to ensure it truly is environmentally friendly. This way any health risks associated with the policy can be effectively included in a cost-benefit analysis. The first version of RFS lacked this holistic analysis, and while corrected in RFS2, subjective assumptions on how to categorize fuels have only introduced new issues. Policymakers should be transparent in order to get feedback on all the effects of policies, not just the ones policymakers choose to emphasize.

RFS is faced with the same issues stemming from the knowledge problem and bureaucratic dynamics. In this instance bureaucrats overlooked the issue of ozone emissions throughout the policymaking process. While the process took a lot of time and thought, no amount of time would allow policymakers to identify every important consequence and impact of a policy.

Interaction between Government Policies

The federal government is simultaneously mandating higher fuel efficiency while lowering fuel efficiency with another policy. CAFE standards mandate higher fuel efficiency, yet RFS and alternative fuels yield lower fuel efficiency due to a lower energy content than oil-based fuel. A gallon of ethanol has only 68% of the energy of a gallon of gasoline.⁹² Because of RFS, consumers need to refill their gas tanks more often. This lowers a car manufacturer's fuel efficiency rating despite taking measures to integrate technology that increases fuel efficiency. Manufacturers face pressures to make further advances in order to avoid fines. US citizens are affected by increased costs from three sources: 1) the increase in gasoline consumption due to lower energy content, 2) costs passed on from advanced technology or fines car manufacturers have to include, and 3) taxes for any subsidies or support to biofuels including the administrative costs and wages paid for the implementation of policy.

Counteractive policies are not surprising given the bureaucratic incentives. An agency implements a policy, then moves on to other issues they have received via legislation. Not all federal policies are required to have explicit measurable goals or to conduct ex post studies of effectiveness. Explicitly stating measurable goals of a policy is not required for every federal policy, either. Each agency has its own mission and legal authority, although multiple agencies often have similar tasks. For example, both the Department of Agriculture and the Food and Drug Administration have authority over different areas of the chicken industry. With multiple agencies working on policies that influence each other, collaboration should be more inclusive, but this is difficult to achieve since agencies do not want to overstep their boundaries with other agencies. This lack of collaboration leads to large policies that end up being counterproductive, but agencies have no incentive to address this as they have proceeded correctly according to legislative authority.

Government Policies Effect on the Market

The lack of collaborative federal policies with explicit measurable goals sends mixed signals to market participants. CAFE standards instruct car manufacturers on a level of fuel efficiency, while RFS guarantees money to renewable fuels, which lower fuel efficiency. This alters the profit calculation a car manufacturer faces.

With current CAFE standards policy, car manufacturers face a guaranteed loss of profit, via the fine, if they do not comply with CAFE standards. This leads them to think about the regulatory agency first instead of the consumer, which happened in the early 1970s when cars were lightened to increase fuel efficiency at the expense of passenger safety. While current fuel efficiency technology utilizes a larger variety of fuel saving techniques, car manufacturers still invest in fuel efficient technology regardless of consumer demand and preferences. Consumers could demand higher personal technology

⁹² Yacobucci, Brent D., and Kelsi S. Bracmort. "Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard." 69.

integration advancement, like Bluetooth compatibility, for which they are willing to pay. But car manufacturers cannot spend the corresponding time developing or acquiring this technology even if this would lead to higher profit.

Mandated fuel efficiency is a rigid target that increases every year, no matter what the price of oil is. RFS is similar in this sense where the mandated blend requirements do not change based on the price of the competing fuel. More importantly RFS rarely grants the waiver of the blend requirements even when severe weather conditions affect the quantity of crops available for both food and fuel. As a result, the economics of the oil and energy market are ignored when companies are faced with regulation compliance. The absolute nature of these regulations also incentivizes car manufacturers to redirect entrepreneurship activities in order to avoid the policies' penalties. Redirected entrepreneurship comes in the form of lobbying for exemptions for certain types of vehicles, like diesel, or trying to report data in a way that makes them look like the emissions are lower. From a societal standpoint, this is wasted money and time that could be spent on production.

CAFE standards are designed to be flexible and give car manufacturers freedom in how to meet them. While it does not mandate specific technology, the mpg requirements are high and increase each year. No single existing technology can make a car meet the CAFE standards mpg requirement. The upfront costs associated with developing new technology are very high. Any technology that needs to be incorporated to offset the corrosive effects of biofuels also directs research funds away from meeting consumer demand. Adopting technology on a large scale is one of the quickest ways to recover development costs. In the case of RFS this is necessary to adopt industry-wide since most gas at a gas station has ethanol blended into it. Hybrid engines are one example of a widely adopted technology to help reach fuel economy requirements since the technology designs can be leased from car manufacturers.

Companies can develop technology from internal corporate research and development, but this is difficult because the technology must be incorporated into production cars in order to recover costs. However, racing allows an alternative way for car manufacturers to experiment and develop technology. The technology proven and developed in racing is primarily used to win races, but also can be used to meet both consumer and regulatory demand. Racing allows for experimentation in innovating technology that does not require immediate application in production vehicles to regain costs. Technology developed can fail or prove useless in racecars. This does not diminish the profit opportunities through advertising and other monetary benefits available to car manufacturers that participate in racing. Companies may elect to participate in racing for the purpose of developing technology to meet fuel efficiency standards, but federal regulation does not force them to innovate in racing.

Markets and the Racing Industry

The private incentives that car manufacturers face in improving fuel economy are: 1) to respond to customer preferences for more environmentally friendly cars, 2) to comply with current regulations or preempt and avoid more government regulation,⁹³ and 3) increase fuel efficiency as an unintended benefit from other changes. Technology can be developed through internal research, rights purchased from other companies, or adopted from other industries like racing.

Adopting technology from racing has led to developments that have improved vehicles over time that have become common equipment in cars such as start engine buttons, suspension designs, and tire

⁹³ "Auto execs regulatory uncertainty" with CAFE standards may lead to preemptive attempts of car manufacturers to try to avoid further and tougher regulation.

See Seetharaman, Deepa. "Auto Execs: US Mpg Standards within Reach, but May Change." *Reuters*. Thomson Reuters, January 15, 2014. <<http://www.reuters.com/article/2014/01/16/autoshow-fueleconomy-idUSL2N0KP27I20140116>>.

compounds.⁹⁴ The development of such technologies in a market situation gives them a lot of incentives. Racecar engineers get to experiment with designs or technologies to achieve faster, lighter, safer racecars. Bad innovations either stay in the workshop or are quickly surpassed by superior designs. This feedback mechanism is not subject to government regulatory interventions that allow bad innovations to stay in the sport forever. Engineers are free to focus on what the company or race team wants in the vehicle instead of developing technology for compliance.

This is important since consumer preferences are always evolving. The policymaking process is long and cannot respond quickly to changing market conditions. The preferences for items such as clothing and food have evolved over time, with entrepreneurs and businesses allowed to respond quickly to the changes. If the style of clothing or diet a person follows were directly regulated by the government, there would be a severe lag in products desired and time delivered, if allowed at all. The ability of a car manufacturer to utilize its racing endeavors to address the fuel efficiency demands of consumers as their preferences change is vital to ensuring the technology be efficiently developed and integrated.

Car Company Involvement in Racing

Car companies are involved with racing for various reasons, notably the advertising benefits. Whether the car manufacturer is a sponsor with the company name on the racecar, parts supplier, or team owner, it benefits from having name recognition with an audience that is passionate about cars. If race enthusiasts can point to racecars sponsored by the maker of the car they drive, like the Mercedes Formula 1 car or the Chevrolet NASCAR, this adds prestige to the brand name on which the car manufacturer can capitalize. This benefit can apply to non-race fans as well, since participating in racing puts high demands on vehicles for safety and speed, so the car company has to be able to engineer a car that can get me from A to B safely and reliably. This may or may not be true, but it seems so on the surface. For example, Infiniti has a vehicle which “features design, engineering, and aerodynamics upgrades inspired by the reigning Formula One World Champion and Infiniti Global Brand Ambassador,”⁹⁵ which lends impressive expertise credentials even if you are unfamiliar with the sport of Formula 1.

Some companies, like Ferrari, started out as racing companies and then produced street-legal cars, so racing is their heritage and built into the brand. Others made their name known by becoming involved with racing. In an attempt to resurrect his first failed car company, Henry Ford entered a highly publicized race at the Detroit Driving Club in 1901 with the purpose of attracting support and financial backers. Ford ended up winning, which successfully allowed him access to enough financial backing to form the Ford Motor Company.⁹⁶

Car companies also see racing as a way to conduct research and development for their mass production cars. It lets them test expensive and radically different technology to see if things work well enough to move to a mass manufacturing stage. A related example is the tire manufacturer Pirelli testing 18-inch tires on Formula 1 cars because it will lead to quicker technology improvements to their road tires.⁹⁷ Currently the data collected from the 13-inch Formula 1 tires must be adapted to reflect the changes in performance when an 18-inch tire is used. By testing and possibly adopting 18-inch tires, research and development of new tire compounds can be quickly used on the road tire counterparts. The

⁹⁴See <http://auto.howstuffworks.com/under-the-hood/trends-innovations/top-10-car-tech-from-racing.htm> for more detail.

⁹⁵“The Infiniti FX Sebastian Vettel Version.” *InfinitiUSA.com*. Web. August 4, 2014.

<<http://www.infinitiUSA.com/now/future-vehicles/infiniti-fx-sebastian-vettel-version.html>>.

⁹⁶ Brauer, Karl. “Ford’s Racing Pedigree Wins with Race Fans and New Car Buyers.” *Forbes*. Forbes Magazine, July 15, 2014. <<http://www.forbes.com/sites/kbrauer/2014/07/15/fords-racing-pedigree-wins-with-race-fans-and-new-car-buyers/>>.

⁹⁷ Joseph, Noah. “Pirelli Testing Low-profile Tires for 18-inch Formula One Wheels.” *Autoblog*, July 9, 2014. <<http://www.autoblog.com/2014/07/09/pirelli-testing-low-profile-tires-for-18-inch-formula-one-wheels/>>.

transfer of proprietary technology is facilitated between companies involved in racing and the car industry's intertwined corporate structure of co-ownerships and subsidiaries.⁹⁸ Most existing technology transfers are geared toward gasoline-powered cars.

Gasoline-Powered Cars

Two ways to improve fuel efficiency are to lighten the vehicle or improve the mechanical parts to be more efficient in turning gasoline into power. Both of these have been possible with technology developed in the racing industry. Adopting racing technology to lighten production vehicles has contributed significantly to increasing fuel efficiency. Materials which reduce the weight of the car increase mpg and require less power to achieve faster speed.

With racing, the lightest and strongest material is the most desirable. Engineers have to come up with featherweight materials that can withstand incredible heat, down force, and in worst-case scenarios, keep a driver alive in 150 mph crashes. Aluminum as a main material was adopted in Formula One for their monocoque chassis, the body frame of the car, in the 1970s.⁹⁹ Both racing machines and normal production cars use aluminum because it provides weight reduction benefits without sacrificing safety. Aluminum engine blocks help reduce weight in cars, although aluminum blocks are more susceptible to failure from overheating and dirty oil.¹⁰⁰ The 2015 Ford F-150 uses a 95% aluminum alloy and has lost 700 pounds of weight from the previous model, improving fuel efficiency and performance.¹⁰¹

Aluminum turned out to not be resistant enough for the down force produced by a Formula One car's wings, and was replaced with carbon fiber composites in 1981.¹⁰² John Barnard, an engineer at McLaren, had the first carbon fiber chassis produced, pioneering the use of the material to address the weaker aluminum chassis. McLaren lacked the expertise to create the chassis themselves and partnered with Hercules Aerospace to create the MP4 chassis.¹⁰³ This turned out to be a good decision for both speed and safety concerns since in 1981 McLaren's driver John Watson survived a crash of which he states, "had I had that accident in a conventional aluminum tub, I suspect I might have been injured because the strength of an aluminum tub is very much less than the carbon tub."¹⁰⁴ The ability of carbon fiber to absorb a large amount of energy, generated in such a crash, contributed to Watson's survival. Carbon fiber absorbs energy by the cracking and fracture of the fibers, matrix fracture, pulling out of fibers from the matrix, and delamination of the layers making up the structure.¹⁰⁵ Carbon composites used in Formula One have a lower density (1.51 versus 2.81) and much higher tensile strength (2500 MPa

⁹⁸ See appendix 7 for information on the relationships between car companies and a detailed chart on the different ownership and subsidiary relationships. (andy harris graph and text)

⁹⁹ De Groote, Steven. "Carbon Fibre." *F1technical.net*, September 21, 2002.

<<http://www.f1technical.net/features/3>>.

¹⁰⁰ Vartabedian, Ralph. "Iron or Aluminum Engines? Debate Continues." *Los Angeles Times*. Los Angeles Times, March 18, 1992. <http://articles.latimes.com/print/1992-03-18/news/vw-3712_1_aluminum-engines>.

¹⁰¹ Hill, Brandon. "2015 Ford F-150 Loses 700 Pounds, 95% of Body Structure Is Made of Aluminum Alloys." *DailyTech*, January 13, 2014.

<<http://www.dailytech.com/2015%2BFord%2BF150%2BLoses%2B700%2BPounds%2B95%2Bof%2BBody%2BStructure%2Bis%2BMade%2Bof%2BAluminum%2BAlloys/article34112.htm>>.

¹⁰² "Red Bull's How to Make an F1 Car Series Explains Carbon Fiber Use: Video."

<<http://www.motorauthority.com>>.

¹⁰³ "History & Heritage." *McLaren Automotive Media Centre*. N.p., August 4, 2014.

<<http://media.mclarenautomotive.com/page/9/>>.

¹⁰⁴ Mackenzie, Iain. "Carbon Fibre's Journey from Racetrack to Hatchback." *BBC News*. BBC, October 3, 2011.

<<http://www.bbc.co.uk/news/technology-12691062>>.

¹⁰⁵ Savage, G. "Composite Materials Technology in Formula 1 Motor Racing." (2008). 30.

versus 350 MPa) than aluminum.¹⁰⁶ Now, carbon fiber composites make up approximately 85% of the volume of a Formula One car while being less than 25% of its mass.¹⁰⁷

Carbon fiber bodies were introduced to production cars by the same company that first used it in Formula One, McLaren, for their supercar the McLaren F1.¹⁰⁸ The new BMW electric i3 is the first mass-produced car made of all carbon fiber composites.¹⁰⁹ The BMW utilizes this design to improve the sustainability of the car and lower the weight to improve the battery range. The price for a base model is \$41,350. Other than the BMW, in the United States only four cars currently produced have carbon fiber chassis: the Bugatti Veyron, Lamborghini Aventador, Lexus LFA, and McLaren MP4-12 C. The manufacturing cost of these cars totals \$2.9 million, with resale values much higher. Other supercars are made of similarly lightweight materials—Spyker cars have an aluminum chassis¹¹⁰ and Pagani's lineup is made up of titanium, aluminum, and Inconel.¹¹¹ The cheaper alternative to these million-dollar-plus supercars, at a little more than \$100,000, is the Nissan GTR, which incorporates aluminum and carbon fiber body parts to achieve its lightness.¹¹² Most similar class cars, including other Lamborghinis, Ferraris, and the Mercedes Benz SLS AMG Black,¹¹³ are made of a material combination that includes aluminum or carbon fiber.¹¹⁴

For these supercars, utilizing advanced materials is the only way to achieve the speed and performance they are after, with fuel efficiency not the reason to adopt the lightweight materials. However, the technology also can be used to produce more fuel-efficient vehicles. The BMW is only the first example of a vehicle to utilize carbon fiber to achieve improved fuel efficiency. Carbon fiber is expensive and complex to manufacture, partially explaining its slow adoption by more car manufacturers. Claudio Santoni, an engineer at McLaren, says that uncertainty with the supply chain may be an issue because “whenever a big aerospace project comes along, carbon manufacturers run for it and they leave the small, niche automotive programmes with no fibres.”¹¹⁵ However, the cost of carbon fiber has come down to about \$10 a pound due to the diversity of materials and manufacturing methods, especially the use of larger fibers.¹¹⁶ Thus, many mass car manufacturers are utilizing it for specific parts alongside steel and aluminum to take advantage of the weight reduction and safety benefits without raising costs.

Future Transfer: Electric Cars and Racing

¹⁰⁶ Id 7.

¹⁰⁷ Id 14.

¹⁰⁸ “History of Road Cars : McLaren Automotive Media Centre.” *McLaren Automotive Media Centre*. August 16, 2014. <<http://media.mclarenautomotive.com/page/11/>>.

¹⁰⁹ “BMW I3 Pioneers Use of Carbon Fiber in Mass-Produced Cars.” *Automotive News*. Automotive News, November 15, 2013. <<http://www.autonews.com/article/20131115/COPY01/311159959/#axzz2nVffLgho>>.

¹¹⁰ “Spyker C8 Aileron.” *Spyker C8 Aileron*. Autozine, 2010. August 16, 2014.

<http://www.autozine.org/Archive/Spyker/new/C8_mk2.html>.

¹¹¹ “Zonda F.” *Pagani Automobili*. August 16, 2014. <http://www.pagani.com/zonda/zonda_F/default.aspx>.

¹¹² “Compare 2015 Nissan GT-R® Models.” *Nissan USA*. August 16, 2014.

<<http://www.nissanusa.com/sportscars/gt-r/versions-specs>>.

¹¹³ “SLS AMG Coupé Black Series.” *SLS AMG Coupé Black Series*. August 16, 2014. <<http://www.mercedes-amg.com/webspecial/slsblackseries/eng.php>>.

¹¹⁴ “Huracán LP 610-4 Technical Specs.” *Automobili Lamborghini S.p.A*. August 16, 2014.

<<http://www.lamborghini.com/en/models/huracan-lp-610-4/technical-specifications/>>.

¹¹⁵ Mackenzie, Iain. “Carbon Fibre's Journey from Racetrack to Hatchback.” *BBC News*. BBC, October 3, 2011. <<http://www.bbc.co.uk/news/technology-12691062>>.

¹¹⁶ Tingwall, Eric. “McLaren MP4-12C, Lexus LFA, Lamborghini Aventador LP700-4 and Bugatti Veyron 16.4 Grand Sport.” *Automobile Magazine*. N.p., May 16, 2014.

<http://www.automobilemag.com/features/news/1207_mclaren_mp4_12c_lexus_lfa_lamborghini_aventador_lp700_4_and_bugatti_veyron_16_4_grand_sport/>.

Toyota is the historic leader of hybrid electric vehicles with the first mass-produced gasoline hybrid car, the Prius. The Prius was first offered in Japan in 1997 and 2001 in the United States. Toyota has sold three million Priuses,¹¹⁷ and more than 6 million total hybrid models worldwide.¹¹⁸ It has taken advantage of its early development and adoption of hybrid technologies by licensing it to other car manufacturers as illustrated below:

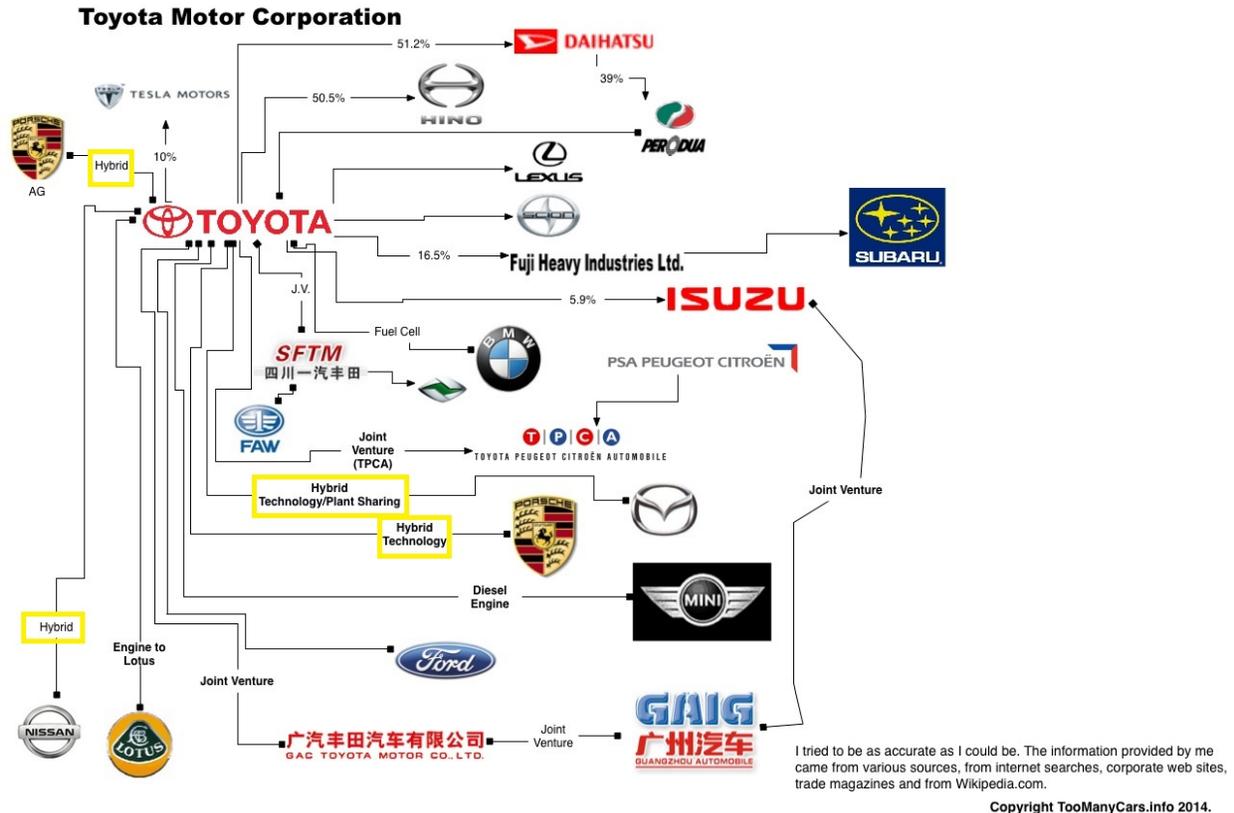


Figure 3: Toyota Corporation Family Tree
Source: Harris, Andy. Automotive Family Tree. <www.toomanycars.info >.

While electric and hybrid vehicles are the most common alternative fuel vehicles, some serious issues prevent widespread adoption. The cost of the first generation of hybrid and electric technology are less of an issue as the initial research and design costs are beginning to pay off. Initially, Toyota took a loss on the first generation of Priuses, available only in Japan for the first four years of production. The first generation Toyota Prius available in the United States cost \$26,780.54, in 2014 dollars, for a 70 horse power (hp) vehicle.¹¹⁹ A current Prius with 132 hp and similar fuel efficiency can be purchased for \$2,780 less, with significant technology upgrades and advancements.

While mpg rates have not increased over time, horsepower has increased in the newer models. This was one of the biggest critiques of early hybrids: that they lacked sufficient power to appease

¹¹⁷ "Worldwide Prius Sales Top 3-Million Mark." *Toyota USA Newsroom*. Toyota, July 3, 2013.

<<http://toyotanews.pressroom.toyota.com/releases/worldwide%2Bprius%2Bsales%2B3%2Bmillion.htm>>.

¹¹⁸ "Worldwide Sales of Toyota Hybrids Top 6 Million Units." *Toyota USA Newsroom*. Toyota, 14 Jan. 2014. Web. <<http://corporatenews.pressroom.toyota.com/releases/worldwide%2Btoyota%2Bhybrid%2Bsales%2Btop%2B6%2Bmillion.htm>>.

¹¹⁹ "Average Toyota Prius Pricing Based on Year." *Autos.com*. August 4, 2014. <<http://www.autos.com/car-buying/average-toyota-prius-pricing-based-on-year>>.

consumer expectations of similar acceleration and ride quality to their gasoline equivalents. Car manufacturers have invested in improving horsepower instead of investing in only achieving high gas mileage.

A current hurdle in alternative fuel vehicles is the limited battery range of all-electric cars and supercars. Now that the vehicles have decent power and acceleration, consumers realize they cannot travel as far as they would like before they have to refuel. The average range of the available all-electric vehicles is less than 100 miles per charge. Only the Tesla models and the 2014 Toyota RAV4 get more than 100 miles per charge.

Furthermore, it takes a lot longer to charge a battery than refill a gas tank. Depending on the type of battery and available outlet power, it takes four to eight hours to fully recharge. A “quick charge,” or high-watt connection currently available at relatively few stations, can charge up to 80% of a battery in 30 minutes—still not nearly as quick as filling up a gasoline tank.¹²⁰

The general availability of charging stations is another major barrier to wide-scale adoption of electric vehicles. While traveling on the road, only 7,720 electric charging stations are available across the entire United States.¹²¹ Installing a more complete infrastructure of charging stations across the United States is not happening since there are not enough electric vehicles to make it profitable for car manufacturers to invest in such wide-scale development. Instead they invest in the other vehicle models they offer in their fleet which have a much higher return and market. Elon Musk, however, the billionaire owner of Tesla, plans to build a privately financed charging infrastructure. This serves his company’s personal interests to make it convenient for his Tesla customers to charge their cars. The charging stations boast two innovations to help Tesla owners—a 120 kilowatt rapid recharging system and a way to exchange a depleted battery in 90 seconds. These charging stations cost \$500,000 each to install, and Musk hopes to build enough of these to serve 98% of the US population by 2015.¹²² Besides this massive undertaking by Musk, the interactive nature of the Internet has led to websites such as plugshare.com, which aggregate the locations of charging stations including businesses and residential stations that members can use.

There are also safety issues associated with electric and hybrid vehicles. A hybrid Chevrolet Volt’s battery caught fire during a government crash test in 2011.¹²³ GM, which owns Chevrolet, notes the lack of fires reported from roadway crashes, but this may be partially due to the vehicles’ post-crash protocol which includes depowering the battery. In January 2014, Tesla had to recall almost 29,000 wall adapters used for charging one of their models when one caught fire inside a residential home. Tesla has also had its battery burst into flames after the car ran over debris.¹²⁴ The common denominator in most of the electric vehicle fires are the lithium ion batteries, which are capable of storing more energy to get further mileage, but also have a higher risk of overheating. Lithium ion only provides 200 watt-hours of energy per kilogram, compared to gasoline’s 12,000, so they do not compare to the amount of miles the car could drive either. A lithium ion battery fire is also dealt with differently than traditional fires, primarily by leaving it alone, using an extremely large amount of water, or special chemical fire

¹²⁰ “All-Electric Vehicles (EVs).” *All-Electric Vehicles*. US DOE, August 5, 2014. <<http://www.fueleconomy.gov/feg/evtech.shtml>>.

¹²¹ As of March 17, 2014. See http://www.afdc.energy.gov/fuels/electricity_locations.html. See footnote 55.

¹²² “Tesla Across America: How Elon Musk Is Building an EV Infrastructure.” *Car and Driver*, October 2013. <<http://www.caranddriver.com/features/how-tesla-and-elon-musk-are-building-an-ev-infrastructure-feature>>.

¹²³ Abbey-Lambertz, Kate. “Chevy Volt Battery Catches Fire, Government Investigates General Motors’ Electric Car.” *The Huffington Post*. TheHuffingtonPost.com, November 26, 2011. <http://www.huffingtonpost.com/2011/11/26/chevy-volt-battery-fire-electric-car-general-motors_n_1114193.html>.

¹²⁴ Trop, Jaelyn. “At Auto Show, Tesla Defends Safety Record.” *The New York Times*. The New York Times, January 14, 2014. <http://www.nytimes.com/2014/01/15/automobiles/after-recall-tesla-defends-its-safety-record.html?_r=0>.

suppressants.¹²⁵ Besides the obvious fire hazards to the driver and surroundings, there is a mix of toxic vapors which are absent from gasoline fires. NHTSA is conducting a study on the safety of lithium ion batteries with their potential fire hazard, which commenced in early 2012.¹²⁶

For these reasons, current electric vehicle technology advancements are not translating into large volumes of sales. In fact, many car manufacturers miss their projected sales target for electric vehicles. Carlos Ghosn of Renault-Nissan Alliance admitted that they would miss the sales target of 1.5 million cars between the two companies by 2016. In November 2013 they collectively celebrated their 100,000th electric vehicle sale. Ghosn estimates that it would take an additional four to five years to reach their intended target, although currently they are on track to sell half a million by 2016, leaving another million to sell by 2018.¹²⁷ Despite the lackluster sales performance of electric vehicles and obstacles facing their widespread adoption in the market, a recent development in racing may be enough to act as a catalyst for change: Formula E racing.

Formula E

The new racing series Formula E lends promise to the development of all-electric vehicles. Formula E cars are powered by batteries and an all-electric engine. Ten teams are participating in ten races in the inaugural 2014 season.¹²⁸ The two goals of Formula E are to develop technology for electric vehicles and “make people believe in electric cars.”¹²⁹ They hope to change the current image that electric vehicles are slow and boring and “shape perceptions of what is cool and exciting” through motorsport.¹³⁰ For example, the Spark-Renault SRT_01E single-seater open-wheel cars are limited to 140 mph with a restricted 133 kilowatt (kw) or 180 brake horse power (bhp) engine. The cars are estimated to accelerate from 0-62 mph in three seconds. A “push-to-pass” system temporarily increases the power of the cars to the full 200 kw or 270 bhp in order to facilitate passing and increase the entertainment of races.

Most of the advancements in electric car technology will result from the fact that this is an “open championship.” After the inaugural year, each team is allowed to design and develop their own cars according to the technical specifications set out by the governing regulatory body, the Federation Internationale de l'Automobile or FIA. The result is a competitive and experimental atmosphere allowing for a large variety of mechanical designs to be engineered, tested, and showcased. Car manufacturers can then adopt these track-proven technologies if they are participating in Formula E themselves or licensing the technology from the owners similar to the way Toyota lends its hybrid technology to many other car manufacturers.

Regulation parts are engineered by experienced racing companies, including Dallara (chassis), McLaren Electronics Systems (electric powertrain and all electronics), Williams Advanced Engineering (batteries), and Hewland (gearbox). The chassis is made from carbon fiber, aluminum, and Kevlar—leading to a lightweight and strong car that still fully complies with the series’ safety crash tests. This exact material combination is used on some current production cars for the same reason, although mainly on luxury models due to the high production costs. The batteries cannot be changed mid-race but are expected to last 20-30 minutes at race speeds. This is the first time a multi-gear transmission will be used

¹²⁵ Biello, David. “Should Battery Fires Drive Electric Cars Off the Road?” *Scientific American Global RSS*. November 12, 2013. <<http://www.scientificamerican.com/article/battery-fires-in-electric-cars-danger/>>.

¹²⁶ Roland, Neil. “Feds Researching Fire Risks from EV Batteries.” *MSN Autos*. 2012. August 5, 2014. <<http://editorial.autos.msn.com/feds-researching-fire-risks-from-ev-batteries>>.

¹²⁷ Ingram, Antony. “Nissan’s Ghosn: We’ll Miss 2016’s 1.5M Electric Car Sales Target.” *Green Car Reports*. November 14, 2013. <http://www.greencarreports.com/news/1088447_nissans-ghosn-well-miss-2016s-1-5m-electric-car-sales-target>.

¹²⁸ See appendix 5 for a complete list of the teams and races.

¹²⁹ “Environment.” Vision of the Future. FIA Formula E Championship, 2014. <<http://www.fiaformulae.com/en/sustainability.aspx>>.

¹³⁰ Id.

with an all-electric engine, although it is a sequential paddle shift gearbox that is not currently found in production cars. Formula E will help promote electric vehicles and development through these gearbox, battery, powertrain, engine, and other mechanical and engineering developments associated with the experimentation of teams and changes to regulation parts of the cars.

Formula E commissioned a report from Ernest and Young to assess the global value of Formula E to the electric vehicle market for 2015-2040.¹³¹ Formula E creates value by encouraging technological innovations and development, communicating electric vehicle potential, and “initiating and facilitating alliances with host cities and the general population.” The report predicts financial benefits of 142 billion euros and 52-77 million additional electric vehicles sold around the world over 25 years. In addition, they estimate that within 40 years 42,000 permanent jobs will be created in the car industry worldwide. All of this comes with the environmental benefits of avoiding 900 million tons of CO₂, 13.9 billion euros saved on CO₂ costs, and 4 billion oil barrels saved over the next 25 years.

This series has garnered international attention as it finalizes plans for the 2014 season, promising star power and big names to help promote the series and electric vehicles. The ten teams include American racing legend Michael Andretti, four-time Formula One world champion Alain Prost, the car company Audi, Richard Branson’s Virgin Group, and Leonardo DiCaprio. Former Formula One drivers Lucas di Grassi and Takuma Sato, along with former Top Gear driver Ben Collins are development drivers for the series. Traditional racing fans are skeptical of an all-electric racecar, but major automobile publications have featured the upcoming series with a positive outlook hoping to still thrill fans,¹³² partially due to the large involvement of former Formula One drivers.

Other Electric Vehicle Series and Electric Racing Developments

Formula E is the newest and largest electric racing series, but by no means the first or only one. The famous Pikes Peak International Hill Climb is the second oldest race in the United States, and has an electric division. Seven competitors in 2014 are in this category, including five which are aiming to set a time under 10 minutes. Until 2013, this was seconds away from the time record of their gasoline-powered counterparts. The goal of the World Solar Challenge is to promote research on solar-powered cars. It is a race across the Australian Outback from Darwin to Adelaide. The rules are complex with the different classes, but self-sufficiency and reliance on kinetic and solar sources for electricity generation to power the car are key to this competition. The TroPhee Andros Electrique is an ice and snow racing series with electric cars in France. All cars are the same model, but the abilities of electric cars to excite and be pushed to their limits are showcased.

Furthermore, Quimera Responsible Racing is part of the Quimera, an organization of multinational companies that work on sustainable projects. They sponsor non-fossil fuel racing endeavors, with both all-electric cars and motorcycles.¹³³ The goal in developing this racing technology is for “assessing the innovation developed and verifying the appropriate application in streetcar manufacturing.”¹³⁴ Quimera Responsible Racing entered a joint venture between the International Motor Sport Association and the American Le Mans Series in January 2012 to bring electric racing classes to current racing and start a global initiative for non-fossil fuel racing.¹³⁵ After the American Le Mans Series

¹³¹ “EY Report Forecasts Formula E to Contribute to Significant Sales Increase in EVs.” Formula E. November 12, 2013. <<http://www.fiaformulae.com/en/sustainability.aspx?page=2534>>.

¹³² See *Car and Driver* as one example: <http://blog.caranddriver.com/everything-you-need-to-know-about-the-formula-e-electric-only-race-series/>.

¹³³ “Racing Categories.” *Quimera Responsible Racing*. August 5, 2014. <<http://www.quimerarr.com/categories>>.

¹³⁴ “All Electric GT.” *Quimera*. August 5, 2014. <<http://www.quimera-project.com/Html/Quimera-Electric-EVO-01.html>>.

¹³⁵ “Joint Venture Between Quimera, IMSA and ALMS.” *Quimera Responsible Racing*. January 12, 2012. <<http://www.quimerarr.com/news-data/8/joint-venture-between-quimera-imsa-and-alms>>.

ended in 2013, the venture was stopped with the International Motor Sport Association. Quimera's prototypes include a 700 bhp all-electric GT-class racing vehicle has been completed since 2011 and has been showcased at many events, with a new prototype currently in development. They hope to turn their 400 bhp all-electric touring car GT4 into a production road-legal car. They have an all-electric single-seater open-wheel racing car with 390 bhp and are in the process of producing a 220 bhp all-electric drifting car. Their all-electric motorcycle is built for the TTXGP World Championship race.

Car manufacturers are increasingly investing in electric vehicles, and will look toward racing to help turn their high-powered, high-range concept vehicles and engineering goals into reality.

Beyond Electric: Hydrogen Fuel Developments

With the current reluctance of consumers to purchase electric vehicles despite all the research and development in the area, manufacturers are also investing in other types of alternative fuel vehicles. This mirrors the exploration of non-electric alternative fuels for racing, where prototypes are often the pioneering application of these fuels in a functioning vehicle.

Hydrogen, one of the most promising non-electric alternative fuels, is in the early stages of development for use in transportation through both racing and manufacturer test and concept models. Hydrogen technology can be two to three times more efficient at converting fuel to power than conventional vehicles, and only emitting water when burned. While relatively little infrastructure is currently in place for fueling stations, hydrogen gas is pumped into gas tanks like gasoline. Thus, time to refuel is not an issue like it is with electricity. One issue with the current generation of hydrogen fuel cell technology in transportation is the weight it adds to vehicles, but manufacturers counter this by using aluminum and carbon fiber materials for the chassis. Currently Mercedes-Benz, Chevrolet, and BMW all make fuel cell vehicles as part of demonstration fleets.¹³⁶ The Mercedes Benz F-Cell and Honda Clarity have a limited amount available for lease in California.¹³⁷ The limit to California is due to the limited availability of refilling stations, which the state California plans to help expand. The Chevrolet Fuel Cell Equinox is only a test vehicle for the company and not available to customers. The 100 BMW Hydrogen 7s produced are loaned to hand-picked people to test drive.¹³⁸ The 2015 Hyundai Tucson Fuel Cell is currently being delivered to dealers in California, with the honor of being the first mass-produced fuel cell vehicles, with 1000 total planned to be built annually.¹³⁹ The Tucson will only be available by lease, for \$499 a month including unlimited hydrogen fuel.

Both Toyota and Honda plan on offering their 2015 models for purchase. Toyota has been showcasing their concept car since 2011 and plan to bring it into mass production for 2015. Similarly, Honda is moving to shift from an experimental fleet to a mass production fleet. The likely price of these will be high when they are introduced, predicted at almost \$100,000,¹⁴⁰ while both companies will

¹³⁶“Hydrogen Fuel Cell Vehicle Availability.” *Alternative Fuels Data Center*. US DOE, March 3, 2014. <http://www.afdc.energy.gov/vehicles/fuel_cell_availability.html>.

¹³⁷ “Honda FCX Clarity Official Web Site.” *Honda Vehicles*. Honda, n.d. August 5, 2014. <<http://automobiles.honda.com/fcx-clarity/exterior.aspx>>.

¹³⁸“The BMW Hydrogen 7.” *BMW EfficientDynamics : BMW CleanEnergy*. The International BMW Website. August 5, 2014.

<http://www.bmw.com/com/en/insights/technology/efficient_dynamics/phase_2/clean_energy/bmw_hydrogen_7.html>.

¹³⁹ Lindberg, Austin. “2015 Hyundai Tucson Fuel Cell: Hydrogen-Powered Motoring for \$499 a Month.” *Car and Driver*. Car and Driver, November 2013. <<http://www.caranddriver.com/news/2015-hyundai-tucson-fuel-cell-photos-and-info-news>>.

¹⁴⁰ “Honda, Toyota to Let Consumers Join the Fuel Cell Party.” *Business Trends*. Neikki Asian Review, March 26, 2013. <<http://asia.nikkei.com/Business/Trends/Honda-Toyota-to-let-consumers-join-the-fuel-cell-party>>.

produce only 1,000 units a year. Toyota hopes to cut prices in half by 2020, once they ramp up production and fuel cell technology catches on with consumers.

Hydrogen fuel cell racing prototypes have shown that the issue of lack of power and range are not present in these early stages. Aston Martin was the first to participate in a sanctioned FIA racing event with their hybrid hydrogen Rapide S at the 24 hours of Nurburgring in 2013.¹⁴¹ The vehicle went 182 miles on hydrogen power alone at race speeds.¹⁴² GreenGT H2 is developing and testing an open-wheel car powered by a hydrogen fuel cell that fully complies with FIA rules, originally producing the prototype in 2012.¹⁴³ They have had success developing and integrating their work in production vehicles before—with their 100% electric drive system and the car manufacturer Citroen. Forze H2 is a foundation where students, chiefly from Delft University of Technology, have developed six models of a fuel-cell-powered racecar. The newest version is designed to race against traditional gasoline-powered cars.¹⁴⁴ BMW based their “loaner” Hydrogen 7 on their H2R record-setting racecar, produced in 2004.¹⁴⁵

The advancements that are happening in the world of hydrogen racing are informing car manufacturers of the potential that hydrogen can have over electricity to provide cars which meet consumer demands for powerful, long-range, and quick-to-refuel vehicles. The success of hydrogen fuel cell vehicles may nonetheless similarly hinge on the development and expansion of refueling infrastructure.

Conclusion

Encouraging energy independence through legislation seems like a straightforward response to increasing gasoline prices, environmental consequences, and a desire for more stability in supply. However, in reality such legislation has not provided the desired outcomes. Many implications affect both supply and demand sides of the fuel and vehicle market. Given the fact that a policymaker cannot know exactly how consumers will adjust their behavior based on policy incentives, such policies should be considered with caution. Attempts to encourage fuel efficiency and produce cleaner domestic fuel with CAFE standards and RFS have been inefficient at best. The variety of negative environmental and economic consequences ended up being counteractive to the stated purpose.

If the government wants to continue to influence the market, policy goals should be limited, targeted, and measurable. If the policy goal is to reduce gasoline consumption for environmental and security reasons, a better option could be to replace all policies which attempt to incentivize gasoline use reduction with one gasoline tax. Current policies which indirectly alter the price signal allow for a range of unintended consequences via substitution and consumer response. A gasoline tax can be equivalent to the sum of calculated benefits from the cost-benefit analysis of the current policies. While this may or may not be the correct valuation, this would alter the price signal directly in the same quantity as policymakers intended with existing policies. There is no possibility of consumers valuing the benefits of gasoline reduction differently than policymakers since the value calculated in the cost-benefit analyses is directly charged. This also would let consumers decide how to reduce gasoline use instead of forcing compliance by car manufacturers or gasoline refiners. Car manufacturers would get to respond to changes

¹⁴¹ Tisshaw, Mark. “Hydrogen-powered Aston Martin - the Story behind the Racer.” *Autocar*. May 25, 2013. <<http://www.autocar.co.uk/car-news/motorsport/hydrogen-powered-aston-martin-story-behind-racer>>.

¹⁴² Dyer, Ezra. “This Race Car Swaps Fossil Fuels for Hydrogen Power.” *Popular Science*. October 18, 2013. <<http://www.popsci.com/cars/article/2013-09/hydrogen-hits-track>>.

¹⁴³ “Bringing Skills Together since 2008.” GreenGT. August 5, 2014. <<http://www.green-gt.com/en/greengt.php>>.

¹⁴⁴ “Forze VI.” *Forze H2 Hydrogen Racing*. N.p., n.d. August 5, 2014. <<http://www.formulazero.tudelft.nl/about/forze-6#specifications>>.

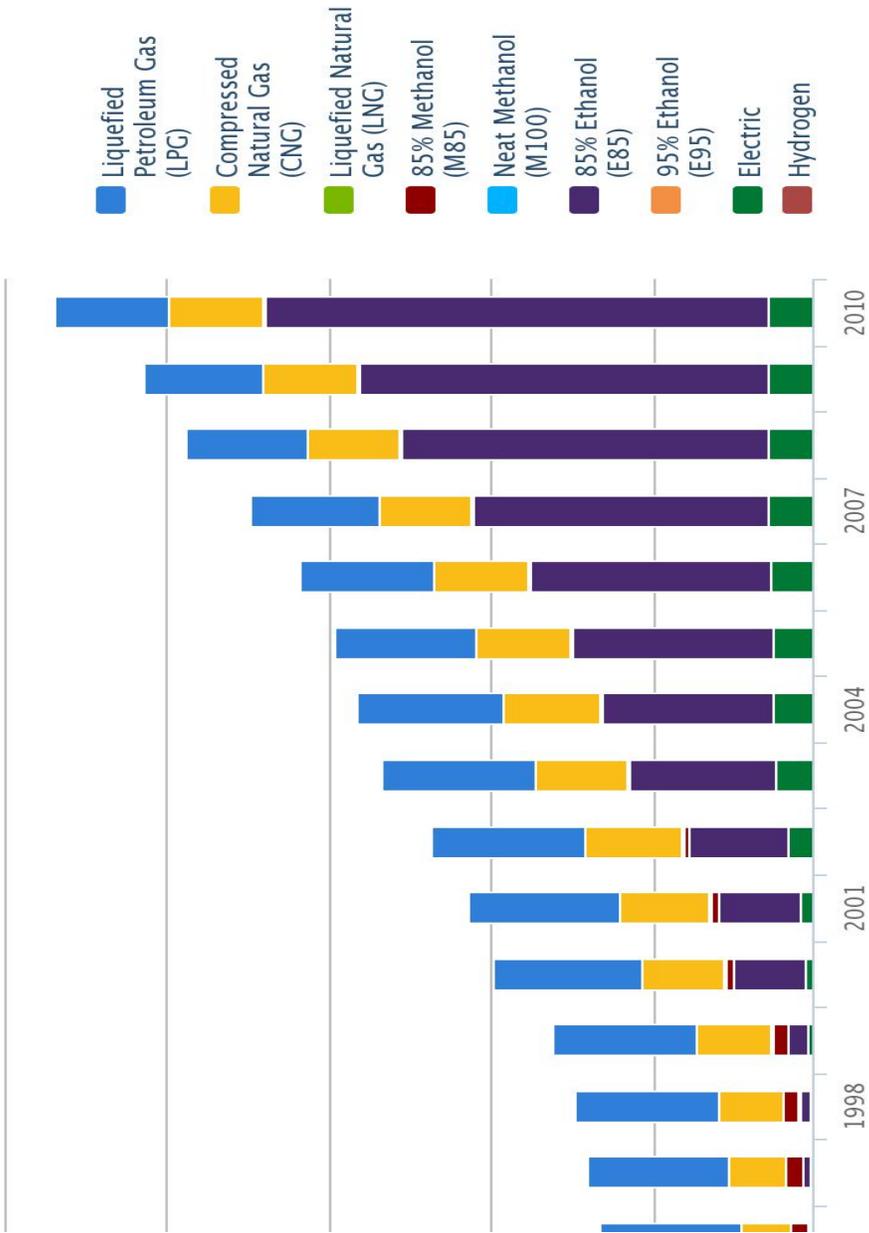
¹⁴⁵ “BMW Hydrogen.” *The International BMW Website*. August 5, 2014. <http://www.bmw.com/com/en/insights/technology/efficientdynamics/phase_2/bmw_hydrogen/index.html>.

in consumer demand for fuel efficiency using normal market mechanisms, including adopting technology from racing that can be used to increase fuel efficiency.

The difference between CAFE standards and a gasoline tax is the mechanism by which the price of driving is increased. CAFE standards force gasoline use reduction by requiring car manufacturers to include expensive technology that a customer is forced to have if they want to purchase a new car. A gasoline tax allows consumers to decide how to adjust their behavior to the increased cost of gasoline. Possible gasoline use reduction behaviors include carpooling more, buying a used car, utilizing public transportation, moving to an area which requires less driving, or purchasing a new car. The production of new cars will not necessarily include developed technology, and if it does it is only because that is what consumers want when facing the inflated gasoline prices.

This analysis shows that markets can provide the incentives to adequately encourage car manufactures to resolve environmental and security concerns due to the necessity of satisfying consumer demands and preferences. One way markets can provide fuel efficient technology is through racing. The racing industry provides a testing ground for new and improved technology, resulting in potential technology spillover to production cars. Car manufacturers can turn to their race teams as a source of technology available for them to utilize in production cars to satisfy consumer demand. Racing's ability to deliver such technology lends promise that Formula E can provide advancements in electric vehicles that will not require taxpayer money to be spent on ineffective policy. These private incentives, determined by the signals and feedback of the market process, can lead to sustainable improvements in increased fuel efficiency and reduction of gasoline use that the CAFE standards and the Renewable Fuel Standard lack.

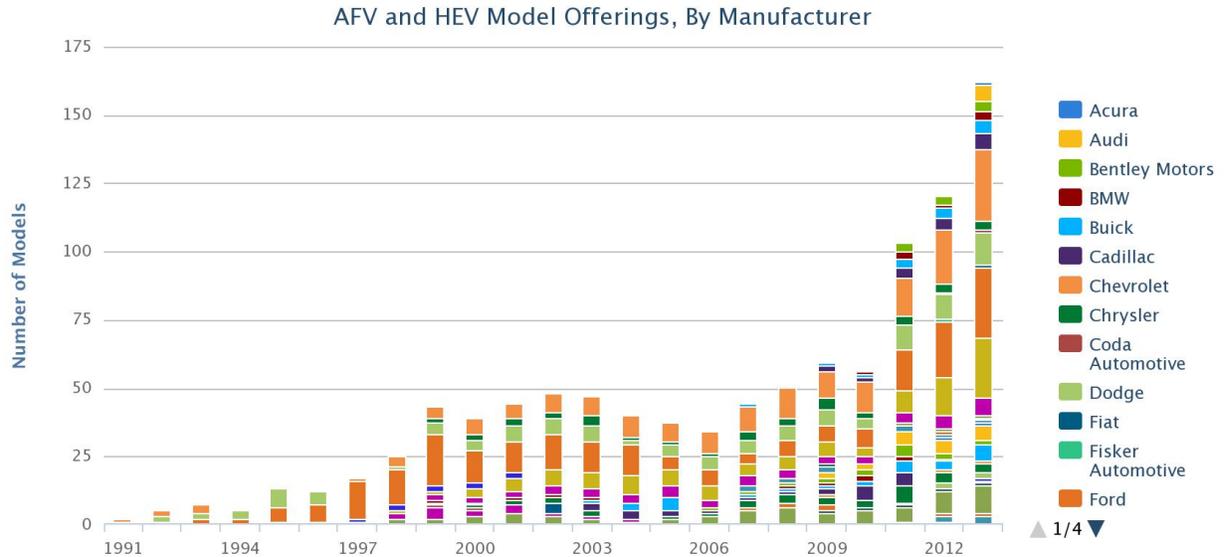
Appendix 1: Alternative Fuel Vehicles in Use through 2010



Source: <http://www.afdc.energy.gov/data/10300>

Appendix 2: Alternative Vehicles for Sale

Number of Alternative Fuel Vehicles and Hybrid/Electric Vehicle Models:

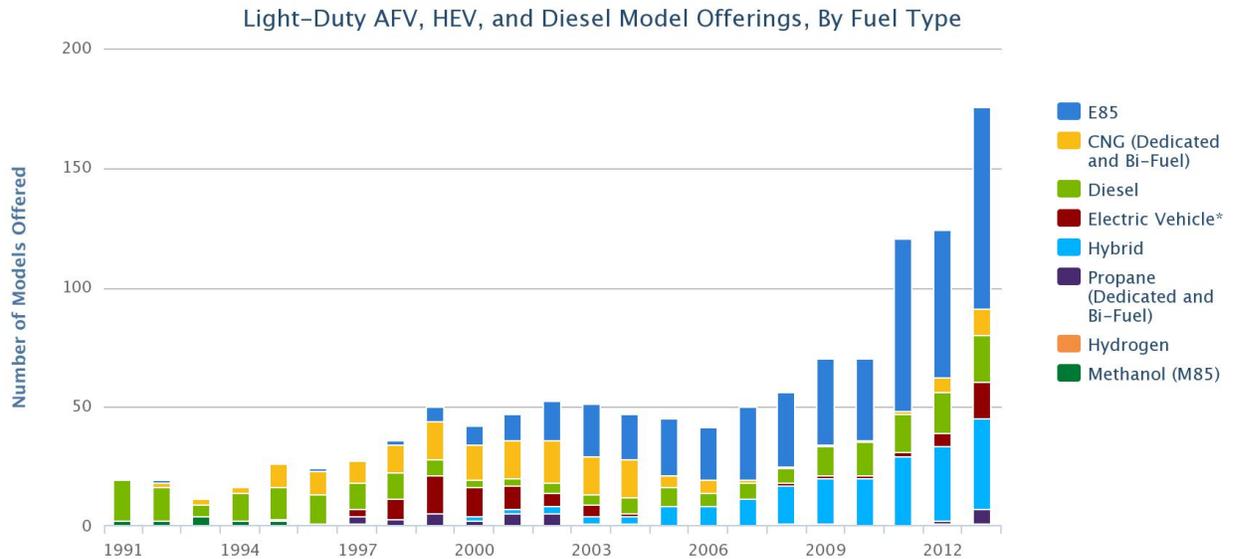


Data Source: AFDC [Alternative Fuel and Advanced Vehicles Buyer's Guide](#), circa 04/25/13.

The number of alternative fuel vehicles (AFVs) and hybrid electric vehicles (HEVs) grew consistently from 1991 to 2002 as flex-fuel vehicles gained popularity. The models dropped between 2002 and 2006 as manufacturers reduced the variety of flex-fuel vehicles available. The number of AFVs and HEVs has been growing rapidly ever since, with the exception of the recession-induced reduction in 2010. Subsidiaries of “The Big 3” manufacturers have brought two-thirds of the AFVs to market throughout the past 22 years.

Graph Source: <http://www.afdc.energy.gov/data/10304>

Types of Alternative Fuel Vehicles:



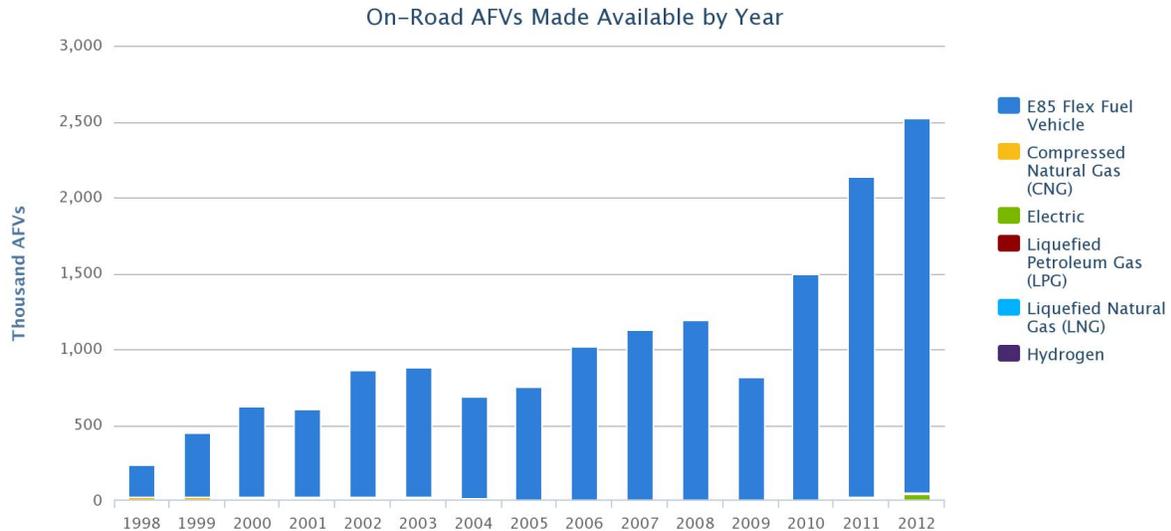
Data Source: National Renewable Energy Laboratory

Notes: *EVs do not include neighborhood electric vehicles (NEVs), low-speed electric vehicles, or two-wheeled electric vehicles.

Conversion models were counted for natural gas and propane vehicles for the first time in 2012. This chart shows the number of light-duty AFVs, HEVs, and diesel models offered by vehicle manufacturers from 1991 through 2013. In 2013 vehicles capable of using E85 represent the largest share of models offered. This is largely because the technology required for E85 vehicles is comparatively inexpensive and compatible with gasoline vehicles.

Graph Source: <http://www.afdc.energy.gov/data/10303>

Alternative Fuel Vehicles Sold, Leased, or Converted:

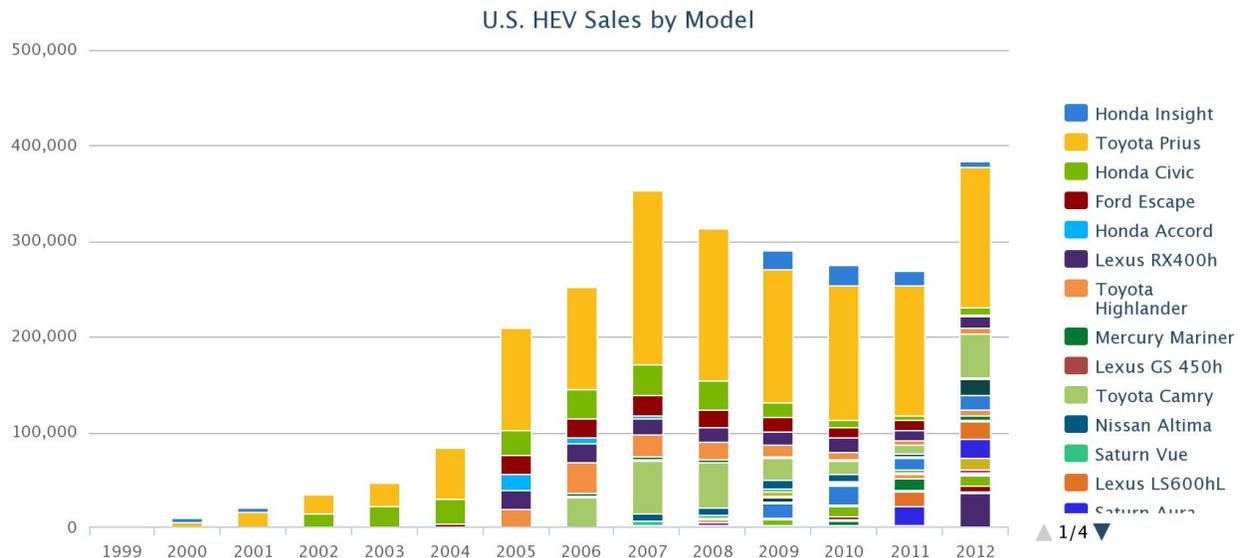


Source: [Energy Information Administration](http://www.eia.doe.gov), Alternatives to Traditional Transportation Fuels 1998-2012 reports.

This chart shows the number of on-road alternative fuel vehicles (AFVs) that were sold, leased, or converted in the United States between 1998 and 2012. Flex-fuel vehicles, which are capable of running on E85, plain gasoline, or any ethanol-gasoline blends in between, represent the vast majority of AFVs made available in the market. This is due to their ability to use readily available gasoline and to federal regulations that require vehicle manufacturers to produce vehicles capable of running on non-petroleum based fuels.

Graph Source: <http://www.afdc.energy.gov/data/10299>

Hybrid Electric Vehicles Sales:



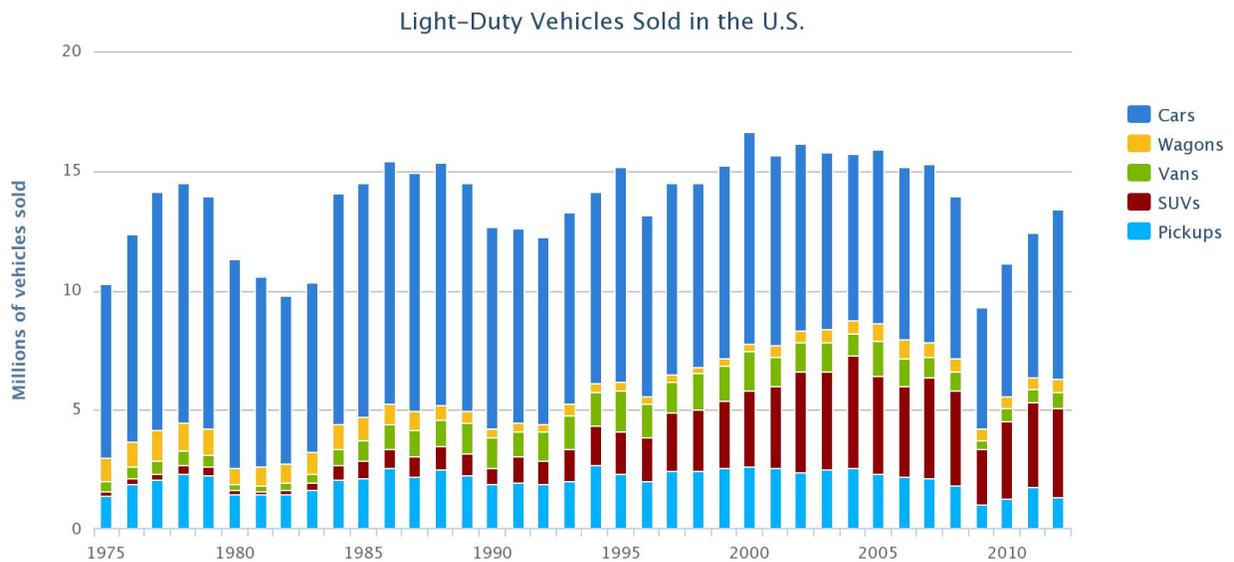
Data Source: [HybridCars.com](http://www.hybridcars.com)

Notes: Vehicles are listed in order of introduction into the market.

This chart shows the number of HEVs broken down by model, sold in the United States between 1999 and 2012. HEV sales surged in 2005, by which point the federal government and many states offered tax incentives or rebates to purchasers of HEVs. The Toyota Prius has been the top-selling HEV model since its introduction in 2000 despite the fact that more than 40 models are now available. Decline in sales, between 2008 and 2011, is consistent with overall declines in vehicle sales during the recession. The increase in 2012 can be attributed to economic recovery, increased gasoline prices, and new CAFE standards. For comparison, see Light-Duty Vehicles Sold in the U.S.

Source: <http://www.afdc.energy.gov/data/10301>

Light-Duty Vehicles:



Data Source: [US Environmental Protection Agency \(2012\)](#).

This chart shows the number and types of light-duty vehicles sold in the United States from 1975 to 2012. In 2005, cars made up the smallest share of the total, relative to all other years. In 2009, the recession significantly impacted US light-duty vehicle sales, which still have not rebounded to pre-2009 levels.

Source: <http://www.afdc.energy.gov/data/10314>

Appendix 3: CAFE Standards over Time

CAFE STANDARDS

MODEL YEAR	PASSENGER CARS	LIGHT TRUCKS		
		COMBINED	2WD	4WD
1978	18.0			
1979	19.0		17.2	15.8
1980	20.0		16.0	14.0
1981	22.0		16.7	15.0
1982	24.0	17.5	18.0	16.0
1983	26.0	19.0	19.5	17.5
1984	27.0	20.0	20.3	18.5
1985	27.5	19.5	19.7	18.9
1986	26.0	20.0	20.5	19.5
1987	26.0	20.5	21.0	19.5
1988	26.0	20.5	21.0	19.5
1989	26.5	20.5	21.5	19.0
1990	27.5	20.0	20.5	19.0
1991	27.5	20.2	20.7	19.1
1992	27.5	20.2		
1993	27.5	20.4		
1994	27.5	20.5		
1995	27.5	20.6		
1996	27.5	20.7		
1997	27.5	20.7		
1998	27.5	20.7		
1999	27.5	20.7		
2000	27.5	20.7		
2001	27.5	20.7		
2002	27.5	20.7		
2003	27.5	20.7		
2004	27.5	20.7		
2005	27.5	21.0		
2006	27.5	21.6		
2007	27.5	22.2		
2008	27.5	22.5*		
2009	27.5	23.1*		
2010	27.5	23.5*		
2011	30.2**	24.2**		

* - The values shown are the standard values applicable under the existing "unreformed" CAFE program. In model years 2008-2010, light truck manufacturers have the option to comply with the unreformed standard values or the new reformed standard values based upon each manufacturers unique vehicle fleet characteristics.

** - Projected 2011 required average fuel economy standard value based on PMY reports.

Source: Summary of Fuel Economy Performance (Public Version) April 28, 2012, US DOT NHTSA.

Appendix 4: Timeline of New Technologies to Reduce Emissions and Improve Fuel Economy

Year	Technology	Comments
1975	Two-way oxidation catalyst	Needed to meet the 1975 HC and CO standards
1975 – 1982	Weight reduction by downsizing and use of lightweight materials	Needed to meet the CAFE standards (1978 – 1985?)
1976 – 1980	Improved radial tires and reduced aerodynamic drag	Lower road load
1977 – 1980	Electronic engine controls	Reduce emissions (NO _x)
1978 – 1985	Front-wheel drive in many models	Improve driveline packages and reduce weight
1978 – 1990	4-speed automatic transmission with lockup	Improve fuel economy
1980 -	V6 engines	New high-power engine replacing some V8s
1980	Three-way, oxidation / reduction catalyst	Needed to meet the 1981 emissions standard (particularly NO _x)
1980	Electronic ignition and single-point fuel injection	Needed by the three-way catalyst to control A/F ratio
1982 – 1985	Computer control of the engine and transmission	Reduce emissions and fuel economy
1985	Multi-point fuel injection	Further reduce emissions
1986 – 1995	Use of 4- valves per cylinder in engines	Increase specific power (kW/Liter) of the engine and improve part-load bsfc
1995	Variable valve actuation and timing	Further improve emissions and fuel economy
2000	5- and 6-speed automatic transmissions with lockup in multiple gears	Improve fuel economy and acceleration performance
2000	Ultra-clean emission control	Meet ULEV and SULEV emissions standards
2000	Continuously Variable Transmission (CVT)	The engine speed/drive wheel speed ratio can be altered to enhance vehicle performance or fuel economy.

Source: Burke, Andrew F., Ethan C. Abeles, Belinda S. Chen (2004) The Response of the Auto Industry and Consumers to Changes in the Exhaust Emission and Fuel Economy Standards (1975-2003): A Historical Review of Changes in Technology, Prices, and Sales of Various Classes of Vehicles. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-04-04.

TABLE 3-1 Fuel Consumption Technology Matrix — Passenger Cars

	Fuel Consumption Improvement %	Retail Price Equivalent (RPE) (\$)						Midsize						Large								
		Low		High		Subcompact		Compact		Midsize		Large		Subcompact		Compact		Midsize		Large		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Baseline: overhead cams, 4-valve, fixed timing, roller finger follower.																						
Production-intent engine technology																						
Engine friction reduction	1-5	35	140	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Low-friction lubricants	1	x	11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Multivalve, overhead camshaft (2-V vs. 4-V)	2-5	105	140	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Variable valve timing	2-3	35	140	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Variable valve lift and timing	1-2	70	210	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cylinder deactivation	3-6	112	252	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Engine accessory improvement	1-2	x4	112	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Engine supercharging and downsizing	5-7	350	560	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Production-intent transmission technology																						
Five-speed automatic transmission	2-3	70	154	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Continuously variable transmission	4-8	140	350	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Automatic transmission w/aggressive shift logic	1-3	---	70	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Six-speed automatic transmission	1-2	140	280	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Production-intent vehicle technology																						
Aero drag reduction	1-2	---	140	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Improved rolling resistance	1-1.5	14	56	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Safety technology																						
Safety weight increase	-3 to -4	0	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emerging engine technology																						
Intake valve throttling	3-6	210	420	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Camless valve actuation	5-10	280	560	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Variable compression ratio	2-6	210	490	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emerging transmission technology																						
Automatic shift/manual transmission (AST/AMT)	3-5	70	2x0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Advanced CVTs—allows high torque	0-2	350	840	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emerging vehicle technology																						
42-V electrical systems	1-2	70	280	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Integrated starter/generator (idle off-restart)	4-7	210	350	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Electric power steering	1.5-2.5	105	150	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Vehicle weight reduction (5%)	3-4	210	350	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

NOTE: An x means the technology is applicable to the particular vehicle. Safety weight added (EPA baseline + 3.5%) to initial average mileage/consumption values.

Source: Page 42, National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, National Academy of Sciences, Washington, DC, 2002.

Appendix 5: Annual Costs of CAFE Standards to Achieve 10% Reduction in Gasoline Consumption

	CAFE	CAFE with trading
Policy modeled	31.3 mpg for cars	
	24.5 mpg for light trucks	
Total cost	\$3.6 billion	\$3.0 billion
Producers Consumers	\$1.2 billion \$2.4 billion	\$0.8 billion \$2.2 billion
Per-vehicle costs	\$228	\$184
Producers	\$75	\$42
Consumers	\$153	\$142

Source:

Austin, David & Dinan, Terry, 2005. "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes," *Journal of Environmental Economics and Management*, Elsevier, vol. 50(3), pages 562-582, November.

**Appendix 6: EISA 2007 Expansion of the Renewable Fuel Standard (in billions of gallons)
RFS2 biofuel mandate**

Year	RFS1 biofuel mandate in EPAAct of 2005	Total renewab le fuels	Cap on corn starch- derived ethanol	Portion to be from advanced biofuels			
				Total non- corn starch	Biomass- based diesel		
				Cellulosic	Other		
2006	4.0	—	—	—	—	—	—
2007	4.7	—	—	—	—	—	—
2008	5.4	9.00	9.0	0.00	0.00	0.00	0.00
2009	6.1	11.10	10.5	0.60	0.00	0.00	0.10
2010	6.8	12.95	12.0	0.95	0.0065b	1.15c	0.29
2011	7.4	13.95	12.6	1.35	0.006d	0.80	0.54
2012	7.5	15.20	13.2	2.00	0.00e	1.00	1.00
2013	7.6 (est.)	16.55	13.8	2.75	0.014f	1.28 f	1.46
2014	7.7 (est.)	18.15	14.4	3.75	1.75	g	1.00
2015	7.8 (est.)	20.50	15.0	5.50	3.00	g	1.50
2016	7.9 (est.)	22.25	15.0	7.25	4.25	g	2.00
2017	8.1 (est.)	24.00	15.0	9.00	5.50	g	2.50
2018	8.2 (est.)	26.00	15.0	11.00	7.00	g	3.00
2019	8.3 (est.)	28.00	15.0	13.00	8.50	g	3.50
2020	8.4 (est.)	30.00	15.0	15.00	10.50	g	3.50
2021	8.5 (est.)	33.00	15.0	18.00	13.50	g	3.50
2022	8.6 (est.)	36.00	15.0	21.00	16.00	g	4.00
2023	—	h	h	h	H	h	H

Source: RFS1 is from EPAAct (P.L. 109-58), Section 1501; RFS2 is from EISA (P.L. 110-140), Section 202.

- a) “Other” advanced biofuels is a residual category left over after the ethanol-equivalent gallons of cellulosic and biodiesel biofuels are subtracted from the “Total” advanced biofuels mandate.
- b) The initial EISA cellulosic biofuels mandate for 2010 was for 100 million gallons. On February 3, 2010, EPA revised this mandate downward to 6.5 million ethanol-equivalent gallons.
- c) The biomass-based diesel mandate for 2010 combines the original EISA mandate of 0.65 billion gallons (bgals) with the 2009 mandate of 0.5 bgals.
- d) The initial RFS for cellulosic biofuels for 2011 was 250 million gallons. In November 2010 EPA revised this mandate downward to 6.0 million ethanol-equivalent gallons.

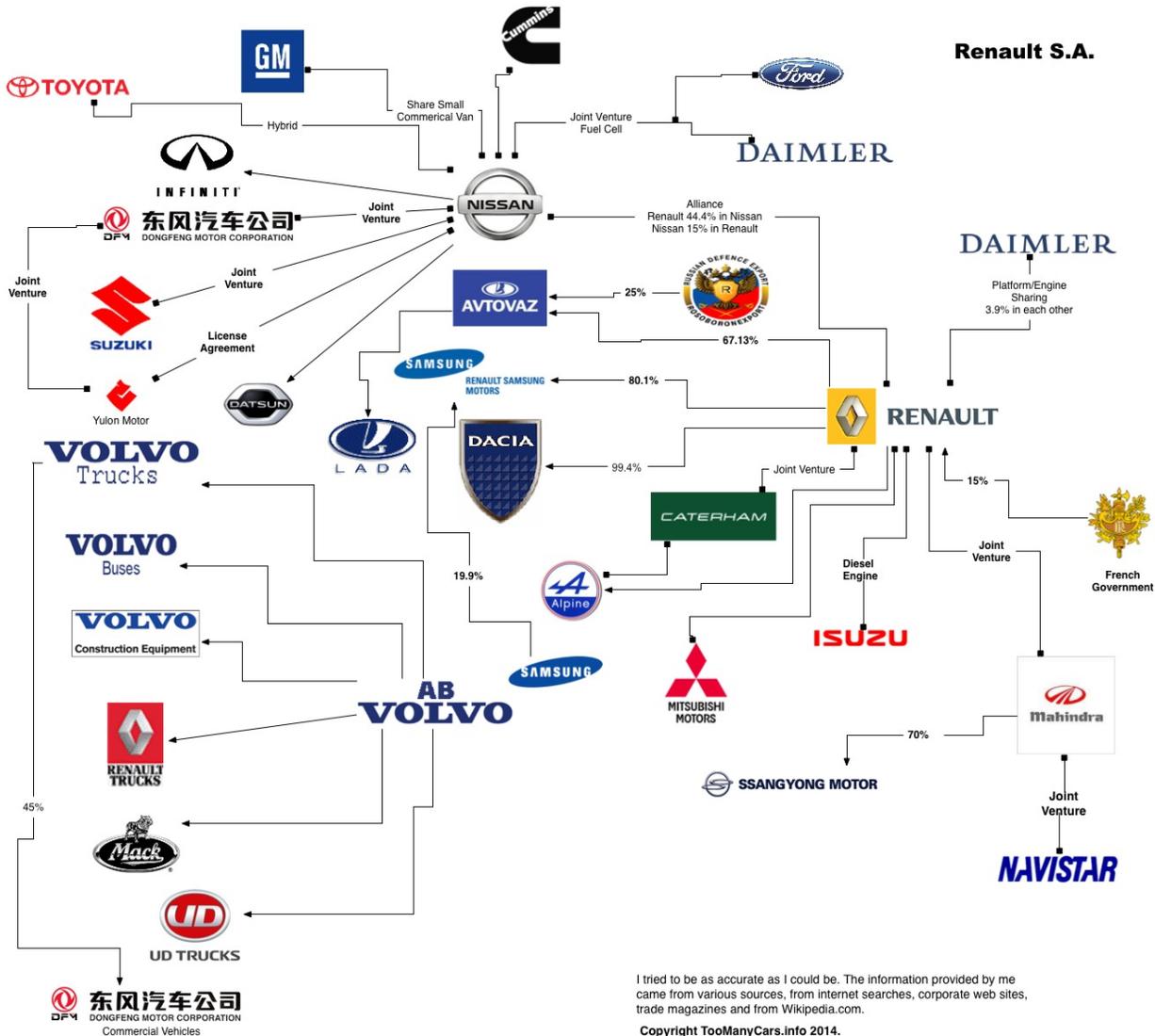
- e) The initial RFS for cellulosic biofuels for 2012 was 500 million gallons. In December 2011 EPA revised this mandate downward to 10.45 million ethanol-equivalent gallons. In January 2013, the US Court of Appeals for D.C. vacated EPA's initial cellulosic mandate for 2012 and remanded EPA to replace it with a revised mandate. On February 28, 2013, EPA dropped the 2012 RFS for cellulosic biofuels to zero.
- f) The initial 2013 cellulosic RFS was 1 bgals. In January 2013, EPA revised this mandate to 14 million ethanol equivalent gals. The 2013 biodiesel mandate was revised upward from 1 bgals to 1.28 bgals actual volume.
- g) To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.
- h) To be determined by EPA through a future rulemaking.

Source: Schnepf, Randy, and Brent D. Yacobucci. "Renewable Fuel Standard (RFS): Overview and Issues." (2010).

Appendix 7: The Current Automobile Production Market

The current car industry's organization is complex. A seemingly endless amount of car choices and options are available for a consumer in the United States. However, only a few major automotive groups own the majority of companies, as seen in entirety in appendix 2. Below is a chart one of the largest parent companies in car manufacturing business:

Other familiar examples include General Motors Corporation, which owns or has stake in Buick,



Cadillac, Chevrolet, GMC, Suzuki, Vauxhall, Holden and Opel—to name the more well-known brands. Fiat Group owns or has stake in Chrysler, Mazda, Abarth, Alfa Romeo, Ferrari, Fiat, Lancia, and Maserati, among others. Volkswagen Aktiengesellschaft owns Volkswagen, Bentley, Bugatti, Porsche, Lamborghini and Audi.¹⁴⁶ Within these family trees are various racing series teams, including companies which own Formula One teams. Knowing these relationships helps explain why similar designs and components are found in seemingly competing car companies. The companies are separated by price point, from entry level fleet offerings up to exclusive luxury fleets, in order to avoid competition within

¹⁴⁶ As of 2/5/2014. http://www.toomanycars.info/CarRelationship/Car_Rel-Image2.html

subsidiaries of parent companies. The transfer of components and technologies from both racing and related car companies is therefore fairly straightforward when it is all owned by a parent company, since the rights to technology developed in one subsidiary can be used by another subsidiary owned by the same parent company. This allows for technologies that increase fuel efficiency to quickly disperse throughout into the market.

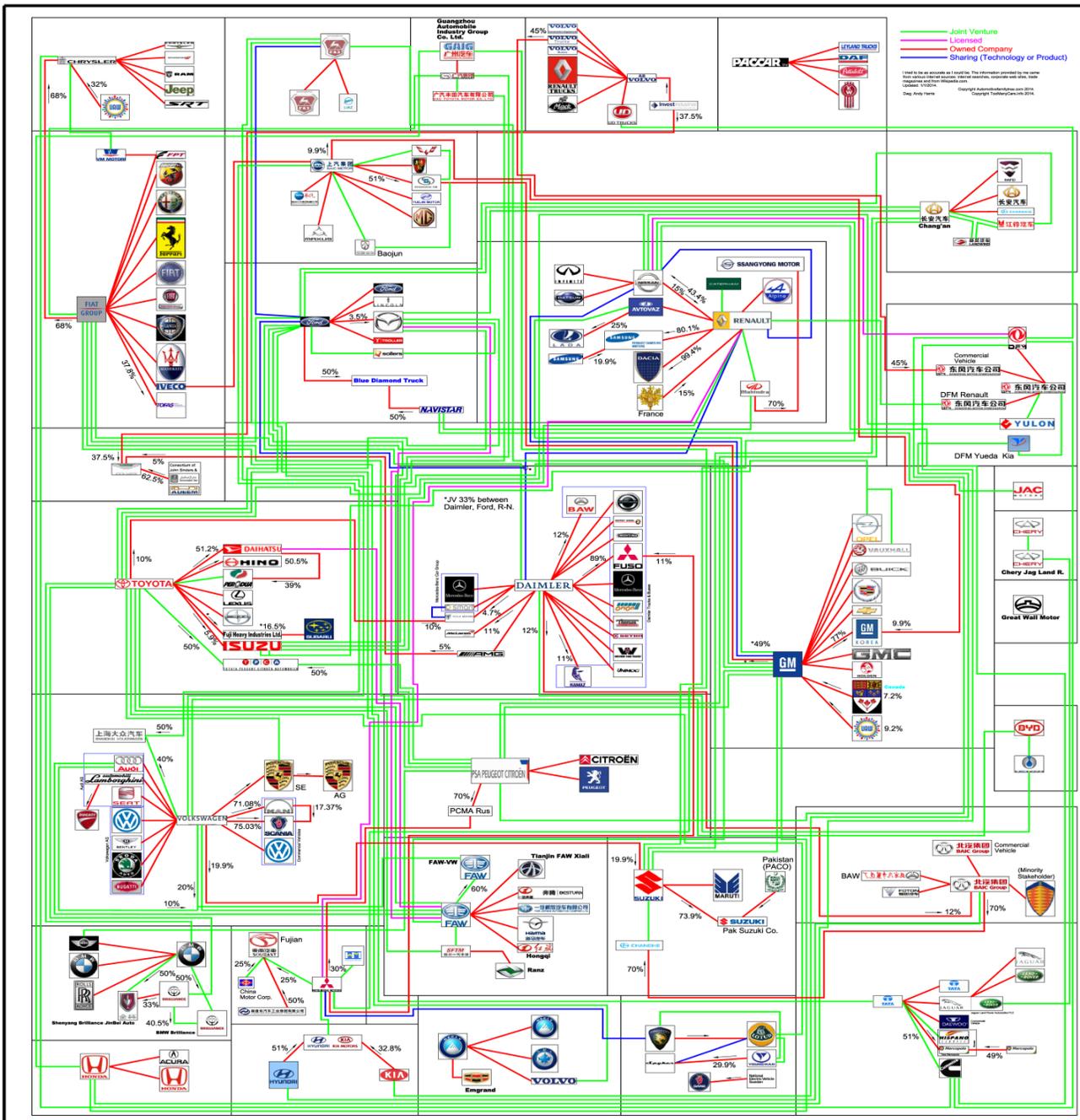
The top five selling brands in the United States are: General Motors (GM), Ford, Chrysler, Toyota, and Honda. In 2013 GM had an 18.6% market share, Ford had 15.9%, Toyota had 15.1%, Chrysler had 11.3%, and Honda had 9%. The top-selling vehicles are trucks and sedans.¹⁴⁷ Out of the 13.34 million light-duty vehicles sold in 2012, 385,204 were alternative fuel vehicles.¹⁴⁸ Alternative fuel vehicles utilize compressed natural gas, liquid natural gas, hydrogen, high ethanol content gasoline blends, propane, methanol blends, biodiesel, and all-electric energy sources. Hybrid-electric vehicles are a separate category since they use gasoline in addition to electric power so they are not true alternative fuel vehicles. For the year 2013, 162 models of AFV or HEV vehicles were available from car manufacturers. The majority of these were hybrid (31) and flex-fuel vehicles (62) models.¹⁴⁹ Flex-fuel vehicles are specially designed to be able to use both gasoline and ethanol, or any blend of the two, as fuel.

¹⁴⁷ Top selling by market share as of 2/3/2014. Constantly updated information can be found at Wall Street Journal online at: http://online.wsj.com/mdc/public/page/2_3022-autosales.html#autosalesE.

¹⁴⁸ The number for alternative fuel vehicles is the combined sales, lease, and conversion (why it is approximate) of AFV and HEV vehicles. Data is from the US DOE Alternative Fuels Data Center; see appendix 2 for citations and more information on amount of sales.

¹⁴⁹ A list of flex-fuel vehicles starting from 2001 until the 2014 car models can be found at <http://www.growthenergy.org/brochures/flexfuelvehicleguide/>

Automotive Family Tree



Source: Andy Harris and automotivefamilytree.com

Appendix 8: Formula E Teams and Cities

2014 Inaugural Race Season Calendar

Grand Prix	City	First Race
China	Beijing	13 September 2014
Malaysia	Putrajaya	18 October 2014
Brazil	Rio de Janeiro	15 November 2014
Uruguay	Punta del Este	13 December 2014
Argentina	Buenos Aires	10 January 2015
United States	Los Angeles	14 February 2015
United States	Miami	14 March 2015
Monaco	Monte Carlo	9 May 2015
Germany	Berlin	30 May 2015
United Kingdom	London	27 June 2015

Ten Teams

Trulli GP
China Racing
Andretti Autosport
Dragon Racing
e.dams
Amlin Aguri
Audi Sport Abt Formula E Team
Mahindra Racing
Virgin Racing
Venturi Grand Prix

Source: <http://www.fiaformulae.com/>