2016

Prospects for Meeting the Corporate Average Fuel Economy Standards in the U.S.

Jessica Zielinski
University of New Haven

Rebecca Andreucci

Can B. Aktas
University of New Haven, caktas@newhaven.edu

Publisher Citation
Zielinski, J., Andreucci, R., & Aktas, C. B. (2016). Prospects for Meeting the Corporate Average Fuel Economy Standards in the US. Procedia Engineering, 145, 460-467.

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 145 (2016) 460 – 467

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Prospects for Meeting the Corporate Average Fuel Economy Standards in the U.S.

Jessica Zielinski [a,*], Rebecca Andreucci [a], Can B. Aktas [a]

[a] University of New Haven, Department of Civil and Environmental Engineering, 300 Boston Post Rd., West Haven 06516, CT, USA

Abstract

In 2013, the transportation sector accounted for 34% of the United States' greenhouse gas emissions, with no significant change from prior years. Efforts to improve vehicle transportation efficiency and curb associated environmental emissions had led to the Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks initially introduced in 1975. The National Highway Traffic Safety Administration has phased in new standards recently that require an average combined fleet-wide fuel economy of 35.1 - 35.4 mpg by 2017, 40.3 - 41.0 mpg by 2021, and 48.7 - 49.7 mpg by 2025. The new legislation has the potential to reduce overall U.S. emissions by close to 6% should the 2025 goals be attained. To reach these targets, compliance levels set to begin in 2017 will require a fine to be paid for every 0.1 mpg a manufacturer's fleet average is below the compliance target. The goal of this study was to assess the potential for CAFE to achieve the desired average fleet fuel economy goals set forth in the U.S., and evaluate its past effectiveness at reducing actual on-road fuel consumption. The possibility of the 2017-2025 CAFE standards to be more or less successful than the 2011-2016 standards at meeting fuel economy goals were evaluated together with strategies that auto manufacturers would most likely use to meet the 2017 - 2025 CAFE standards. The study analyzed past transportation efficiency trends and future projection models, and explored the industry and consumer-side impacts of the CAFE standard within the proposed timeframe. The possibility of automakers adapting to presented changes quickly to meet the increasingly strict CAFE standards and keeping up with improving the average fleet fuel economy seem difficult at best. While the effectiveness of allowances and credits similar to a cap and trade mechanism has prevented a major shortfall between CAFE standards and average fleet fuel economy to date, it is likely that most manufacturers will not be able to adapt in time to avoid facing fines moving into the future.

Peer-review under responsibility of the organizing committee of ICSDEC 2016

Keywords: CAFE; fuel economy; vehicle transportation efficiency

* Corresponding author.
E-mail address: jziel1@unh.newhaven.edu

Peer-review under responsibility of the organizing committee of ICSDEC 2016
doi:10.1016/j.proeng.2016.04.018

1. Introduction

The National Highway Traffic Safety Administration (NHTSA) will begin enforcing updated standards based upon the preexisting CAFE requirements in 2017. These standards require an average combined fleet-wide fuel economy of 40.3 - 41.0 miles per gallon (mpg) by 2021 and 48.7 - 49.7 mpg by 2025. These new guidelines update those presented in the 1975 Energy Policy and Conservation Act; the first attempt in the U.S. at encouraging increased fuel economy and reduced dependence on foreign energy supply. Within the decade following the Act, fuel economy of passenger vehicles doubled between 1975 to 1984, while light truck fuel economy increased by 50% [1]. Still, the U.S. lags behind other developed countries in terms of average fuel economy. According to the United Nations Department of Economic and Social Affairs, in 2014 Europe had an average fleet-wide fuel economy of 50 mpg, China had 38 mpg, while the United States stood at 32 mpg [2]. Despite technological and legislative developments following the Energy Policy and Conservation Act, fuel economy in the United States has remained unchanged for the past 15 years [3].

According to EPA, the transportation sector was responsible for 27% of total emissions in 2013 [4]. Of the total energy used by the transportation sector, 58% was associated with light-duty vehicles [5]. Increased fuel economy will continue to be a necessary component in reaching the emissions goals that were agreed upon at the 2015 Paris Agreement to Combat Climate Change, where the U.S. has committed to greenhouse gas reductions of 26-28% from 2005 levels by year 2025 [6-7]. Making adjustments to increase average fleet fuel economy would be the primary way for automakers to avoid the high fines imposed by CAFE and contribute positively to the United States' carbon emissions goals.

The goal of this paper was to assess whether CAFE is an effective policy for meeting U.S. greenhouse gas emissions goals in comparison to other available policies. The past effectiveness of CAFE from 1975 until today at reducing actual on-road fuel use was evaluated, and the possibility of the 2017-2025 CAFE standards to be more or less successful than the 2011-2016 standards at meeting fuel use reduction goals were assessed. Also, strategies that auto manufacturers would most likely use to meet the 2017 - 2025 CAFE standards and their potential success in terms of actually meeting U.S. fuel use reduction goals were investigated.

2. Factors Influencing Total Fuel Consumption

There are a variety of variables influencing the fuel usage of passenger vehicles and light-duty trucks. These factors include vehicle size and weight, vehicle efficiency and performance, consumer driving behavior, vehicle purchasing behavior, fuel prices, fuel types and alternative fuel technology, differences between on-road fuel economy versus tested values, and methods used to track fuel use and emissions. Relationships between these listed factors and total fuel consumption are discussed in this section.

Vehicle Size and Weight: Weight and power have risen in vehicles across the globe, enough to counteract any improvements made in technological efficiency in the United States from the mid-1990s [8]. Still, U.S. cars and light trucks are ranked as being the heaviest of any nation. In other developed countries of Europe, Sweden was found to have the heaviest cars while Italy had the lightest--this is thought to be due to taxation and existing car policies in the respective countries [9].

Engine Efficiency and Performance: Engine efficiency has increased over the past several decades, insinuating that fuel economy should have seen improvements far higher than what has been observed. However, a simultaneous increase in vehicle size, weight, and power has counteracted any such performance improvements, as was mentioned previously [8].

Driving Behavior: It is important to understand the relationship between fuel prices and driving behavior. Consumers respond in a predictable way to higher fuel prices, by decreasing mostly the amount of unnecessary, as well as the most fuel-intense, miles they drive. However, the long-term impacts of an increase in fuel price are less straightforward, although more important to determine trends. For example, it is necessary to understand how fuel prices influence a multi-car family's decision on which car to drive, and how those increased fuel prices influence car manufacturers in developing more fuel-efficient vehicles [8]. A study focusing on the European Union (EU) market identified that increased fuel prices were more effective at reducing fuel use than incentive programs for fuel-efficient cars [10].

Purchasing Behavior: Regarding the relationship between fuel prices and a consumer's car buying decision, recent studies indicate that consumers place more value on increased power rather than increased fuel efficiency. From an economic perspective, in the U.S., 2014's best-selling compact and midsize vehicle models with increased fuel economy were found to have a benefit-cost ratio of 0.72, a value less than 1.0, which does not incentivize purchasing these vehicles economically. The benefit-cost ratios reach 1.0 when annual driving distance was greater than 16,400 miles, or when fuel prices exceed $5.60 per gallon [11].

Differences Between Actual On-Road Fleet Fuel Economy and Test Values: Real world fuel economy, often referred to as "adjusted fuel economy" is lower than the values reported by the EPA [11]. Some real-world factors affecting the adjusted fuel economy would be congestion, aggressive driving behavior, and in-car accessory use, making a 35 mpg EPA rated vehicle test values be closer to 29 mpg on the actual road [8].

Fuel Types and Alternative Technology: Automakers can take advantage of flex fuels such as ethanol to receive credits under the CAFE requirements. The additional costs of adding flex fuel capabilities onto a vehicle is estimated to be around $100-$200 per vehicle [12-13]. A 2015 study by Chen and Huang found that ethanol biofuel from biowastes as opposed to corn could produce about 900 million gallons of fuel per year at a cost of $1.85/gallon in the near term (2015) and $1.10 in the midterm (2015-2025) [14]. Hybrid electric vehicles offer significant fuel efficiency improvements as well. As of 2011, plug-in hybrids (PHEV) consumed 72% less liquid fuel than a conventional car, while full hybrids consumed 30% less liquid fuel than conventional vehicles [15]. Hydrogen fuel powered vehicles also offer an alternative, however pose the challenge of significant effort needed to adapt the current gasoline infrastructure for hydrogen use [16].

3. History of CAFE

CAFE standards were enacted in the U.S. in 1975 through the Energy Policy and Conservation Act in response to the 1973-1974 oil crisis as a way to reduce oil imports [17]. The standards required new passenger vehicles to meet minimum fuel economy levels. Following the first phase of CAFE standards in 1975, the standards remained unchanged for nearly 20 years. While the first phase of the standard achieved a significant increase in average fleet fuel economy between mid-1970's and mid-1980's, from 18 mpg to 27.5 mpg for cars, actual sales-weighted fuel economy of new vehicles slipped down due to light trucks (which have a lower standard than cars) becoming an increasingly larger share of the market of vehicles sold [13, 17]. CAFE standards were altered in 2007, and then again in 2009. In 2007, the standards were significantly increased by legislation calling for a 40% increase in car and light truck standards phased in over a 9-year period beginning in 2011. In 2009, the Obama administration advanced the compliance timeline from 2020 to 2016 [13].

Compliance is measured by calculating a sales-weighted average of the fuel economies of an entire manufacturer's product line. It is worth noting the difference between fuel economy and fuel efficiency--while fuel economy represents a mpg value, fuel efficiency is calculated by dividing the mpg value by weight or power [3]. Initially, the penalty was $5 for every 0.1 mpg below the standard, multiplied by the number of cars sold by the manufacturer in that given year. This penalty was later increased to $5.50 in 1997 [13]. Between 1983 and 2002, total penalties accrued were slightly more than $600 million, paid largely in part by small and specialty car manufacturers [18]. CAFE civil penalties have been deposited in a U.S. Treasury fund that supports rulemaking efforts as well as research and development and retooling for fuel efficiency increases [18].

Initially, CAFE standards had a large influence on the way cars and light trucks were manufactured. Cars became smaller and lighter, while being powered by smaller engines, leading to an increase in fuel economy during the 1970s and 1980s [13]. Through the late 1980s, power and weight of vehicles increased, reducing any previous advances in fuel economy. These characteristics continued to rise through the 1990s and 2000s [13, 17]. This illustrates that initially the strategy for compliance with CAFE standards was to downsize vehicles. Whether automakers will use the same strategy with the updated CAFE standards, or choose an alternate option as discussed later in this paper, or a combination of several options is still largely unknown.

The second set of CAFE standards established with the Energy Independence and Security Act of 2007 were phased-in in 2011 with the ultimate goal of reaching 35 mpg by 2020, which was later advanced to 2016. A significant difference between the two sets of CAFE standards were that greenhouse gas emissions were made part of the regulation, leading to EPA co-involvement in CAFE regulations [19]. Other significant modifications in the standard were the use of the vehicle footprint as the basis of determining target fuel economy, and the allowance of tradable credits within and among manufacturing firms, both across car and light truck fleets, as well as forward and backward over model years. The intended goal of the former was to prevent major vehicle downsizing by manufacturers as some studies indicate that smaller footprint cars could have reduced safety [13]. Other studies have challenged this relation between vehicle size and increased traffic fatalities [20]. The goal of the latter change was to reduce the cost of the new regulation, with studies placing the cost reduction between 7-16% [13, 21]. Costs would be reduced as a function of manufacturer's ability to apply CAFE compliance credits from one vehicle class to non-compliance in another class. Credits may also be bought and sold between manufacturers [18].

A more recent rule released by EPA and NHTSA is in regards to the period 2017-2021. While increases in the standards proposed for 2022-2025 have been discussed, they have not yet been stated in a final rule [22]. Similarly, President Obama has announced that past 2025, fleet wide economy would need to reach 58 mpg by around 2030 [23]. These standards are expected to double the current fleet-wide fuel economy by 2025 [24].

The question remains as to how automotive manufacturers will address the challenge of increasing fuel economy to meet the standard. More recent improvements in fuel economy have come from reductions in vehicle weight, friction and drag, engine downsizing, transmission upgrades, and growth of hybrid vehicle options [11]. Still, much of the improvements have been largely overshadowed and even undone by the growing popularity of SUVs and light trucks; in 1975, light truck sales were 19% of total sales, while in 1987 they were 28%, and in 2000 they were 46% [17]. It appears consumer-purchasing habits have been motivating the manufacture of relatively large, fuel inefficient vehicles, even while commercial delivery of fuel efficiency by the auto industry has realized industry compliance with CAFE standards. Between 2011 and 2014, the auto industry delivered a 10% increase in fleet-wide passenger car fuel economy, and 2014 model year auto sales showed a 45% sale rate for vehicles specifically exhibiting fuel-saving technologies [11]. Achieving greater fuel efficiency in a cost effective manner for significant CO_2 reductions is readily feasible, however market motivations in the recent past seem relatively weak for design changes resulting in meaningful fuel economy improvements across both passenger car and light truck fleets [17].

3.1. Comparison of CAFE with Fuel Efficiency in Other Developed Countries

As noted previously, the U.S. lags behind other several other countries in vehicle fuel efficiency. In the EU and Japan, a mix of voluntary agreements and proposed mandatory agreements have resulted not only in increased fuel efficiency but also smaller, lighter vehicles. In the 1990's, all 15 countries of the EU entered into a voluntary fuel efficiency agreement, resulting in much better efficiency gains than seen in the 1980's when mainly only Germany and France were engaging EU auto manufacturers in the area of fuel efficiency. As a result, fuel intensity in the EU began declining in the 1990's. In Japan, the 1990's Top Runners program eventually garnered decreases in fuel intensity by the early 2000's. In both Japan and the EU, it has been difficult to assess whether these gains were mainly a result of voluntary agreements and programs, or were affected by slowing economies, high fuel prices, and limited urban space [8]. With the global price of oil currently at around $30/barrel (down from more than $100/barrel in 2014) [25], it is in doubt whether fuel efficiency gains seen in the recent past may be maintained. Furthermore, with the U.S. lagging other countries in fuel efficiency, and continuing positive population growth in the U.S. and EU coupled with increased car-ownership in some EU countries, some question whether fuel economy increases will be able to attain global emissions reduction goals [8]. In light of these valid concerns, both the U.S. and other countries will need innovative solutions that may require more than solely the proposed fuel efficiency standards.

4. Problems with current CAFE standards for 2016 / 2025

4.1. Footprint based standards encourage manufacturers to increase vehicle size

There has been discussion that footprint-based standards will encourage automakers to increase their vehicle size, therefore avoiding the more strict regulations placed on smaller vehicles. Under the CAFE standards, vehicles have target fuel economies based on footprint, defined as the area between its four wheels. Automakers who sell mostly light-trucks and larger cars (with large footprints) will have to reach a lower average fuel economy than those automakers that sell predominantly small cars [23]. While the policy may seem counterintuitive and incentivizing manufacturers to produce larger cars, the goal of the policy was to avoid penalizing automakers that sell large SUVs and trucks, and avoiding vehicle downsizing, seen as jeopardizing passenger safety. However, the unintended consequence of the policy shift may be that it encourages manufacturers to create larger, less fuel-efficient vehicles. There is research that indicates that this is the case. Whitefoot and Skerlos (2012) studied simulations and found that firms would be incentivized to increase vehicle footprint size (to avoid meeting higher CAFE standards of smaller footprint vehicles) in all cases except when consumer preference for vehicle size is near its lower bound and when consumer preference for acceleration is near its upper bound. Firm options considered for the simulations were either to modify vehicle dimensions, add fuel saving technologies to the vehicle, or trade off vehicle performance for fuel economy. The study argued that the CAFE standards for vehicles produced between 2011 and 2016 creates an incentive to increase vehicle footprint as opposed to improving fuel economy due to the standard's use of vehicle footprint (wheelbase by track width) as the basis for fuel-economy targets. According to the simulations, there is a sales weighted average vehicle size increase of 2 - 32%, which undermines fuel economy gains by 1 - 4 mpg. As a result, CO_2 emissions from these vehicles are 5 - 15% higher [26].

4.2. Perceived Safety Concerns

While the NHTSA is trying to avoid vehicle downsizing due to safety concerns, there is little data suggesting that small vehicles are a less safe option. Ahmad and Greene (2005) argue that there is no causal relationship between average fuel economy and increased traffic fatalities. Their study found a negative relationship between average fuel economy of passenger cars and highway fatalities, in contrast to earlier studies suggesting a positive correlation between the two [27]. Although research may suggest otherwise, consumers continue to perceive smaller vehicles as less safe.

4.3. Incentivization challenges

Other concerns about the new CAFE ruling involve the methods used to incentivize manufacturers to meet the standards. More specifically, these concerns surround the ability of the non-compliance fees to encourage fuel economy improvements, the fairness to manufacturers producing predominantly small footprint vehicles, and whether it would be best to couple the CAFE standards with another financial incentive to coax manufacture and purchase of high fuel economy vehicles by way of gas tax, subsidies for fuel efficient cars, and taxes on inefficient cars. Car manufacturers have expressed concern about consumers not wanting to pay for fuel-efficient vehicles because of the desire to realize a return on investment more quickly than is allowed by relative increases in vehicle prices and fuel economy. However, Turrentine and Kurani (2007) found that consumers in general do not know when they have reached the return on investment point, and that most consumers base their decisions on perceived future cost savings on fuel with other incentives, such as being committed to lower resource consumption, reductions in greenhouse gas emissions through efficiency features, or other reasons. Other studies have shown that consumers will need to be further incentivized in order for more fuel-efficient vehicles to penetrate the market. Simmons et al. (2015) discuss that short-term uncertainty leads consumers away from purchasing fuel efficient vehicles. Comparing financial incentives against each other can be difficult, considering their differing impacts on the market. While gas taxes impact fleet-wide fuel use of all model years, CAFE affects only new vehicles falling into that particular model year. It is important to monitor fuel efficiency and gasoline use holistically, as consumers may offset newly increased fuel economy by driving more miles, offsetting any benefits expected from CAFE [13]. Similarly, it is important to examine how CAFE interacts with the complex market of new vehicles, and the resulting impact on used vehicle supply and demand.

5. Prospects of average fleet fuel economy to meet the 2016 and 2030 mandates

Review of pertinent CAFE documentation indicates that auto manufacturers are on track to meet the 2016 CAFE targets, continuing the success of the CAFE program in new vehicle emissions reductions. In fact, thanks to the tradability of CAFE credits and the ability to carry over credits through years, auto manufacturers have exceeded the standards posed thus far. Figure 1 presents the CAFE requirement for fleet economy together with average fuel economy performance in the U.S. between 1978-2014.

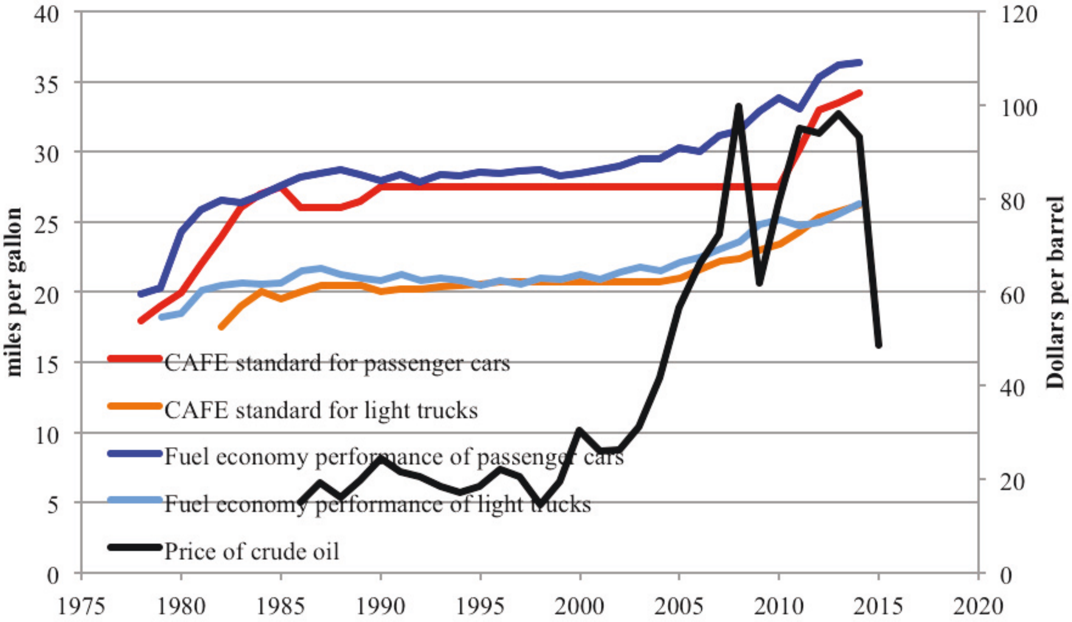

Fig. 1. CAFE requirement for fleet economy together with average fuel economy performance in the U.S. between 1978-2014. The price of crude oil has also been plotted for comparison. [29, 30]

However, past performance does not guarantee future success, especially if one considers that the target is set at around 49 mpg by 2025. This signifies that a fuel economy improvement of comparable magnitude must be achieved within half the time frame of past improvements. Looking forward beyond the 2016 standards, two initial challenges are recognized as manufacturers strive toward the incremental fuel efficiency goals laid out for 2017 - 2030. These challenges are determining:

1. Which methods to use for increasing the amount of models in compliance with future standards; and
2. How to attract automobile purchasers to the models that are already in compliance with future standards, given that about 5% of current models are compliant with the 2025 standards [11]. To achieve compliance with future standards, manufacturers are likely to consider a mix of business and marketing methods, such as vehicle pricing, as well as technological methods, such as reduction in vehicle weight and / or power, or engine and transmission efficiency improvements alongside or in place of such reductions [13].

As with the attainment of any other sizeable policy, achieving CAFE standards goals can be tracked as occurring in phases ranging from short, through medium, to long term. In the short term (annually), auto manufacturers can most readily adjust prices to elicit the desired outcomes. In the midterm (4 or 5 years), manufacturers may incorporate low cost design changes such as engine tuning, weight trimming, and small aerodynamic and friction improvements. These midterm changes increase fuel economy only slightly, but cumulatively have a worthwhile impact. Engine tuning may include such measures as gasoline direct injection, variable valve timing and switching from a 5 to a 6-speed transmission (or moving to a continuous variable transmission) [11, 13, 17]. Reductions in aerodynamic drag and friction go hand in hand with reducing vehicle size and weight [17, 23]. Between 1980 and 2000, vehicle drag coefficients decreased by about 2.5% per year while vehicle downsizing reduced frontal areas on many vehicles. Presently, aerodynamic drag reduction designs have reached a plateau. However, reductions in tire rolling resistance through the use of improved rubber compounds and tire design can also serve to improve efficiency as much as 4% added fuel economy for every 20% reduction in rolling resistance [17]. Decreasing the weight of a vehicle further reduces its rolling resistance [23]. The long term (10 years) encompasses the most costly, major improvements in fuel economy, such as power train redesign. Potential changes could include switching to hybrid technologies, cylinder deactivation measures, and integrated starter-generator systems [11, 13, 17, 23].

While several long term technologies are slated as available to apply towards meeting the CAFE standards, few if any are yet expected to be economically marketable to vehicle purchasers under the given projected fuel prices. To attract buyers to the appropriate sales mix of fuel efficiency these technologies can provide, manufacturers may have to rely more heavily on pricing strategies unless increases in fuel prices beyond what are expected serve to incentivize consumers [11]. In review of Greene's 1991 work, Klier and Linn (2011) found that many other studies corroborated Greene's finding that vehicle price manipulation was at the time a relatively expensive way to comply with CAFE standards, costing slightly more than the $100 to $200 per vehicle required for 1-mpg fuel economy increases. However, Simmons et. al. (2015) reported that the auto industry has likely been altering vehicle prices to aid in meeting recent CAFE standards, and that all costs being equal, the industry would rather sell volume at lower prices than pay fines. A study by An et. al. (2001) indicates that vehicles with moderate fuel economy gains (between 7 and 13 mpg) cost between $900 and $1500 more to produce, and if this total cost is passed on to consumers, annual fuel savings would result in a payback period between 3.4 and 5.9 years. To induce consumers to invest in such returns, price alterations appear to have become a common element of CAFE compliance tactics.

6. Challenges in rapid deployment of new vehicle technologies into the market

While many of the discussed technologies are promising in their ability to improve fuel efficiency and reduce greenhouse gas emissions, the reality is that it takes time for technology implementation in vehicle manufacturing. The process of engine redesign and switching to hybrid/electric powertrains are lengthy, taking as long as 4-8 years [11]. On the other hand, new financial and regulatory pressures imposed by CAFE could shift more focus of automakers towards redesign, and could accelerate the update cycle that is typically 4 years for an established model [31]. Minor improvements may be installed on a gradual basis for each model year, such as weight reductions, friction and drag improvements, and advanced transmissions; however, these improvements would not create significant shifts in fuel economy [23]. The time for consumers to embrace the new technology, such as in the case of plug-in electric vehicles, also needs to be taken into account. Consumer acceptance is expected to be slower when high upfront costs are required [23].

7. Summary

Together with its economic and societal significance, the transportation sector can be expected to receive further attention and undergo major shifts and changes in the coming years due to national goals set forth to reduce CO_2 emissions and other environmental impacts. The CAFE standard, although initially enacted in 1975, has been revised in recent years with higher fuel economy requirements set on automakers. The new legislation has the potential to reduce overall U.S. emissions by close to 6% should the 2025 goals be attained. However, the possibility of automakers adapting to presented changes quickly to meet the increasingly strict CAFE standards and keeping up with improving the average fleet fuel economy seem difficult at best. It is likely that most manufacturers will not be able to reduce weight, redesign engines, or completely switch to new hybrid/plug-in electric technology in time to avoid facing fines. The annually increasing requirements do not make the situation any more likely that they will succeed. However, the effectiveness of allowances and credits similar to a cap and trade mechanism has prevented a major shortfall between CAFE standards and average fleet fuel economy to date. Additional research is needed to determine the potential impact of alternative fuel vehicles in reaching the goals, along with other financial incentives such as a gas tax and peak pricing when coupled with CAFE.

References

[1] Greene, D. L. (1998). Why CAFE worked. *Energy Policy*, *26*(8), 595–613. http://doi.org/10.1016/S0301-4215(98)00016-0

[2] An, F., Earley, R., & Green-Weiskel, L. (2011). Global overview on fuel efficiency and motor vehicle emission standards: policy options and perspectives for international cooperation. *United Nations Department of Economic and Social Affairs*, (3). Retrieved from http://graenaorkan.is.w7.nethonnun.is/wp-content/uploads/2011/10/Background-paper3-transport1.pdf

[3] Schipper, L. (2007). Automobile Fuel; Economy and CO2 Emissions in Industrialized Countries: Troubling Trends through 2005/6. *Annual Meeting of the Transportation Research Board, World Resources Institute, Washington, DC, August*, 3–05. Retrieved from http://pdf.wri.org/automobile-fuel-economy-co2-industrialized-countries.pdf

[4] EPA. (2013). Sources of Greenhouse Gas Emissions - Transportation Sector Emissions. *United States Environmental Protection Agency, http://www3.epa.gov/climatechange/ghgemissions/sources/transportation.html*

[5] DOE. (2015). Transportation Energy Data Book: Edition 34-2015, Table 11.5: Transportation share of U.S. carbon dioxide emissions from fossil fuel consumption, Oak Ridge National Laboratory, Department of Energy, http://cta.ornl.gov/data/tedb34/Edition34_Chapter11.pdf

[6] White House, (2015a). U.S. Leadership and the Historic Paris Agreement to Combat Climate Change, Office of the Press Secretary, The White House, https://www.whitehouse.gov/the-press-office/2015/12/12/us-leadership-and-historic-paris-agreement-combat-climate-change

[7] White House, (2015b). FACT SHEET: U.S. Reports its 2025 Emissions Target to the UNFCCC, Office of the Press Secretary, The White House, https://www.whitehouse.gov/the-press-office/2015/03/31/fact-sheet-us-reports-its-2025-emissions-target-unfccc

[8] Schipper, L. (2011). Automobile use, fuel economy and CO2 emissions in industrialized countries: Encouraging trends through 2008? *Transport Policy*, *18*(2), 358–372. http://doi.org/10.1016/j.tranpol.2010.10.011

[9] Schipper L, Johnson F, Howarth R, Andersson BG, Andersson BE, Price L. (1993). Energy Use in Sweden: An International Perspective (LBL-33819). Berkeley, Calif. Lawrence Berkeley Laboratory.

[10] Ryan, L., Ferreira, S., Convery, F. (2009). The impact of fiscal and other measures on new passenger car sales and CO2 emissions intensity: evidence from Europe. Energy Economics 31 (3), 365–374.

[11] Simmons, R. a., Shaver, G. M., Tyner, W. E., & Garimella, S. V. (2015). A benefit-cost assessment of new vehicle technologies and fuel economy in the U.S. market. *Applied Energy*, *157*, 1–13. http://doi.org/10.1016/j.apenergy.2015.01.068

[12] Anderson, S.T., Sallee, J.M. (2011). Using loopholes to reveal the marginal cost of regulation: the case of fuel-economy standards. *American Economic Review.* In press.

[13] Klier, T., & Linn, J. (2011). Corporate Average Fuel Economy Standards and the Market for New Vehicles. *Annual Review of Resource*

[14] Chen, C.-W., & Huang, Y. (2015). Handbook of Bioenergy: Bioenergy Supply Chain - Models and Applications. In D. S. Eksioglu, S. Rebennack, & M. P. Pardalos (Eds.), (pp. 67–84). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-20092-7_3

[15] Atabani, A. E., Badruddin, I. A., Mekhilef, S., & Silitonga, A. S. (2011). A review on global fuel economy standards, labels and technologies in the transportation sector. *Renewable and Sustainable Energy Reviews*, *15*(9), 4586–4610. http://doi.org/10.1016/j.rser.2011.07.092

[16] Romm, J. (2006). The car and fuel of the future. *Energy Policy*, *34*(17), 2609–2614. http://doi.org/10.1016/j.enpol.2005.06.025

[17] An, F., & DeCicco, J. (2001). Assessing the Fuel Economy Potential of Light-Duty Vehicles. *Fuel Cells and Alternative Fuels/energy Systems*, 9–21.

[18] Yacobucci, B. D., & Bamberger, R. (2008). Automobile and Light Truck Fuel Economy: The CAFE Standards. *Congressional Research Service*, 18.

[19] Yacobucci, B. D. (2010). EPA and NHTSA: the new auto greenhouse gas and CAFE standards. Presented at "After the Perfect Storm: Competitive Forces Shaping the Auto Industry," Detroit, MI, May 11. http://www.chicagofed.org/digital_assets/others/events/2010/automotive_perfect_storm/2010_ Detroit_autoconference_Yacobucci.pdf

[20] Ahmad, S., & Greene, D. (2005). Effect of Fuel Economy on Automobile Safety: A Reexamination. *Transportation Research Record*, *1941*(1), 1–7. http://doi.org/10.3141/1941-01

[21] Rubin, J., Leiby, P. N., & Greene, D. L. (2009). Tradable fuel economy credits: Competition and oligopoly. *Journal of Environmental Economics and Management*, *58*(3), 315–328. http://doi.org/DOI 10.1016/j.jeem.2009.05.002

[22] EPA (2012). 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards. *Federal Register*, *77*(199), 577.

[23] Cheah, L., & Heywood, J. (2011). Meeting U.S. passenger vehicle fuel economy standards in 2016 and beyond. *Energy Policy*, *39*(1), 454–466. http://doi.org/10.1016/j.enpol.2010.10.027

[24] Al-Alawi, B. M., & Bradley, T. H. (2014). Analysis of corporate average fuel economy regulation compliance scenarios inclusive of plug in hybrid vehicles. *Applied Energy*, *113*, 1323–1337. http://doi.org/10.1016/j.apenergy.2013.08.081

[25] EIA. (2016). Data Highlights. *United States Energy Information Administration, http://www.eia.gov.*

[26] Whitefoot, K. S., & Skerlos, S. J. (2012). Design incentives to increase vehicle size created from the U.S. footprint-based fuel economy standards. *Energy Policy*, *41*, 402–411. http://doi.org/10.1016/j.enpol.2011.10.062

[27] Crandall, R.W., Graham, J.D. (1989). The effect of fuel economy on automobile safety. *Journal of Law and Economics. 32*(1):97–118.

[28] Turrentine, T. S., & Kurani, K. S. (2007). Car buyers and fuel economy? *Energy Policy*, *35*(2), 1213–1223. http://doi.org/10.1016/j.enpol.2006.03.005

[29] NHTSA (2014). Summary of Fuel Economy Performance, U.S. Department of Transportation NHTSA NVS-220, Washington DC.

[30] EIA (2016). Spot Prices for Crude Oil, Petroleum and Other Liquids, U.S. Energy Information Administration, https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm

[31] Hill, K., Edwards, M., Szakaly, S. (2007). How automakers plan their products: a primer for policymakers on automotive industry business planning, Economics and Business Group, Center for Automotive Research.