Putting Policy in Drive: Coordinating Measures to Reduce Fuel Use and Greenhouse Gas Emissions from U.S. Light-Duty Vehicles

by

Christopher W. Evans

B.Sc. Mechanical Engineering
University Manitoba, 2004

Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Technology and Policy

at the

Massachusetts Institute of Technology

June 2008

Signature of Author..
Technology and Policy Program, Engineering Systems Division
May 9, 2008

Certified by ....
John B. Heywood
Sun Jae Professor of Mechanical Engineering
Director, Sloan Automotive Laboratory
Thesis Supervisor

Accepted by ....
Dava J. Newman
Professor of Aeronautics and Astronautics and Engineering Systems
Director, Technology and Policy Program

Putting Policy in Drive: Coordinating Measures to Reduce Fuel Use and Greenhouse Gas Emissions from U.S. Light-Duty Vehicles

by

Christopher W. Evans

Submitted to the Engineering Systems Division on May 9, 2008
in Partial Fulfillment of the Requirements for
the Degree of Master of Science in Technology and Policy

Abstract

The challenges of energy security and climate change have prompted efforts to reduce fuel use and greenhouse gas emissions in light-duty vehicles within the United States. Failures in the market for lower rates of fuel consumption necessitate government involvement. But efforts have been weakened by a controversial regulatory system, and the need for perverse incentives that have contributed to a slight increase in the average rate of light-duty vehicle fuel consumption alongside a 70% increase in vehicle travel relative to the mid-80's.

This research evaluates the role of fiscal policies in overcoming barriers to reducing fuel use and greenhouse gas emissions in U.S. light-duty vehicles. It conducts a survey of fiscal policies and their implementation internationally. A model of the U.S. light-duty vehicle fleet is used to assess a fuel tax in comparison to—and in coordination with—the recently legislated Corporate Average Fuel Economy (CAFE) standard legislated by the Energy Independence and Security Act. Engineering cost estimates of technology improvements and vehicle powertrains are used to evaluate the costs and benefits of a technology penetration scenario that approximates the new CAFE standard.

Alongside CAFE, fiscal options can achieve reductions more effectively by: (i) acting on a broader range of stakeholders; (ii) influencing behavioral responses as well as technological changes; and (iii) by sending price signals across multiple stages of vehicle purchase, operation, and retirement. Using illustrative scenarios, the report demonstrates that fiscal policies align consumer demand for lower rates of fuel consumption with the requirements that CAFE imposes on manufacturers. The costs of reducing fuel consumption are estimated to be 8 to 20% of the baseline cost if fuel consumption remained unchanged from today, corresponding to retail price increases of $1,500 to $4,500 for the average vehicle between 2020 and 2035. These significant costs are largely offset by fuel savings benefits within 2 to 4 years relative to no change.

Thesis Supervisor: John B. Heywood
Title: Sun Jae Professor of Mechanical Engineering
Director, Sloan Automotive Laboratory
Director, MIT-Ford Alliance Program
Co-director, Center for 21st Century Energy

Acknowledgements

This thesis is dedicated in loving memory to my father, Bill Evans.

I would especially like to thank my supervisor, Professor John Heywood of the Sloan Automotive Laboratory for his guidance and encouragement. Besides being an excellent supervisor, Professor Heywood has taught me about the qualities of mentoring and leadership that can inspire excellence in people.

I am incredibly thankful of—and deeply indebted to—the great people that I have had the chance to work with in the Sloan Laboratory. Anup Bandivadekar, Lynette Cheah, Matt Kromer, Kristian Bodek, Tiffany Groode, Emmanuel Kasseris, Don Mackenzie, Jeff McAulay, Irene Berry, and Mal Weiss. Thanks especially to Don for his thorough and thoughtful review of this report. The opportunity to work with this group of exceptional people has been the most fulfilling experience that I will take from M.I.T. Others at the Sloan Lab, Karla Stryker, Nancy Cook, Janet Maslow, and Thane DeWitt deserve many thanks as well.

I would also like to thank those in the Technology and Policy Program who have been a great source of support and inspiration. Sydney Miller in particular deserves a heap of praise for her great work in the program; Yoko Urano, Shane Selleck, and Ed Ballo as well. The friendships I have formed with the incredible students who make this program the fantastic place it is have been invaluable.

Finally, thanks to my family and loved ones: Marns, Mom, and Christine, in particular, but many others as well back home in Winnipeg and elsewhere.

This research project was funded by Ford Motor Company through the Alliance for Global Sustainability, CONCAWE, ENI, Shell, and Environmental Defense. Many thanks to these sponsors and their representatives for the support and feedback provided for this project.

Table of Contents

1.0 Introduction

1.1 Motivation

In 2005, a reporter for the *Chicago Tribune* named Paul Salopek arrived at a Marathon gas station in South Elgin, Illinois—a small town on the outskirts of Chicago's encroaching suburbs. Here, he met with station owner Michelle Vargo, a single mother trying to make a life out of a $2,000 per month income. Despite her stretched budget, Vargo is her own best customer: she spends a third of her take-home pay on gas. Between 11-hour shifts at the station, writes Salopek (2006, p. 9):

> Vargo drives to work in a car she can't afford. It is a white Chevrolet Suburban that churns out a ruinous 10 miles per gallon and rides so high off the street she has to boost herself into the driver's seat as if jumping into a saddle. Her two-hour commute, about 40 miles each way [...] is roughly double the national average.
>
> 'I don't feel safe in small cars,' Vargo said defensively, refueling one day at the pump.

It's a fair question whether Michelle Vargo would be better off today if Senator Richard Bryan had had his way 15 years earlier. In 1990, Senator Bryan tabled a bill that proposed a 40% increase in the number of miles that new cars would get on a gallon of gasoline by 2001. The bill would have achieved this by raising Corporate Average Fuel Economy, or CAFE standards, a policy lever enacted in 1975 that established fuel economy targets for new passenger cars sold in the United States. Non-passenger vehicles, termed "light trucks" were later regulated as well. In introducing his bill, Senator Bryan's goal was to sustain a striking trend initiated in the late 70's and early 80's, when the average fuel economy of new passenger cars doubled in ten years.

But times had changed by 1990. Public interest in fuel economy waned alongside declining fuel prices through the late 80's. At the same time, in response to Bryan's Bill, a strong lobbying effort on the part of automotive manufacturers and labor unions organized to stop Congress from mandating further increases to fuel economy standards. In the end, these powerful interests prevailed: the bill failed to pass the Senate, and passenger car fuel economy standards remained unchanged for the next 17 years.

The Bryan Bill was a polarizing event that shed light on the political battlefield around fuel economy regulations. Environmentalists and politicians supported reductions in greenhouse gas (GHG) emissions and shifts away from dependence on foreign-sourced oil. The New York Times editorialized the Bill as an oasis in a “Sahara of leadership” that would “slash America's dependence on foreign oil, trim the trade deficit, roll back smog and avert global warming” (New York Times, 1990). On the other side, automotive makers and labor unions opposed stringent CAFE requirements, arguing that they mandated the production of less-safe vehicle types that consumers didn’t want to buy (Hanna, 1990). A majority of consumers—perhaps even a young Michelle Vargo—found themselves somewhere in the middle, desiring a mix of safe and reliable vehicles that could meet their varied preferences for performance, size, and fuel consumption at a reasonable price.

More fundamentally, the failure of the Bryan Bill highlighted questions about the usefulness of CAFE as a way of improving the fuel economy of vehicles: Was it the most effective policy measure for achieving the goals of reducing GHG emissions and petroleum imports in the U.S.? Why did automakers and labor unions so vehemently resist the proposed increases in fuel economy? If fuel economy was so important, why did there seem to be an unrelenting demand from consumers like Michelle Vargo for bigger, faster, stronger? And, in the face of powerful private opposition and weak public interest in the issue, were policymakers at the mercy of concentrated automotive and labor interests?

In 2007, rising fuel prices and concerns over the growth in GHG emissions from transportation spurned the first increase in CAFE standards in two decades. But the same questions raised back in 1990 persist today. History suggests that aggressive increases in CAFE can improve fuel economy in the short-term, but as high prices subside it is questionable whether the standards can maintain a strong push for continued improvements. Since CAFE was frozen in 1987, the average new vehicle has roughly doubled its horsepower and is nearly a third heavier. Rather than channeling efficiency improvements into better fuel economy, technology has been used to provide larger, higher performance vehicles. If vehicle performance and weight had remained constant at 1987 levels, fuel economy could have been increased by more than 20 percent in new 2007 vehicles—up from today’s 25 miles per gallon to more than 30; instead it has stood still (Bandivadekar, 2008, pp. 67-69).

What's needed is a second look at how CAFE operates, and consideration of the options available to complement and improve its effectiveness. A number of policy options exist that may enhance the ability of fuel economy regulations in achieving sustained improvements over the long-term. The debate between policy-makers and automotive executives has fixated on how high to raise the standards, but unless the underlying weaknesses of CAFE are addressed, we may be doomed to repeat the past. And if we do, what will Americans like Michelle Vargo be driving 20 years from now?

1.2 Research question

The goal of this report is to outline a rationale for the use of coordinated policy measures alongside CAFE as a means of reducing fuel use and GHG emissions from light-duty vehicles. It seeks to address two primary research questions:

1. How do different policy measures to reduce fuel use and GHG emissions interact with Corporate Average Fuel Economy (CAFE) standards?
2. Can a set of coordinated measures reduce fuel use and GHG emissions more effectively than CAFE alone?

To approach the first question, policy options available for reducing fuel use and GHG emissions from light-duty vehicles in the U.S. are surveyed. Implementation of these policies in countries around the world is assessed to determine the extent to which measures are being coordinated and the impact that these policies have had on fuel use and GHG emissions from light-duty vehicles. Historical trends in vehicle attributes including weight, size, horsepower, and acceleration are analyzed to assess how the implementation of policies may impact light-duty vehicles.

To address the second question, policy packages are constructed to illustrate how policy measures might be coordinated to complement the role of CAFE in improving vehicle fuel consumption. Technology and cost assessments are integrated within a model of the U.S. light-duty vehicle fleet to produce illustrative estimates of the cost of reducing fuel use and GHG emissions. Policy packages are then illustrated in the vehicle model to quantitatively assess how coordinated measures alongside CAFE may achieve reductions in fuel use and GHG emissions more effectively.

1.3 Report overview

Chapter 2 outlines the rationale for reducing GHG emissions and fuel use in the U.S. light duty vehicle fleet. It establishes the need for government regulation in the market for fuel consumption, and identifies challenges that CAFE has faced as a sole instrument for saving fuel in light-duty vehicles. The chapter finds that there is need to study additional policy interventions alongside CAFE that can improve its effectiveness.

Chapter 3 briefly discusses the methodology of this report, focusing primarily on the details of a U.S. light-duty fleet model developed in the Sloan Automotive Laboratory at MIT. The model is used in Chapter 5 to illustrate the impacts of policy instruments.

Chapter 4 presents a survey of policy measures that could be used to cut GHG emissions and fuel use in light duty vehicles. The chapter draws on experience that regions and countries around the world have had with these instruments. Where available, historical data, results from vehicle technology assessments, and cost estimates are used to quantitatively support the analysis of international policy approaches.

Chapter 5 develops several policy cases to illustrate the behavior of a CAFE regulatory mandate relative to a fuel tax policy that increases the cost of private vehicle travel. The packages are then coordinated to show the complementary effects from reducing vehicle travel while aligning consumer demand with manufacturer's regulated targets. The production costs and changes in vehicle retail price of an aggressive reduction target are evaluated, and the role that feebates could play in subsidizing the required technology changes is identified. Sensitive parameters in the analysis are varied to check for robustness in the modeling approach.

Chapter 6 concludes by detailing the role that fiscal policy approaches can play alongside CAFE. Areas for further study are briefly explored.

2.0 The challenge

This chapter outlines the challenge of reducing fuel use and GHG emissions from light-duty vehicles in three parts: first, it explains why these reductions are important; second, it establishes the case for government intervention in achieving these reductions; and third, it explores the challenges facing government intervention. The purpose of this chapter is to outline key areas where the current policy framework faces barriers. Later chapters will elaborate on how coordinated policy measures might help to address these challenges.

2.1 The need to reduce fuel use and greenhouse gas emissions

More than any country in the world, Americans are reliant upon the automobile as a means of mobility. There are now over 800 light-duty vehicles[1] per 1,000 people in the U.S. amounting to 240 million cars and light trucks on the road. In 2005, Americans drove a total of 2.75 trillion kilometers in cars and light trucks alone—nearly a 25% increase from a decade earlier (S. C. Davis & Diegel, 2007, pp. 4-2, 4-3, Tables 4.1 and 4.2). With increasing rates of vehicle ownership and travel, the demand for fuel has grown in near-lockstep: between 1995 and 2005, light-duty vehicle fuel consumption increased by 21%, from 448 to 543 billion liters (EIA, 1998, 2008a).

The tight relationship between private vehicle travel and energy consumption has generated concern for two reasons. First, volatility and imperfections in the global market for petroleum impose sudden shocks and elevated oil prices on consumers and industry. The economic costs of U.S. dependence upon oil imports between 1970 and 2005 have been estimated at 30% of 2006 U.S. gross domestic product (Greene & Ahmad, 2005). Light-duty vehicle fuel consumption accounts for roughly 40% of total U.S. petroleum use. At the same time, crude oil and refined petroleum imports from other countries contribute to 66% of total U.S. petroleum consumption (EIA, 2007; Tables 1.2, 1.3, & 1.4). Reducing the large share of petroleum consumed by light-duty vehicles will help insulate the U.S. from costs imposed by imperfections and volatility in the price of oil.

[1] Light-duty vehicles are comprised of cars, light trucks (including minivans and sport utility vehicles).

Second, it is very likely[2] that GHG emissions from human sources have contributed to most of the increase in global average temperatures since the mid-20th century (IPCC, 2007; WG I, SPM, p. 10). Warming induced by human-made emissions will have impacts in the form of hundreds of millions of people exposed to water stress, increased damage from floods and storms, variation in ecosystems and cereal production, and increased burdens from malnutrition and diseases (IPCC, 2007; WG II, SPM, p. 16). Transportation accounts for one-third of U.S. GHG emissions, of which light-duty vehicles comprise 62%, or 1,178 million metric tons of CO_2 (322 million metric tons carbon) (DeCicco, Fung, & Scrafford, 2007, p. i). Reductions in U.S. GHG emissions on the order of 60 to 80% by 2050—if accompanied by commensurate actions from major emitters around the world—are believed to be necessary in order to stabilize GHG concentrations below dangerous levels. Cost-effective reductions in GHG emissions from cars and light trucks will play an important role in meeting these stringent targets.

2.2 Failures in the market for fuel economy

Reducing fuel use and GHG emissions from light-duty vehicles is necessary, but is there a need for government intervention to address this challenge? This is a controversial issue. Proponents of government intervention argue that failures in the market for fuel economy promote higher rates of vehicle fuel consumption than if the market operated efficiently. If these failures do exist, then social welfare can be improved when government regulation result in rates of fuel consumption that are closer to the efficient level for society.

Three specific failures are often identified in the market for fuel economy as a rationale for government intervention (Portney, Parry, Gruenspecht, & Harrington, 2003). First, imperfect competition and price volatility in the global oil market impose economic costs that are not taken into account by individual consumers of petroleum imports. Second, there are externalities associated with GHG emissions produced in the consumption of gasoline and diesel fuel that are not fully accounted for by consumers in the U.S.. Finally, there are imperfections in the private vehicle market that cause

[2] Greater than 90% certainty.

producers and consumers to undervalue the benefits of improving fuel economy. Each is addressed here in turn.

2.2.1 Global oil market failures impose costs on the U.S. economy

The global oil market does not operate perfectly due to the concentrated market power of the Organization of Petroleum Exporting Countries (OPEC). OPEC is able to exploit its large share of global oil exports to raise the price of oil above the perfectly competitive level. Volatile swings in the price of oil create shocks that can impose economic costs on consumers of petroleum products. The National Research Council has estimated the costs of oil market imperfections at $5 per barrel of oil, or 12 cents per gallon of gasoline (National Research Council, 2002, p. 86).

2.2.2 External costs of fuel use are not accounted for by consumers

Transportation fuels, such as gasoline, generate GHG emissions that will impose costs on society through the impacts of global climate change. These costs are currently not reflected in the price of gasoline in the U.S. Estimates of the magnitude of his externality vary widely. In a 2002 review of CAFE standards, the NRC assumed a external cost of $50 per metric ton of carbon emissions ($14 / ton CO_2), which corresponds to a fuel tax increase of 12 cents per gallon (National Research Council, 2002, p. 85). Damages from emissions are expected to rise over time, and efforts to quantify the full range of impacts associated with climate change are still subject to large uncertainties.

Other transportation externalities, such as traffic congestion, accidents, and local air pollution are estimated to be larger than the costs of GHG emissions. Parry (2005) found that these externalities were individually three to six times as large as the external costs of GHG emissions (see Table 10 in Section 4.4). These external costs are related to vehicle distance traveled, rather than the amount of fuel consumed over a given distance.

Although regulating the rate of fuel consumption in vehicles is one way of reducing the external costs of GHG emissions, incorporating the damages into the price of fuel or into the price of vehicle travel is a more cost-effective approach (Austin & Dinan, 2005; Kleit, 2004; Parry, 2006). To the extent that lower fuel consumption promotes increased vehicle travel, the benefits of regulation may be offset to some degree by increases in congestion, accidents, and local air pollution as a result of these external costs not being accounted for in the price of travel.

2.2.3 Consumers and producers undervalue fuel economy benefits

Without high fuel prices or increases in CAFE standards, technology improvements in light-duty vehicles have been used to provide vehicles that are much more powerful and slightly larger in size. Cheah et al. note that if this were to continue (2007, p. 8),

> ...the average new car in 2035 could potentially boast 320 horsepower and a 0-to-60 mph acceleration time of 6.2 seconds, outperforming today's BMW Z4 Roadster. It is questionable whether this level of performance is necessary, or even safe for the average driver on regular roads, regardless of whether the future consumer truly wants or expects this.

Is the assertion that consumers demand more power than is good for them valid? Why would consumers *undervalue* the benefits of reducing fuel consumption relative to improving other vehicle attributes such as performance and size? This is a controversial issue within the CAFE debate, but there are at least three clear reasons that suggest consumers may value fuel consumption less than the socially optimal level.

First, the ability of consumers to correctly assess the benefits of lower fuel consumption has been hotly debated (Austin & Dinan, 2005, p. 568; Gerard & Lave, 2003; Kleit, 2004; Nivola & Crandall, 1995). Even so, there is evidence of imperfect information failures in the market. Up until recently, fuel economy displayed on vehicles deviated by roughly 20% from what the vehicle could actually achieve on-road (Wald, 2006), and there may still exist a shortfall. Even with a realistic accounting of the fuel savings *benefit*, it may be difficult for consumers to separate the extra *cost* attributable to improved fuel economy across a mix of vehicles with varying attributes (Greene, 1998, p. 598).

There is also evidence of a failure of collective action in the fuel economy market. While the collective benefits of improved fuel economy are substantial, each single consumer has a negligible incentive to consider vehicles with even large improvements in fuel economy. Greene estimates that this incentive is as small as $100 for a cars over a range of 30 to 40 miles per gallon (i.e. up to a 2.0 L / 100 km reduction in fuel consumption) (Greene, 1998, p. 597). When faced with higher retail prices for vehicles with improved rates of fuel consumption, consumers are inclined to select vehicles with lower up-front costs over lower operating costs (Gerard & Lave, 2003, p. 12).

Finally, even those who argue that consumers value fuel consumption efficiently agree that consumers implicitly discount future benefits at rates that are higher than the societal discount rate (Kleit, 2004). Private consumers are therefore less willing to pay for future benefits from reduced fuel consumption (Gerard & Lave, 2003). The impact of discounting on fuel savings is shown in Table 1 below. If consumers place a high discount rate on the value of future fuel savings, the period of time required for technologies to recoup their initial price increase can exceed the average 15-year lifetime of a vehicle.

Table 1: Retail price increase, fuel consumption benefit, and payback period of today's turbocharged gasoline, diesel, and hybrid vehicles. Discount rate (r) is varried from 0% to 20%. Retail price values are taken from Section 5.2.1, Table 19; fuel consumption values taken from Table 20. Assumes fuel price of $2.50 per gallon (incl. federal, state and local taxes) and 240,000 km travel over 15 years of vehicle life. (ICE = Internal combustion engine; Turbo. Gasoline = Turbo-charged gasoline engine).

TECHNOLOGY	RETAIL PRICE INCREASE	BENEFIT	PAYBACK PERIOD [years]				
	[$2007]	[Δ L/100km]	r = 0%	5%	10%	15%	20%
Gasoline ICE	$0	Baseline	--	--	--	--	--
Turbo. Gasoline	$700	0.95	2	2	2	3	3
Diesel	$1,700	1.45	3	4	5	6	10
Hybrid	$4,900	2.69	6	8	14	>15	>15

On the supply side, manufacturers may also face inadequate incentives for investing in fuel economy improvements. If the benefits of developing new technologies spill-over to other competing firms, research and development for fuel economy will be under-provided by private automakers (Parry, 2006, p. 7). Additionally, it has been suggested that oligopolistic nature of the automotive industry may incentivize risk aversion to increasing fuel economy, in that "the biggest manufacturers can observe what competitors do and choose to lead, follow, or stand pat, up to a point" (Greene, 1998, p. 599).

Taken together, these three market failures provide a persuasive rationale for intervention in the market for fuel consumption. Government intervention offers a clear societal benefit of reducing the externalities associated with fuel use. At the same time, the value of the improvements in power and size above today's levels that would be forgone by reducing fuel consumption are small relative to the societal benefits, depending on the extent to which private consumers undervalue fuel consumption benefits. On a broader level, recent volatility in the price of oil and the consensus that reductions in GHG emissions are necessary have renewed public interest in reducing petroleum consumption in U.S. light-duty vehicles. Given these strong economic, political, and societal drivers, further government intervention in the market for fuel economy is both important and inevitable in the future.

2.3 Failures in the regulation of fuel economy

Given that government intervention in the market for fuel consumption is warranted, the question becomes: how *should* the government intervene? In the U.S. policy-makers have used Corporate Average Fuel Economy Standards (CAFE), which mandate reductions in the average fuel consumption of new vehicles. While CAFE has been effective in regulating fuel economy, two issues have challenged its effectiveness in reducing fuel use and GHG emissions in light-duty vehicles. First, CAFE is not designed to address the full range of opportunities outside of vehicle fuel consumption that are available for reducing fuel use and GHG emissions. Second, in order to placate the concerns of auto manufacturers, policy-makers have had to include concessions that have weakened the overall effectiveness of CAFE in improving fuel consumption in a sustained fashion (CBO, 2002, pp. 14-15).

2.3.1 CAFE is not able to address the full range of opportunities available

Bandivadekar (2008, p. 15) notes that fleet fuel use and GHG emissions are a function of the efficiency of driving (expressed in liters of fuel consumed per kilometer of travel) and the total amount of driving. CAFE is designed to improve the rate of fuel consumption in new vehicles, but it does not address ways of improving the efficiency of travel through driver behavior, is it able to influence the amount of vehicle travel demanded by consumers.

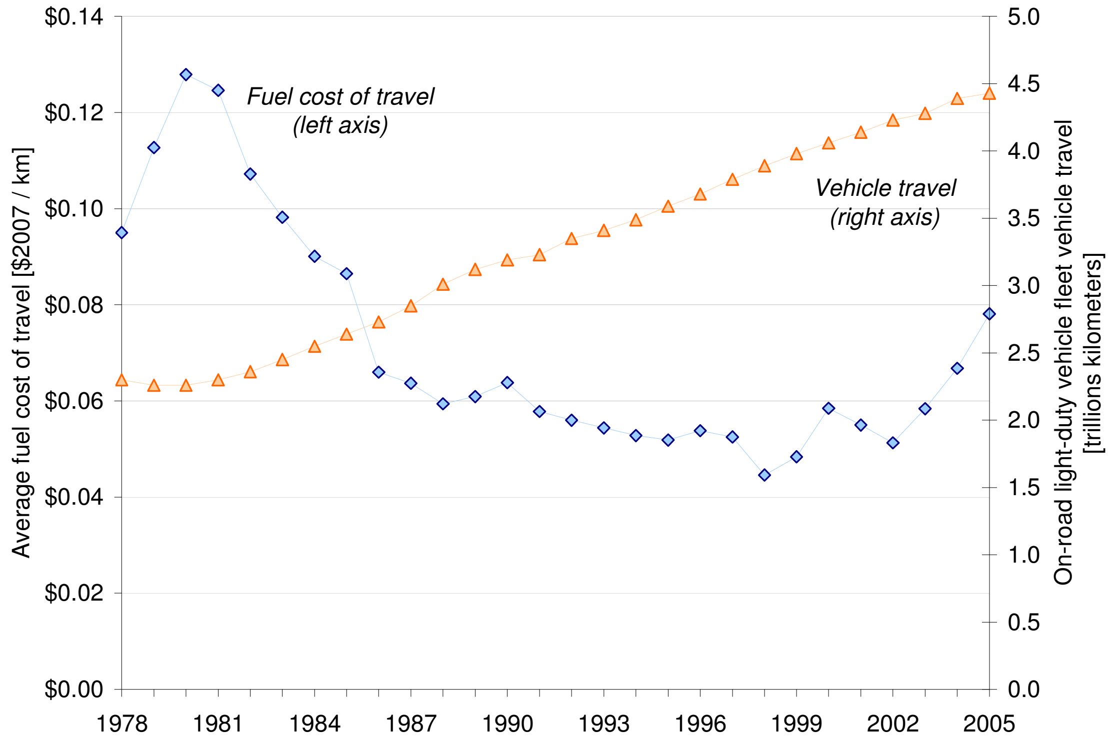


Figure 1: Average fuel cost of travel from 1978 - 2005[3]. Adapted from average on-road light-duty vehicle fuel consumption [L / 100 km] and average retail price across all types of motor gasoline [$ / L]. (S. C. Davis & Diegel, 2007; fuel consumption and vehicle travel from Tables 4.1, 4.2; motor gasoline price from Table 10.4)

Annual vehicle travel grew by roughly 2.5% per year between 1980 and 2005 (S. C. Davis & Diegel, 2007; Tables 4.1, 4.2) as a result of both increasing sales of new vehicles, and growth in the number of annual kilometers traveled per driver. Additionally, CAFE creates a small incentive for consumers to drive further each year—a phenomenon known as the *rebound effect*. The fuel cost of travel (P_t, in dollars per kilometer) is the cost of fuel required to drive a vehicle a certain distance. It is calculated from the price of fuel (P_f, in dollars per liter) and the on-road fuel consumption (E, in liters per kilometer) of a vehicle (Small & Dender, 2005, p. 2):

$$P_t = P_f \times E \qquad \text{Fuel cost of travel} \qquad \text{-- (2.1)}$$

[3] Note that the fuel cost of travel does not account for other variable costs such as oil, tires, and maintenance, nor does it include fixed costs such as registration fees or insurance premiums.

As gasoline prices have remained low over the 1990's, and CAFE requirements have gradually dropped the average fuel consumption of on-road vehicles, the cost of the fuel required to drive a vehicle a certain distance has dropped compared to what it was twenty years ago (Nivola & Crandall, 1995, pp. 7-8). Over the same time, the annual amount of vehicle travel from light-duty vehicles has steadily climbed (Figure 1).

CAFE is by no means a primary reason for this growth in travel—population and income growth, an increased reliance upon private transportation, and lower fuel prices have likely had the largest effect (EIA, 2008b). The critical issue however, is that CAFE cannot address the growth in vehicle travel that has occurred over the last twenty years, even though yet high rates of growth in private vehicle travel have made it more difficult to achieve absolute reductions in fuel use and GHG emissions. Alongside CAFE, other policies which are able to influence the growth in vehicle travel may have an important role to play.

2.3.2 Perverse incentives have lessened CAFE's effectiveness

CAFE was created to correct failures in the market for fuel economy, but its effectiveness has been limited by the need to address the concerns of concentrated political interests, namely auto manufacturers and labor unions. These concerns have resulted in provisions that have benefited domestic manufacturers while perversely offsetting some of the reductions in fuel use and GHG emissions from light duty vehicles[4].

One perverse effect was the distinction created between passenger cars and light trucks. Although Congress established fuel economy standards for passenger cars[5] in 1975, it delegated responsibility to the National Highway Traffic Safety Administration (NHTSA) for setting standards for non-passenger vehicles. In 1978, NHTSA implemented a separate light truck class with a lower fuel economy standard. The gap that was created between the car and light truck standards generated an incentive for automakers to stretch the definition of "light trucks" as broadly as possible in order to

[4] For a detailed discussion of these political failures, see MacKenzie et al. (2005).
[5] A passenger car is defined as "an automobile…manufactured primarily for transporting not more than 10 individuals, but does not include an automobile capable of off-highway operation" (49 U.S.C. 32901(a)(16)).

take advantage of the lower fuel economy requirement in this class of vehicles. The resulting growth in light truck market share is telling: sales of light trucks increased from two out of every ten vehicles to over half of all sales between 1975 and 2005[6].

A second well-known provision is the "dual-fuel loophole". Under the system, dual-fuel vehicles that run on different blends of alternative fuels[7] with gasoline or diesel are rated at a higher fuel economy to reflect their use of non-petroleum substitute fuels. The extra fuel economy provided by these vehicles can be credited against a manufacturer's CAFE requirement up to a maximum of 1.2 mpg. Although the stated purpose of the policy was to stimulate demand for alternative fuels, a 2002 Department of Transportation report found that "the vast majority of dual-fuel vehicles rarely operate on alternative fuel"[8] (Department of Transportation, 2002, p. xiii). In effect, auto manufacturers have recieved substantial fuel economy credits for vehicles that had no impact on reducing fuel consumption.

The Energy Independence and Security Act of 2007 has taken steps to address both of these issues. It has prescribed a combined average fuel economy standard across both cars and light trucks, removing the incentive to broadly classify vehicles as trucks. It has also set a timeline for abolition of the duel-fuel incentive, with a gradual phase-out of flexible fuel credits between 2015 and 2020 (EISA, 2007 H.R.6 § 109).

Despite their perverse effects on petroleum consumption, these provisions have served a purpose within the regulatory structure of CAFE. They have effectively softened the regulatory blow placed upon auto manufacturers—predominantly U.S. manufacturers, who have the highest share of light truck sales out of the twelve largest automobile manufacturers in the world and up until 2005 were the only companies using dual-fuel credits against their CAFE compliance[9] (DeCicco, Fung, & Scrafford, 2007, p. 31).

---

[6] Auto manufacturers have also exploited the fact that larger light trucks weighing between 8,500 and 10,000 lbs (3,860 to 4,540 kg) are not subject to the CAFE standards. It is difficult to quantify to what extent the market share of these vehicles has grown, as information on their sales and fuel economy of these vehicles is not collected by federal agencies. It is assumed that this has also had a perverse effect by encouraging manufacturers to sell greater numbers of these heavier vehicles (DeCicco, Fung, & Scrafford, 2007, p. vi).

[7] Defined in the bill as methanol, ethanol or natural gas.

[8] The report states that dual-fuel vehicles were run on gasoline blends of 85% ethanol "somewhat less than 1%" of the time (Department of Transportation, 2002, p. 40).

[9] In 2005, Nissan was the first foreign manufacturer to use CAFE credits from sales of its dual-fuel Titan pickup (DeCicco, Fung, & Scrafford, 2007, p. 28).

Moving forward, policies will need to find some way of addressing the regulatory burden placed upon manufacturers. Ideally, policy approaches would align the interests of manufacturers with the goals of reducing fuel use and GHG emissions from vehicles, rather than providing loopholes that weaken progress towards them.

2.4 Summary and discussion

This chapter has explored the challenges associated with the need to reduce fuel use and GHG emissions, the complex interactions among stakeholders in the system, and the failures in the market for reduced fuel consumption and in policy interventions to correct these failures. The key findings from this chapter are summarized by Table 2.

Table 2: Barriers to reducing fuel use and GHG emissions in light-duty vehicles

POLICY GOAL	STAKEHOLDER GROUP		
	CONSUMERS	INDUSTRY	POLICY-MAKERS
Reduce vehicle fuel consumption	Individuals value fuel consumption less than other vehicle attributes. Individual benefits of fuel consumption can be small relative to up-front cost.	Automakers are hesitant to reduce fuel consumption without clear, consistent demand from consumers.	To support domestic manufacturers and win support for regulation, perverse incentives have lessened CAFE's regulatory burden at the expense of fuel savings.
Reduce annual vehicle travel	External costs related to the amount of vehicle travel, such as congestion and accidents, are not fully accounted for in price of vehicle travel.	CAFE standards impact new vehicle fuel consumption only; they are not meant to address the goal of reducing vehicle travel.	Increasing the cost of vehicle travel is politically unpopular; it affects the public broadly, and may be regressive if revenue is not redistributed.

From this review, the following conclusions are drawn:

- Cost-effective reductions in the fuel use and GHG emissions from light-duty vehicles will be important in addressing energy security and global climate change concerns.
- Government intervention in the market for fuel consumption is justified by costs imposed by global oil market imperfections, externalities that are not

reflected in the price of transportation fuels, and evidence of a collective action failure in the market for fuel consumption.

- Even though government intervention is warranted, CAFE forms an incomplete approach to reducing fuel use and GHG emissions from light-duty vehicles.
    - Growth in vehicle travel, and externalities that are independent of vehicle fuel consumption—such as air pollution, congestion, and accidents—are also important issues to address in a comprehensive policy approach.
    - In order to win support among stakeholders, CAFE has used perverse incentives, rather than aligning the interests of consumers and automakers with the goal of reducing fuel use and GHG emissions.
- These challenges provide a strong rationale for examining the role of other policy instruments in improving the effectiveness of CAFE in achieving long-term, sustained reductions in fuel use and GHG emissions.

3.0 Methodology

This chapter summarizes the methods used to assess the role of policy options in reducing fuel use and GHG emissions from light-duty vehicles. Two separate approaches were applied:

1. A qualitative survey of policy options and their real-world application; and
2. An illustrative analysis of the impact of fuel tax and CAFE policy options on new vehicle fuel consumption, annual vehicle travel, fuel use, greenhouse gas emissions, and cost using a model of the U.S. light-duty vehicle fleet.

The qualitative survey of policy options is provided in Chapter 4. This chapter focuses on the structure of the light-duty vehicle model used to analyze the impact of policy options on future fuel use and GHG emissions from cars and light trucks in the United States. The methodology used for modeling the affect of a fuel tax policy on light-duty vehicles is covered in Section 3.2

3.1 Structure of the light-duty fleet model

This section provides a brief overview of the light-duty vehicle model used to evaluate the policy cases developed in Chapter 5. The model is an Excel-based spreadsheet that extrapolates future fuel use and GHG emissions from cars and light trucks in the United States based assumed rates of fleet growth and energy use. The structure of the model is shown in Figure 2. A detailed description can be found in Bandivadekar et al., 2008.

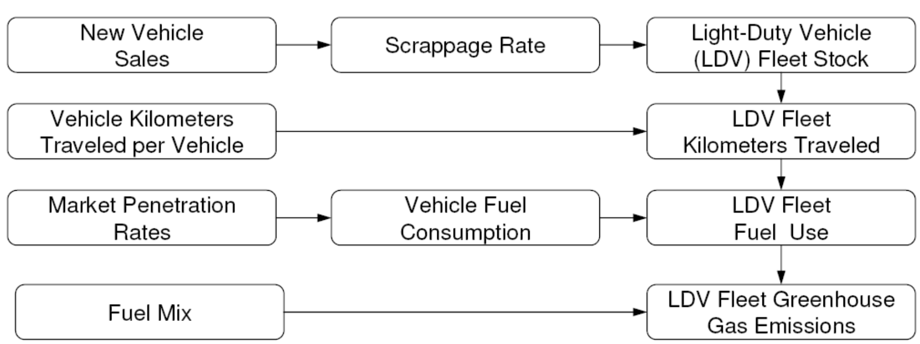


Figure 2: Structure of the light-duty vehicle fleet model. Adapted from Bandivadekar, 2008.

The model is calibrated using the Transportation Energy Data Book (TEDB), which compiles data from the Federal Highway Administration's Highway Statistics publication. Key assumptions are shown in Table 3.

Table 3: Light-duty vehicle fleet model assumptions (Bandivadekar, 2008)

ASSUMPTION	CARS	LIGHT TRUCKS
New Vehicle Sales		
Sales growth	0.8% per year	
Share of new sales that are light trucks	55%	
Scrappage Rate		
Median lifetime (years)	16.9	15.5
Growth parameter (β)	0.28	0.22
Vehicle Kilometers Traveled (VKT)		
Starting VKT for 2000 model year	27,000 km	27,770 km
Degradation rate	4%	5%
Annual growth in individual vehicle travel	0.5% (2005 to 2020) 0.25% (2020 to 2030) 0.1% (2030 to 2035	
On-road Vehicle Fuel Consumption		
Adjustment factor	22%	
Baseline Fuel Mix (by volume, constant from 2005 to 2035)		
Share of corn ethanol	3%	
Share of cellulosic ethanol	0.2%	
Share of oil from oil sands	3%	

The model uses TEDB data for calculating fleet growth, which includes all light-duty vehicles weighing less than 10,000 lbs (4,540 kg). It is assumed that light-duty vehicle sales grow by 0.8%, and the market share of light trucks is kept constant at 55% of new vehicle sales. The survival rate of new vehicles is determined by:

$$Surival\ Rate = 1 - \frac{1}{\alpha + e^{-\beta(t - t_o)}} \quad \text{Vehicle survival rate} \qquad \text{-- (3.1)}$$

Where t_0 is the median lifetime of the vehicle in a given model year; t is the age of the vehicle in a given year, β is a growth parameter that describes how quickly vehicles retire around the median lifetime, and α is a model parameter set to 1. These assumptions are consistent with Bandivadekar, 2008.

Estimates of vehicle kilometer travel were drawn from historical growth rates between 1971 to 2005. Future rates of growth in vehicle travel are assumed to decrease, starting from a rate of 0.5% per year between 2005 to 2020, declining to 0.25% per year from 2020 to 2030, and to 0.1% per year from 2030 to 2035. Per-vehicle kilometers traveled are calculated from starting values of 27,000 km for cars and 27,770 km for light trucks in the 2000 model year. After the first year of travel, annual per-vehicle kilometers decrease by 4% per year for cars, and by 5% per year for light trucks.

Light-duty vehicle fuel consumption is based on EPA fuel consumption data, which does not include fuel economy credits for dual-fuel vehicles. Test cycle data is converted to on-road fuel consumption using an adjustment factor of 22% to account for the shortfall between test results and the actual on-road fuel consumption of vehicles. Fuel use is calculated for each vehicle type (gasoline spark-ignition, diesel, turbocharged gasoline, hybrid, and plug-in hybrid) by multiplying the fuel consumption by the vehicle travel in a given calendar year for vehicles of a given age. Total fuel use across the light-duty fleet is calculated by summing the fuel use of all ages of vehicles for a given calendar year across all vehicle types.

Table 4: Well-to-wheel (WTW) GHG intensity of transportation fuels (Bandivadekar et al., 2008)

FUEL	WTW GHG INTENSITY [g CO_2 per MJ]
Conventional gasoline	92
Conventional diesel	94
Gasoline from oil sands	109
Ethanol from corn	77
Ethanol from cellulose	9
Electricity	214

GHG emissions are calculated on a well-to-wheel (WTW) basis, which includes upstream emissions produced in the extraction, refining, and transportation of fuels (well-to-tank) as well as emissions from combustion during vehicle operation (tank-to-wheels). Emission factors of various transportation fuels are shown in Table 4. Material cycle emissions are also included, which are the emissions generated from producing the materials embodied in vehicles. Material cycle energy use and GHG emissions are shown in Table 5 for current and future vehicle types.

Table 5: Material cycle energy use and GHG emissions for different vehicle types (Bandivadekar et al., 2008)

VEHICLE TYPE	CARS Energy [GJ / vehicle]	CARS GHG [$MtCO_2e$ / vehicle]	LIGHT TRUCKS Energy [GJ / vehicle]	LIGHT TRUCKS GHG [$MtCO_2e$ / vehicle]
Current Gasoline	96.9	7.7	124.6	10.0
Current Diesel	95.9	7.7	134.3	10.8
Current Turbo	99.0	8.0	128.4	10.4
Current Hybrid	113.6	9.1	144.2	11.6
2035 Gasoline	114.9	9.3	159.3	12.9
2035 Diesel	113.7	9.2	159.3	12.8
2035 Turbo	117.4	9.5	152.2	12.3
2035 Hybrid	134.7	10.8	171.0	13.8
2035 Plug-in	137.8	11.1	174.9	14.1

3.2 Fuel tax policy analysis

This section reviews the methodology used to model the fuel tax policy scenarios developed in Section 5.1.2. Two separate responses to increased fuel prices were modeled:

1. The reduction in vehicle travel (km) relative to an increase in the fuel cost of travel (in $ / km); and
2. The increased demand for lower rates of new vehicle fuel consumption (L / 100 km) in response to an increase in the price of fuel (in $ / liter).

These responses were modeled using estimates of the elasticity of demand for vehicle travel and fuel consumption, given by the following:

$$\varepsilon_{travel,Pt} = \frac{\%\ change\ in\ vehicle\ travel\ (T)}{\%\ change\ in\ fuel\ cost\ of\ travel\ (P_t)} = \frac{\frac{dT}{T}}{\frac{d(P_t)}{P_t}} \quad \text{-- (3.2)}$$

$$\varepsilon_{FC,Pf} = \frac{\%\ change\ in\ fuel\ consumption\ (FC)}{\%\ change\ in\ fuel\ price\ (P_f)} = \frac{\frac{d(FC)}{FC}}{\frac{d(P_f)}{P_f}} \quad \text{-- (3.3)}$$

Where $\varepsilon_{travel,Pt}$ is the elasticity of the demand for vehicle travel with respect to changes in the fuel cost of travel, and $\varepsilon_{FC,Pf}$ is the elasticity of the demand for vehicle fuel consumption with respect to changes in the price of fuel. From these relations, the vehicle travel and fuel consumption under a change in fuel price can be calculated as follows:

$$T = T_O \left(\frac{P_t}{P_{tO}} \right)^{\varepsilon_{travel,Pt}} \quad \text{-- (3.4)}$$

$$FC = FC_O \left(\frac{P_f}{P_{fO}} \right)^{\varepsilon_{FC,Pf}} \quad \text{-- (3.5)}$$

Where T_o and FC_o denote starting values of vehicle travel and fuel consumption, and P_{to} and P_{fo} are starting values for fuel cost of travel and fuel price. These expressions define iso-elastic (constant elasticity) demand curves in a given calendar year for vehicle travel and fuel consumption relative to changes in the fuel cost of travel and fuel price. Knowing the starting values for vehicle travel, fuel consumption and the price of fuel, the starting fuel cost of travel can be calculated from equation 2.1. Using equation 3.5, the fuel consumption for a given year can be calculated based on the assumed price elasticity of fuel consumption and the change in fuel price. With this fuel consumption, the fuel cost of travel for a given year can then be calculated. Inserting the fuel cost of travel into equation 3.4 yields the amount of vehicle travel in a given calendar year.

These equations were used to model the changes in new vehicle fuel consumption and vehicle travel under the fuel tax policy cases developed in Section 5.1.2. The assumed values for each of the elasticity values are discussed in Section 4.4. The sensitivity of the results to these elasticity assumptions and starting fuel price is further investigated in Section 5.3.

4.0 Assessment of policy measures

Chapter 4 provides a survey of the relevant literature and real-world experience—both in the U.S. and internationally—of different policy measures that reduce fuel consumption in light-duty vehicles. Recent reviews encompassing a broad range of options and policy instruments have been conducted by Schafer and Greene (2003), Bandivadekar (2006), and Gallagher et al. (2007). Rather than attempt an exhaustive review of policy options, this survey focuses on the role of several fiscal policy options: differentiated vehicle taxes, feebates, fuel tax increases, pay as you drive systems, and scrappage incentives, alongside vehicle standard regulations.

The goal of this chapter is to provide a qualitative assessment of the features of each policy option and its real-world implementation. A summary is provided of the goal, the targeted stakeholders, and key advantages and disadvantages of each option. Broader conclusions about the suitability of a coordinated set of policy options alongside a CAFE regulatory standard are discussed.

4.1 Vehicle standards (fuel consumption standards)

Vehicle standards are requirements that government entities place on the fuel consumption or GHG emissions of manufacturers' vehicle fleets. The effect of these standards is to regulate the fuel consumption of vehicles produced by manufacturers. Indirectly, vehicle standards impact consumers by requiring manufacturers to offer product mixes and pricing strategies that put a greater emphasis on reduced fuel consumption than purchasers might otherwise demand (Kleit, 1990; Nivola & Crandall, 1995, pp. 28-30).

The advantage of mandatory vehicle standards is that they can have an immediate and binding effect upon vehicle fuel consumption and GHG emissions. Strategies that manufacturers adopt to meet these targets will depend upon the magnitude and timeframe of the required changes:

1. When faced with a binding standard over the short term, manufacturers can *mix-shift*, or sell vehicles with a low rate of fuel consumption at a discount

while raising the price of high-consuming models. This is an expensive approach for reductions in fuel consumption beyond 3 to 5% (Greene, 1991; Kleit, 1990).

2. If manufacturers have enough lead-time to consider the impact of regulation in planning their product mix, they can introduce technology improvements that allow engines and other components to be downsized, enabling reductions in fuel consumption (NRC, 2002, p. 5). Over a shorter time-frame, manufacturers may choose to reduce the size or power of existing vehicles in favor of achieving lower rates of fuel consumption.
3. Manufacturers may also simply opt to pay fines to the government in order to exceed the regulated standards. In the U.S., several European manufacturers of high-performance luxury vehicles have consistently paid fees in place of meeting CAFE requirements (NHTSA, 2007).
4. Finally, if vehicle standards include provisions for banking, borrowing, or trading, manufacturers can accumulate credits for use against their target.

In the U.S., vehicle fuel consumption is regulated by Corporate Average Fuel Economy (CAFE) Standards. These standards were enacted in 1975 as part of the Energy Policy and Conservation Act, and initially required manufacturers to meet an average fuel consumption of no more than 8.55 L / 100 km (or at least 27.5 mpg) in passenger automobiles[10] by the 1985 model year. The Secretary of Transportation was delegated responsibility for establishing standards for the "maximum feasible fuel economy level" for non-passenger automobiles, or light trucks. The first light truck standard was established in 1979.

---

[10] The CAFE statute defines "automobile" (encompassing both passenger cars and non-passenger vehicles) as "a 4-wheeled vehicle that is propelled by fuel, or by alternative fuel, manufactured primarily for use on public streets, roads, and highways (except a vehicle operated only on a rail line), and rated at not more than 6,000 pounds gross vehicle weight (GVW)" [U.S.C 49 § 32901 (a) (3)], although the Secretary of Transportation was delegated authority to include of automobiles up to 10,000 pounds GVW if feasible and warranted. In 1980, this was subsequently extended by the Secretary to include automobiles between 6,000 and 8,500 pounds GWV (NHTSA, 2006a, p. p. 20).

"Passenger automobile" is defined by the CAFE statute as an automobile that the Secretary decides by regulation is manufactured primarily for transporting not more than 10 individuals", but not including automobiles with "a significant feature (except 4-wheel drive) designed for off-highway operation", and 4-wheel drive automobiles rated at more than 6,000 gross vehicle weight (GVW) [U.S.C 49 § 32901 (a) (16)].

For the past 20 years, CAFE standards have remained unchanged for passenger cars. The Secretary delegated responsibility for light truck standards to the National Highway Traffic Safety Administration (NHSTA), which continued to set light truck standards until funds for further improvements in the standards were restricted by Congress in 1996 (Figure 3).

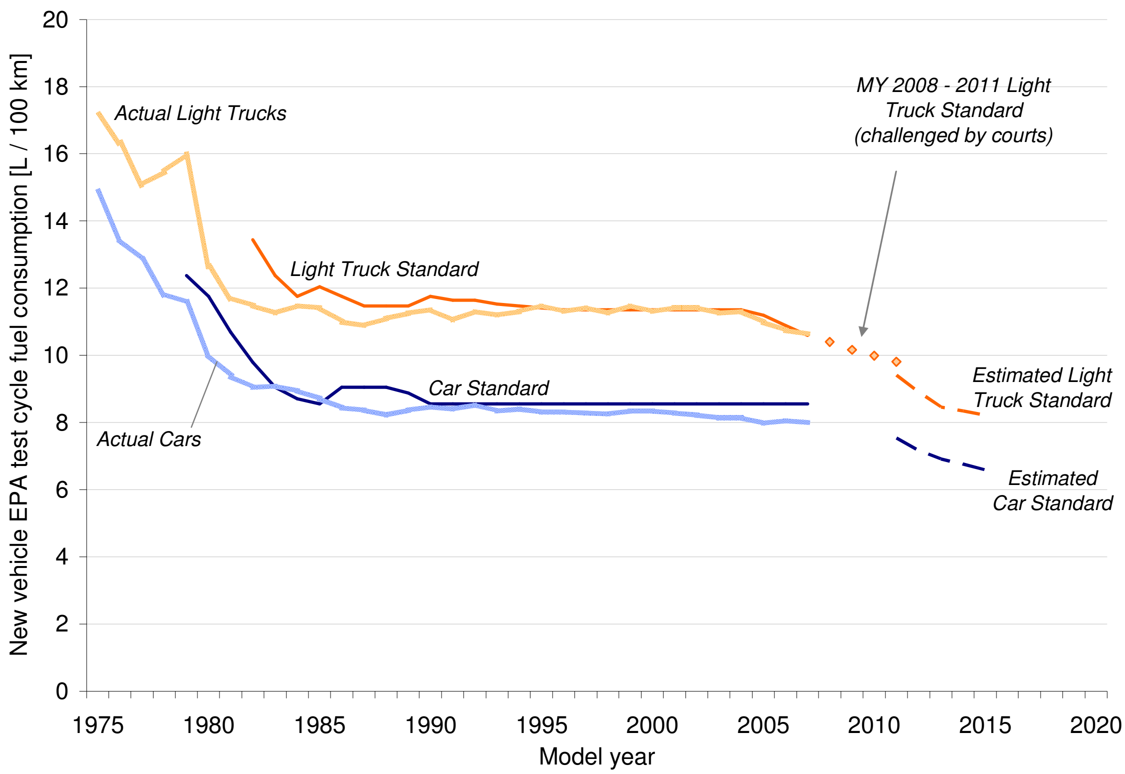


Figure 3: New car and light truck fuel consumption and CAFE standards (S. C. Davis & Diegel, 2007, pp. 4-18, 14-19; EPA, 2007b, pp. 8-9; NHTSA, 2006a, pp. VI-7, 2008, p. 14)

After the restriction was lifted, NHSTA prescribed light truck standards for model years (MY) 2005 to 2007, and a separate rule three years later for MY 2008 to 2011. The new MY 2008 to 2011 standards were normalized according to a light truck's "footprint"—the area obtained by multiplying a vehicles' wheelbase by its track width. The footprint method was designed to improve safety by removing the option of downsizing vehicles as means of meeting CAFE, and to prevent manufacturers from categorizing large passenger vehicles as small light trucks (NHTSA, 2006a, p. 10).

On November 16, 2007 the Ninth Circuit Court of Appeals handed back NHTSA's light truck rulemaking, arguing that it did not go far enough in regulating light trucks (U.S. Court of Appeals for the Ninth Circuit, 2007). One month later, the 2007

U.S. Energy Independence and Security Act (EISA) increased CAFE standards to a combined average of 6.72 L / 100 km (35 mpg) for cars and light trucks in the U.S. by 2020 (The White House, 2007). The Act effectively supersedes NHTSA's previous rulemaking for MY 2008 to 2011 light trucks.

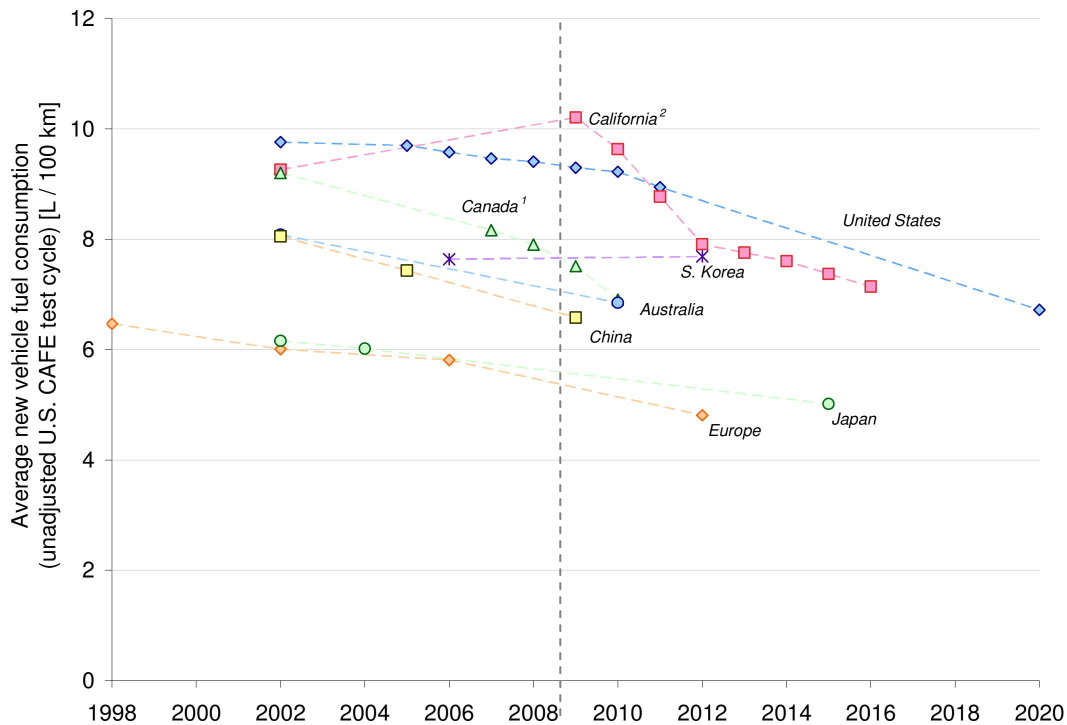
In April 2008, NHTSA proposed standards for cars and light trucks from MY 2011 to 2015 to comply with the EISA. The standards are size-based, measured according to vehicle footprint. The estimated fuel consumption levels of the proposed rulemaking for cars and light trucks are shown by Figure 3. NHTSA's proposed standard "front-loads" the reductions in fuel consumption needed to meet the 2020 target. Between 2011 and 2015, the average annual fuel consumption improvement is roughly 3.3%; at this rate, the annual improvement between 2015 to 2020 must average 2.1% (NHTSA, 2008, pp. 11-16).

The EISA legislation also introduced a credit trading program as part of the CAFE regulations. Manufacturers that exceed the fuel economy standard for a given model year may earn credits that can be sold to those who fail to meet the requirements, provided that all manufacturers comply with a specified minimum standard for cars. Automakers may also transfer credits within their own fleets between cars that are made domestically, cars made non-domestically, and light trucks. For internal trading, credits may be used up to a limit that gradually becomes more lenient from 2011 to 2020[11]. It is believed that these measures will grant auto manufacturers more flexibility in determining how to achieve CAFE requirements within the mix of products that they offer to consumers.

Internationally, vehicle standards around the world differ from one another in their design and implementation. Currently, nine different governmental entities enforce vehicle standards (ICCT, 2007). Figure 4 shows global vehicle standard targets normalized to the test drive cycle used to determine fuel consumption levels for CAFE in the U.S.[12]

[11] Credits may be used to achieve no more than one mile per gallon of fuel economy compliance between 2011 and 2013. This limit is relaxed to 1.5 miles per gallon between 2014 and 2017, and to 2 miles per gallon in 2018.
[12] For details on the procedure used to estimate equivalent CAFE fuel consumption from different drive cycles, see ICCT (2007, p. 28, Appendix).

California has passed legislation that would require vehicles to reduce CO_2-equivalent emissions by roughly 25% below the combined average for cars and light trucks in 2002, or 30% between 2009 to 2016 (California Air Resources Board, 2004; California Code of Regulations, 2005). Twelve states planned to adopt these regulations alongside California, but in December 2007, the EPA denied a waiver that would have allowed enforcement of these requirements; California is appealing the decision (EPA, 2007a; Office of the Governor. State of California, 2008).



[1] The standard shown for Canada is an estimate of the changes that will be required in new vehicle fuel consumption to meet the government's voluntary standard of a 5.3 megatonne CO2-equivalent reduction in light duty vehicle GHG emissions in 2010.

[2] The standard shown for California does not take into account non-fuel consumption related reductions that may also be used to meet the state's GHG emission regulation. If other non-fuel consumption reductions are pursued, ICCT (2007, p. 24, figure 6) estimates that the fuel consumption of new vehicles could be 30% higher, or 9.2 L / 100 km in 2016 and still satisfy the GHG reduction target.

Figure 4: Global vehicle standards (adapted from ICCT, 2007, pp. 23, 24)

Outside of the U.S., the European Commission has a voluntary agreement with European, Japanese, and Korean auto manufacturers to limit passenger vehicle CO_2 emissions to 140 g CO_2 / km (European Commission, 1999, 2000a, 2000b). In December, 2007 the European Commission proposed legislation that would require passenger cars in the European Union to meet a target of 130 g CO_2 / km emissions target on average across the new car fleet by 2012. The Commission's proposal would complement this target with an addition reduction of 10 gCO_2 / km, to be achieved through "efficiency improvements for car components…such as tires and air conditioning systems" [13]. The 130 g CO_2 standard by setting targets for individual vehicles based on their weight such that the fleet average meets the overall target (European Commission, 2007).

Japan set vehicle standards in 1999 to achieve a 23% improvement in the fleet average fuel economy from 1995 to 2010. By 2004, this goal was reached five years ahead of target[14] (Energy Conservation Center Japan, 2006, Chapter 2-4). In 2006, the Japanese government increased both the stringency of the standard and the drive cycle used to test the fuel consumption of vehicles, pledging to achieve an average of 16.8 kilometers per liter of fuel consumed in new passenger vehicles[15] (ICCT, 2007).

Canada has developed a voluntary agreement with the domestic auto industry to reduce GHG emissions from the on-road fleet of light duty vehicles by 5.3 CO_2-equivalent megatonnes by 2010[16] (Natural Resources Canada, 2005). The Government of Canada plans to regulate the fuel consumption of cars and light trucks starting in 2011 under the Motor Vehicle Fuel Consumption Standards Act. The act was passed in 1982, but was not enacted in favor of a voluntary Company Average Fuel Consumption program that has closely followed U.S. CAFE standards. In November 2007 the Government proclaimed the act into law and is beginning consultations with industry on fuel consumption regulations (Transport Canada, 2007b, 2008).

China, Australia, South Korea, and Taiwan have also established vehicle standard programs. China's standards were enacted in 1995, and a second, more stringent phase came into effect in 2008 (Sauer & Wellington, 2004). Australia has established a voluntary agreement to reduce average fuel consumption of the passenger vehicle fleet by 15 percent by 2010. South Korea's vehicle standards were made mandatory in 2004,

[13] The standard was estimated by ICCT (2007) to be equivalent to 4.8 liters per 100 kilometer (49 miles per gallon). The high fraction of diesel vehicles improves the fuel consumption of the European fleet relative to its CO_2 emissions

[14] Already in 2004, fuel economy had improved by 22%, essentially achieving the 2010 target five years ahead of schedule.

[15] This standard was estimated by ICCT (2007) to be equivalent to 5.0 L / 100 km (47 mpg) on the U.S. CAFE test cycle, or 125 gCO_2 / km on the European NEDC test cycle.

[16] The effect that this voluntary target will have on new vehicle fuel economy cannot be determined outright. ICCT (2007) has estimated new light duty vehicles will average 6.9 L / 100 km (34 mpg) on the U.S. CAFE test cycle, or 178 gCO_2 / km on the European NEDC test cycle by 2010.

establishing targets based on the engine displacement of vehicles. Perversely, the growing share of vehicles with larger engine displacements is expected to slightly increase the average fuel consumption of new passenger vehicles by 2012 (ICCT, 2007, p. 20). In 2007, South Korea announced its plans to lower its fuel consumption standard by 15% for cars by 2012 (Chosun Ilbo, 2007).

Based on this review of vehicle standards, the following observations are made:

- Vehicle standards have an immediate an binding effect on vehicle fuel consumption. In response, manufacturers may mix-shift, employ technologies that reduce fuel consumption, reduce the size or power of vehicles, pay fines, or apply credits against their obligations. These strategies will depend upon the magnitude and timeframe of the required changes as well as manufacturer's product mix.
- Internationally, there is a movement towards more stringent regulation of passenger vehicle fuel consumption and GHG emissions rates. The European Union, Canada, and South Korea plan to—or already have—enforce mandatory standards; while Japan and the U.S. have increased the stringency of their existing regulations.
- Attribute-based standards are increasingly favored as a means of specifying fuel consumption regulations. The U.S. has proposed a standard based on vehicle footprint, while the E.U. is considering weight-based regulations.

4.2 Differentiated vehicle taxes

Vehicle purchase and registration taxes are taxes that are scaled relative to specific attributes, such as fuel consumption, horsepower, engine displacement, fuel type, or retail price. Differentiated taxes are systems that adjust vehicle tax rates relative to attributes that affect emissions, providing consumers with price signals that can alter their purchase and vehicle use decisions.

The advantages of differentiated vehicle taxation systems are that they provide an ongoing incentive for manufacturers to reduce the tax burden that consumers may face through improvements in fuel consumption. They also stimulate changes in consumer purchase decisions and increase the demand for fuel-sipping vehicles. Administratively, differentiated taxation schemes offer a relatively straight-forward and low-cost means of providing incentives to reduce fuel consumption. Differentiated tax schemes can also be adapted into road pricing or congestion charging systems; in this way, they may serve as an “intermediate” step between fuel consumption regulations and pricing systems (Sterner, 2003, pp. 234-235).

Table 6: Basis for registration and annual vehicle taxes in EU member countries (Branden, Knight, Potter, Enoch, & Ubbels, 2000; COWI, 2002; Gordon, 2005; IEA & OECD, 2000).

COUNTRY	PURCHASE AND REGISTRATION TAX	ANNUAL CIRCULATION TAX
Austria	Retail price, fuel type (gasoline vs. diesel) and fuel consumption	Horsepower
Belgium	Engine displacement	Horsepower
Denmark	Retail price	Fuel consumption
Finland	Retail price	Weight, vehicle type (gasoline vs. diesel)
France	Horsepower, *grams CO_2 per kilometer*[17]	Horsepower, age
Germany	N/A	Engine displacement, fuel type
Greece	Retail price, engine displacement	Engine displacement
Ireland	Retail price, engine displacement	Engine displacement
Italy	Horsepower	Horsepower
Netherlands	Retail price	Fuel type
Portugal	Engine displacement	Fuel type, engine displacement, voltage (for electric cars), age
Spain	Retail price, engine displacement	Horsepower
Sweden	Environmental classes based on rate of emissions	Weight, fuel type
Great Britain	N/A	Engine displacement volume (pre-2001), CO_2 per kilometer (post-2001)

The U.S. Gas Guzzler tax is a differentiated vehicle tax levied relative to the rate of fuel consumption of passenger cars. Cars that consume fuel at a rate above 10.5 L / 100 km are taxed relative to their rate of fuel consumption. At 10.5 L / 100 km, the tax is $1,000; a car that consumes 19 L / 100 km must pay $7,700 (S. C. Davis & Diegel, 2007).

[17] France has proposed a feebate system based on the grams of CO_2 emitted per kilometer from vehicles. See section 4.3 for details.

European countries currently use a wide range of differentiated vehicle taxation policies (Table 6). In an effort to harmonize the diverse tax structure, the European Commission has proposed transitioning annual taxes on vehicles, or annual circulation taxes (ACTs), toward a tax system based on the amount of CO_2 emitted per kilometer of travel by vehicles. It has also recommended levying registration taxes to an increasing extent on per-kilometer CO_2 emissions from cars, and eventually phasing out registration taxes across EU member states by the end of 2015 (European Commission, 2005).

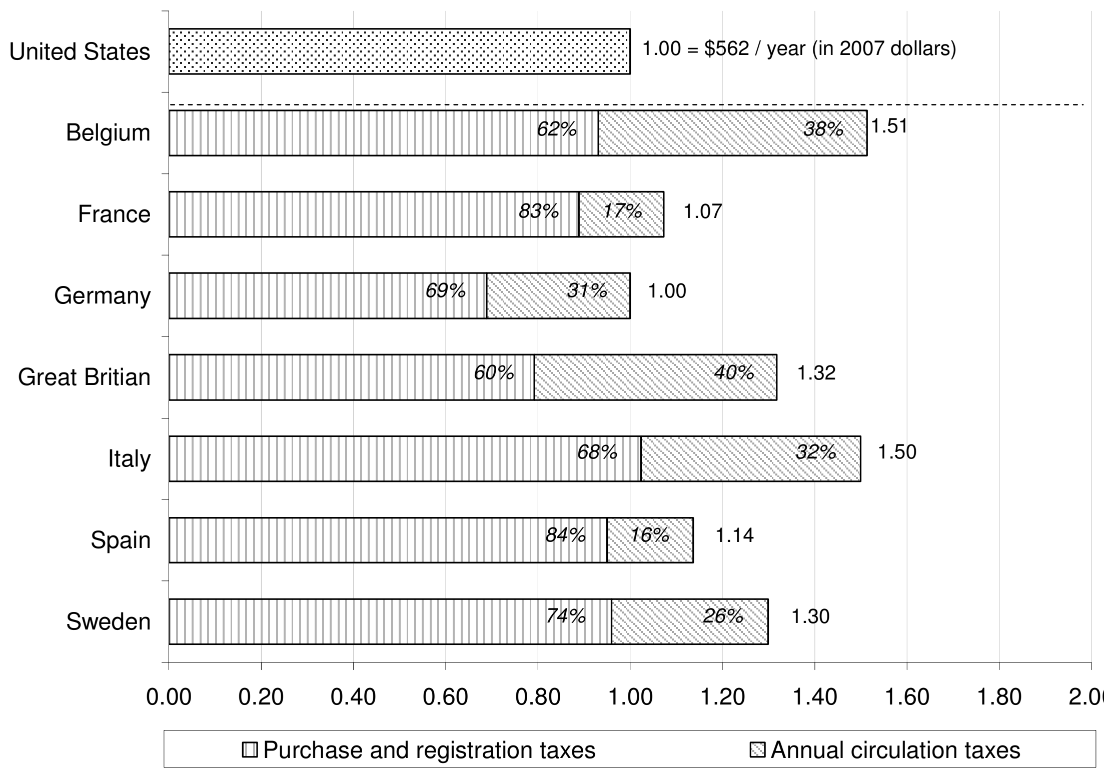


Figure 5: Purchase, registration, and annual circulation taxes on a 1.4 L Volkswagen Golf gasoline car in major European countries, relative to the level of taxation on a mid-sized sedan in the United States (U.S. data from AAA, 2008, p. 6; European data from Kunert & Kuhfeld, 2006).

.

The rates of taxation also very widely across EU member countries. Figure 5 shows the shares of purchase and registration taxes and annual circulation taxes of several European countries for a representative gasoline vehicle[18] relative to a mid-size sedan in the U.S. These countries fall into the mid-range of taxation rates—some countries have much higher or lower levels. For example, Denmark's registration and

[18] A Volkswagen Golf with a 1.4L engine displacement; assumed an exchange rate of $1.25 U.S.

circulation taxes are *seven times as high* as the U.S., with registration taxes contributing to 84% of the overall tax rate. In contrast, Luxembourg's taxes are the lowest in the EU at four-fifths of the U.S. rate. A recent study concluded that this disparate system of taxation in the EU reduces transparency in the car market and creates barriers for relocating vehicles from one country to another (Kunert & Kuhfeld, 2006).

As an example of a differentiated taxation system within the EU, the United Kingdom currently levies an annual tax based on the per-kilometer CO_2 emissions produced by vehicles. The tax separates cars by fuel type into seven categories, or "bands", based on the grams of CO_2 emitted per kilometer. Cars registered prior to March 2001 are still assessed based on their engine displacement (European Conference of Ministers of Transport., 2007, p. 162).

Critics have argued that the UK's CO_2-based system duplicates the role of taxes on transport fuels, and that reductions in the tax rate for low-emitting vehicles are too small to affect consumers' choices. The government has defended the system as a means of ensuring compliance with vehicle safety testing and insurance requirements, for discouraging the ownership of multiple vehicles, and for providing funds necessary for vehicle licensing and enforcement (politics.co.uk, 2007).

Differentiated tax schemes can also be adapted into road pricing or congestion charging systems. In January 2008, the city of Milan introduced a differentiated congestion charge based on the European emissions rating of vehicles (The City of Milan, 2008). The city of London has announced that it will vary its congestion charge based on the per-kilometer CO_2 emissions of vehicles starting in October 2008[19].

Outside of Europe, Japan levies a extensive system of taxes on vehicle purchase and ownership. Many of these taxes are differentiated by vehicle type, weight, and engine displacement. In the past, automotive manufacturers in Japan have lobbied against the high rate of vehicle taxation, arguing that the system is complicated and confusing for consumers and the distribution of revenues is not clearly communicated in budgetary documents (JAMA, 2003; PR Newswire, 2003).

In 1999, the Japanese government introduced a system of "green automobile taxation" which provides a tax reduction for vehicles that currently exceed Japan's Top

[19] See http://www.tfl.gov.uk/roadusers/congestioncharging/7394.aspx. Accessed April 19, 2008.

Runner fuel consumption standard for 2010. To qualify, a vehicle's exhaust pollutant emissions must be 75% lower than Japan's 2005 regulations. Of these, vehicles with a fuel consumption that is 10% below the 2010 standard receive a 25% reduction on the annual automobile tax, while vehicles with fuel consumption that is 20% blow below the standard pay half of the annual tax. These same vehicles also qualify for lump sum reductions in the acquisition tax levied at the time of vehicle purchase (Tabo, Yoshina, Sekine, & Saito, 2006, p. 7).

Table 7: Passenger vehicle-related taxes in Japan (Ministry of the Environment. Government of Japan, 1999)

TAX	LEVEL	DESCRIPTION	RATE[20]
Automobile Acquisition Tax	Local	Point of sale based on price of the vehicle. Revenue directed to regional and municipal funds for roads.	5% of vehicle purchase price
Motor Vehicle Weight (Tonnage) Tax	National	Based on vehicle type and weight at time of inspection. Revenue is split 75% / 25% between national and municipal road funds.	New vehicles are inspected after 1st three yrs., then every two yrs.
Annual Auto Tax and Light Vehicle Tax	Local	Annual, based on total engine displacement and the type of vehicle. Auto tax revenues go to regional governments' general funds; light vehicle tax revenues go to municipalities.	Rate depends on engine displacement and vehicle type.

The following observations can be drawn from this survey of countries who have implemented differentiated taxation systems:

- In order to achieve environmental benefits, taxes must provide a sufficient incentive for consumers to value vehicles with lower fuel consumption. The distribution of revenue generated by differentiated tax schemes should be clearly communicated to the public.
- Differentiated systems should be applied as broadly as possible to increase their effectiveness in reducing fuel consumption. The U.S. Gas Guzzler tax has had a strong, but limited effect in reducing fuel consumption as it only applies to vehicles with rates of fuel consumption higher than 10.5 L / 100 km.
- Experience in the European Union suggests that a harmonized system of differentiated taxes may be more effective than a patchwork of different registration and annual circulation charges.

[20] Source: Fuel Taxation Inquiry (2001).

- Differentiated tax systems appear to be most viable politically when existing taxation schemes can be modified to provide exemptions for vehicles with lower rates of fuel consumption. Japan, for example, has modified existing vehicle taxes to include incentives for less fuel-consumptive technologies.

4.3 Feebates

Although essentially a type of differentiated vehicle tax, feebates have received a great deal of individual attention. Their structure offers unique benefits and challenges that warrant separate treatment from other forms of differentiated taxation. This section reviews the feebate-specific literature and international implementation of feebate systems.

Feebates are financial incentives that use a sliding-scale to adjust the retail price of cars and light trucks. Under a typical feebate system, a rebate is subtracted from the price of vehicles that consume fuel at a low rate, while a fee is added to the price of those that consume fuel at a high rate. Important features of feebates include:

- The vehicle *attribute* from which the feebate incentive is calculated. For instance, a feebate's sliding scale may be based on vehicles' fuel consumption (L / 100 km), fuel economy (mpg), or GHG emissions (grams CO_2 / km).
- The *schedule* of the feebate, or the rate at which the feebate is applied. A linear schedule is the simplest type of feebate, where a flat rate is applied per unit of the attribute the feebate acts on (e.g. x dollars per L / 100 km, or y dollars per mpg, etc.). Feebate schedules may apply continuously across a full range of vehicle offerings, or they may be discretely applied across a limited range. Nonlinear feebate schedules have been suggested that increase the rate of fee or rebate across the range where most vehicles fall, increasing the impact of the policy without placing large feebates on the few vehicles with low or high rates of fuel consumption. Size-based schedules have also been suggested that would normalize feebates to some measure of vehicle size, such as interior volume or footprint.

- The *pivot* or *zero point* of the feebate. This is the point where the feebate is zero; vehicles which do better than this point receive a rebate—vehicles that do worse than this point are levied a fee. Instead of a point, the pivot may be a band, or range of values across which the feebate is set to zero. An interesting characteristic of feebates is *revenue neutrality*—their ability to be designed such that the revenue generated from the collection of fees is cancelled by the rebates paid out. If revenue neutrality is desired, it is necessary to continually adjust the zero point downward as the fuel consumption of vehicles improves under a feebate system.
- The *point of application* of the feebate. This determines whether the feebate is applied directly upon manufacturers based on their sales mix for a given model year, or whether it is applied to consumers at the time when they purchase vehicles. Nearly all feebate systems are applied to consumers, since it is generally assumed that manufacturers will react to feebate incentives regardless of whether they are applied upon them directly or not, while consumers will only react to feebates if they are applied at the point of purchase.

Feebates induce a two separate responses from consumers who purchase vehicles, and from auto manufacturers that supply vehicles. From consumers, the elicit a *demand* response. When fees and rebates are applied to the price of vehicles at the time of purchase, these prices changes are visible to consumers, who shift their purchases towards vehicles with attributes that favor smaller fees or larger rebates (i.e. lower rates of fuel consumption or GHG emissions). Feebates also generate a *supply* response from manufacturers. Vehicle producers can apply technologies that reduce the rate of fuel consumption in order to lower the fee or increase the rebate assessed on a given vehicle.

Feebates share many advantages with differentiated vehicle tax systems. They tend to be progressive, since lower-income groups are more likely to purchase smaller vehicles with lower rates of fuel consumption that are made cheaper under the incentive (HLB Decision Economics Inc., 1999, p. 10). As a fiscal incentive, feebates can work alongside CAFE to hasten the penetration of technologies that reduce fuel use and GHG emissions in the fleet. Accounting for the value of energy consumption over a vehicles' lifetime in a lump sum at the time of vehicle purchase, feebates send a price signal to consumers who may value fuel savings over a short pay-back period (Greene, Patterson, Singh, & Li, 2005, p. 761). Feebates can also be combined with road use charges and fuel tax charges to send reinforcing price signals to consumers (Levenson & Gordon, 1990, pp. 413, 414).

It is argued that feebates may be easier to implement than fuel tax increases since they charge only those who elect to purchase vehicles that consume fuel faster, rather than a fuel tax that is applied broadly across the public. Finally, feebates provide a "continuing incentive" to direct new technologies towards achieving lower fuel consumption (Greene, Patterson, Singh, & Li, 2005, p. 758).

Feebate proposals may face barriers due to their disproportionate impacts across manufacturers: they tend to benefit those with fleets that obtain lower fuel consumption than competitors (Greene, Patterson, Singh, & Li, 2005, p. 758). These impacts can be lessened through size-based feebates, which normalize the rebate or fee according to vehicle interior volume, footprint, or some other measure of vehicle size. Additionally, a feebate system applied across the entire fleet might be cheaper and more efficient than the internal pricing strategies that individual automakers undertake to meet CAFE standards.

A weakness of feebates is that they only influence new vehicles entering the fleet. They are also susceptible to the *rebound effect* of increased travel in response to reducing the cost of travel through lower fuel consumption (Levenson & Gordon, 1990, p. 413). It may be possible to game the system if the feebate schedule is designed in discrete "steps" rather than a continuous function (Keenan, 2007). Finally, to the extent that the response of manufacturers to a feebate forms a large portion of the overall impact, separate state feebate systems may not be as successful as a unified national system that sends a clear signal to automakers (HLB Decision Economics Inc., 1999, p. 11).

Table 8 provides a summary of feebate studies. DRI/McGraw-Hill studied the feebate rates required achieve two targets: a stabilization of fuel use and reduction in fuel use by 20%. The demand response from consumers was approximated by assuming fixed consumer budgets and only considering fuel consumption reductions from shifts between classes of vehicles, rather than shifts within classes. DRI/McGraw-Hill justified this approximation by their estimate that demand response is a small amount (4 to 18%) of the total reduction in new vehicle fuel consumption. The study found that feebate rates of $425 per L / 100 km on average were required to stabilize fuel use, and rates of $1,500 per L / 100 km were required to achieve a 20% reduction in fuel use (W. B. Davis, Levine, Train, & DuLeep, 1995, p. 10).

Greene, 1991 assessed the level of fees and rebates required to incentivize short-term improvements in the fuel consumption of vehicles produced by GM, Ford, and Chrysler. The study found that small improvements—on the order of a 4% reduction in new car fuel consumption—could be achieved through short-term changes in consumer demand at costs competitive with engineering and design changes, but that larger improvements were two to five times as expensive as technology improvements. Greene did not attempt to model the longer-term supply response.

Davis et al. conducted a detailed study of different feebate systems across different rates, one- and two-pivot point schedules, non-linear feebates, and size-based feebates. They assessed both supply and demand responses, accounting for sales-shifts across 19 vehicle classes and within 95 subclasses. This approach allowed greater accuracy in modeling the consumer response to feebates, since it captured shifts within vehicle classes as well as between classes. They also calculated the change in consumer surplus—or the value derived by consumers from vehicle attributes such as price, fuel cost, shoulder room, luggage space, weight, and horsepower—in addition to fuel savings and GHG reduction benefits (Train, Davis, & Levine, 1997).

Fuel consumption improvements on the order of 10 to 15% were found to be possible between 1990 and 2010, resulting in cumulative fuel savings of some 300 billion liters and an 800 Mt reduction in CO_2 emissions. Similar to the DRI/McGraw-Hill study, it was found that the supply response from manufacturers accounted for around 90% of the total improvement in vehicle fuel consumption. Consumer surplus was found to increase for all of the feebate systems assessed—intervention resulted in a new-vehicle mix preferred by consumers compared to what would have been provided in a free market. The authors speculate that this may due to market risk associated with introducing new technologies, or a result of competition amongst new- and used-vehicle markets (Train, Davis, & Levine, 1997, pp. 11-12).

Table 8: Summary of feebate studies

SOURCE	DESCRIPTION	PIVOT TYPE	RATE [$ per L/ 100km]	RATE [$ / gallon]	CHANGE IN NEW VEHICLE FC[21] [%]	SUPPLY SIDE RESPONSE [% of total]	CONSUMER SURPLUS[22] [$ billion, 2005]	PRODUCER REVENUE [$ billion, 2005]
DRI / McGraw-Hill, 1991	Studied feebates necessary to: 1. stabilize FC in vehicles, and 2. reduce FC by 20%.	Single pivot with increasing rate	$425 (avg.) $1500 (avg.)	$1.00 $3.25	Stabilize FC 20% reduction in FC	82 to 96%	--	--
Greene, 1991	Studied feebates needed to meet a reduction in FC at const consumer surplus. Only considered demand response for Chrysler, Ford, GM cars for one model year in 1986.	Not applicable	$250 - $600 $650 - $1650	$0.5 $1.25 - $3.50	4% 13%	Did not consider supply response from manufacturers	Held constant	Not applicable
Davis, et al. 1996	Studied supply and demand response in cars and trucks for foreign, domestic automakers over 15-year period between 1995 to 2010.	Separate pivot for cars & light trucks	$225	$0.5	12% (new cars) 10% (new light trucks)	93%	+$76[23]	-0.7% in sales
			$425	$1.00	15% (new cars) 12% (new light trucks)	88%	+$83[23]	-0.2% in sales
		Single pivot	$225	$0.5	12% (new cars) 10% (new light trucks)	93%	+$70[23]	+0.2% in sales
HLB, 1999	Studied feebates in Canada over 20-year period from 2000 to 2020.	Single pivot point	$350[24]	$0.75	20% to 30%	44%[25]	-$5.9 to -$11.7[26]	-$5.6 to -$6.7[27]
Greene, 2005	Re-examined feebates w/ recent national vehicles sales data over a 10 to 15-year period from 2000.	Separate pivot point for cars and light trucks	$225 $425	$0.5 $1.00	13% 23%	96% 95%	-$2.3 to +$12.7[28] -$7.3 to +$10.2[28]	+$1.7 to +$48.43[29] +$0.5 to +$49.6
		Single pivot point	$225	$0.5	14%	Nearly all	-$2.4[28]	+$0.2

[21] Percentage reduction in new vehicle fuel consumption from projected baseline. Note that the baseline differs across the different analyses.
[22] Cumulative discounted change in surplus given in 2005 dollars using the Bureau of Labor and Statistics Inflation Calculator (www.bls.gov).
[23] Accounts for the value consumers derive from changes in vehicle attributes including vehicle price, fuel cost of travel, shoulder room, luggage space, weight, and horsepower of vehicles. Does not include benefits from fuel savings and greenhouse gas emission reductions (Train, Davis, & Levine, 1997, p. 6)
[24] Approximated from maximum fee of -$4,000 and maximum rebate of $1,450 assuming fuel consumption range from 5 L / 100 km to 20 L / 100 km across all cars and light trucks in the 2000 model year (HLB Decision Economics Inc., 1999, p. 8)
[25] Calculated from a consumer-only reduction of 19 Mt in CO_2-equivalent emissions (i.e. no manufacturer response) divided by a total reduction of 33 Mt (i.e. including both consumer- and manufacturer-response) (HLB Decision Economics Inc., 1999, pp. 24, 26)
[26] Net present value of the extra vehicle cost to consumers between 2000 and 2020, minus fuel savings using a 5% discount rate (see table in Appendix D, HLB Decision Economics Inc., 1999, pp. 57-58)
[27] Net present value of manufacturer revenue loss between 2000 and 2020 using a 5% discount rate (see table in Appendix D, HLB Decision Economics Inc., 1999, pp. 57-58).
[28] The change in value that consumers attach to: the price of the vehicle, and the expected discounted present value of fuel costs (Greene, Patterson, Singh, & Li, 2005, p. 773). Low end assumes consumers undervalue fuel savings over an undiscounted 3-year period; high end assumes consumers value fuel savings over a 14-year vehicle lifetime at a rate of 6%. A high end case was not evaluated for the single pivot point.
[29] The net change in manufacturer's revenues, including lost sales and increased revenue from the added value of technologies that improve fuel consumption. Low end assumes consumers undervalue fuel savings over an undiscounted 3-year period; high end assumes consumers value fuel savings over a 14-year vehicle lifetime at a rate of 6%. A high end case was not evaluated for the single pivot point.

HLB Decision Economics undertook a study of feebates in the Canadian vehicle market. They investigated supply and demand responses using the same vehicle subclasses used by Davis et al. (1995). The study focused on the effect of a Canada-only feebate system relative to a harmonized feebate with the U.S., and found that greater reductions were possible at lower cost due to economies of scale and the quicker manufacturer response under a harmonized system (HLB Decision Economics Inc., 1999, p. 21). HLB found that consumers would face increased costs from the change in vehicle price due to a feebate system, and producers would incur losses from lower vehicle sales (p. 18).

The HLB study found that the supply-side response accounted for only 44% of the total reduction in GHG emissions—a much lower share than estimated by other feebate modeling studies. The smaller supply-side response may be a result of the model's assumption that "manufacturers respond to fees rather than rebates" (p. 14), which is at odds with the response from manufacturers anticipated by Davis et al. (1996) and Greene et al. (2005). To manufacturers, it does not matter "whether a dollar of rebate is gained or a dollar of fee is avoided"; theoretically, they will respond as long as the marginal incentive provided by the feebate is larger than the opportunity cost of a given reduction in fuel consumption (Greene, Patterson, Singh, & Li, 2005, p. 769). The high demand-side response in the HLB study may also reflect the fact that the Canadian consumers—who are subject to higher fuel taxes and have historically shown a preference for vehicles with lower rates of fuel consumption—are more sensitive to price changes that discriminate between the fuel consumption of vehicles.

Greene et al. (2005) re-examined feebates over various rates and pivot points. Greene at al. confirmed that supply side responses from manufacturers accounted for around 95% of the total improvement in vehicle fuel consumption—a similar result to DRI/McGraw-Hill (1991), and Davis et al. (1995). Doubling the sensitivity of the consumer response lowered the supply response to 84% of the total improvement. The effect of feebates on consumer surplus was found to be highly dependant on the value that consumers attach to fuel savings. If consumers undervalue fuel savings (represented by using a conservative 3-year undiscounted payback period), consumer surplus was found to be slightly reduced by feebate systems. If consumers fully value fuel savings over the 14-year lifetime of a vehicle at a 6% discount rate, the study found that consumer surplus increases under a feebate.

The majority of modeling studies have found that the supply response from manufacturers is a large share of the overall impact of a feebate system. Models typically assume that a feebate will incentivize manufacturers to apply technologies that reduce fuel consumption until the extra technology costs are offset by the change in fee or rebate. This may, to some extent, overlook the complex trade-offs manufacturers must make against vehicle attributes within a constrained budget (CAR, 2007). Even with a feebate incentive, manufacturers may still prefer to direct technologies to improve the power and size of vehicles if the consumer willingness to pay for these attributes is higher than the feebate incentive for reducing fuel consumption[30]. If this is the case, modeling studies may overestimated the supply-response from manufacturers to a certain extent.

State-level and national feebates systems have been proposed in the past, although no feebate system has been enacted in the United States to date. Gas Guzzler Tax mentioned in Section 4.2 is essentially a one-sided feebate system that applies an escalating fee to the sale of vehicles with a fuel consumption rate above 10.5 L / 100 km. Internationally, feebates appear to be gaining popularity as a way of providing incentives to reduce new vehicle fuel consumption. Figure 6 provides a comparison of feebate systems in place or proposed around the world.

Austria has applied a feebate tax to the purchase of new vehicles. The tax is levied based on the fuel type, retail price and fuel consumption of the purchased vehicle. Depending on whether the vehicle uses gasoline or diesel fuel, the tax rate is calculated using the following formulae (Gordon, 2005, p. 55; Tellus Institute, 2002):

$$Rate_{gasoline\,vehicle} = 2\% \times Retail\ Price \times (Fuel\ Consumption - 3) \quad \text{-- (4.1)}$$

$$Rate_{diesel\ vehicle} = 2\% \times Retail\ Price \times (Fuel\ Consumption - 2) \quad \text{-- (4.2)}$$

The maximum tax rate of the Austrian scheme is capped at 16% of the retail price for vehicles that exceed a fuel consumption of 11 L / 100 km. There are no vehicles currently on the market which qualify for a rebate under the Austrian system. Gasoline vehicles must achieve a fuel consumption lower than 3 L / 100 km, and diesel vehicles

[30] Personal communication with John DeCicco, May 7, 2008.

must have a fuel consumption below 2 liters per 100 km to qualify for a rebate. The Toyota Prius has the lowest overall fuel consumption for gasoline vehicles of 4.3 L / 100 km, while the Volkswagen Polo achieves the lowest consumption for diesel vehicles of 3.8 L / 100 km.

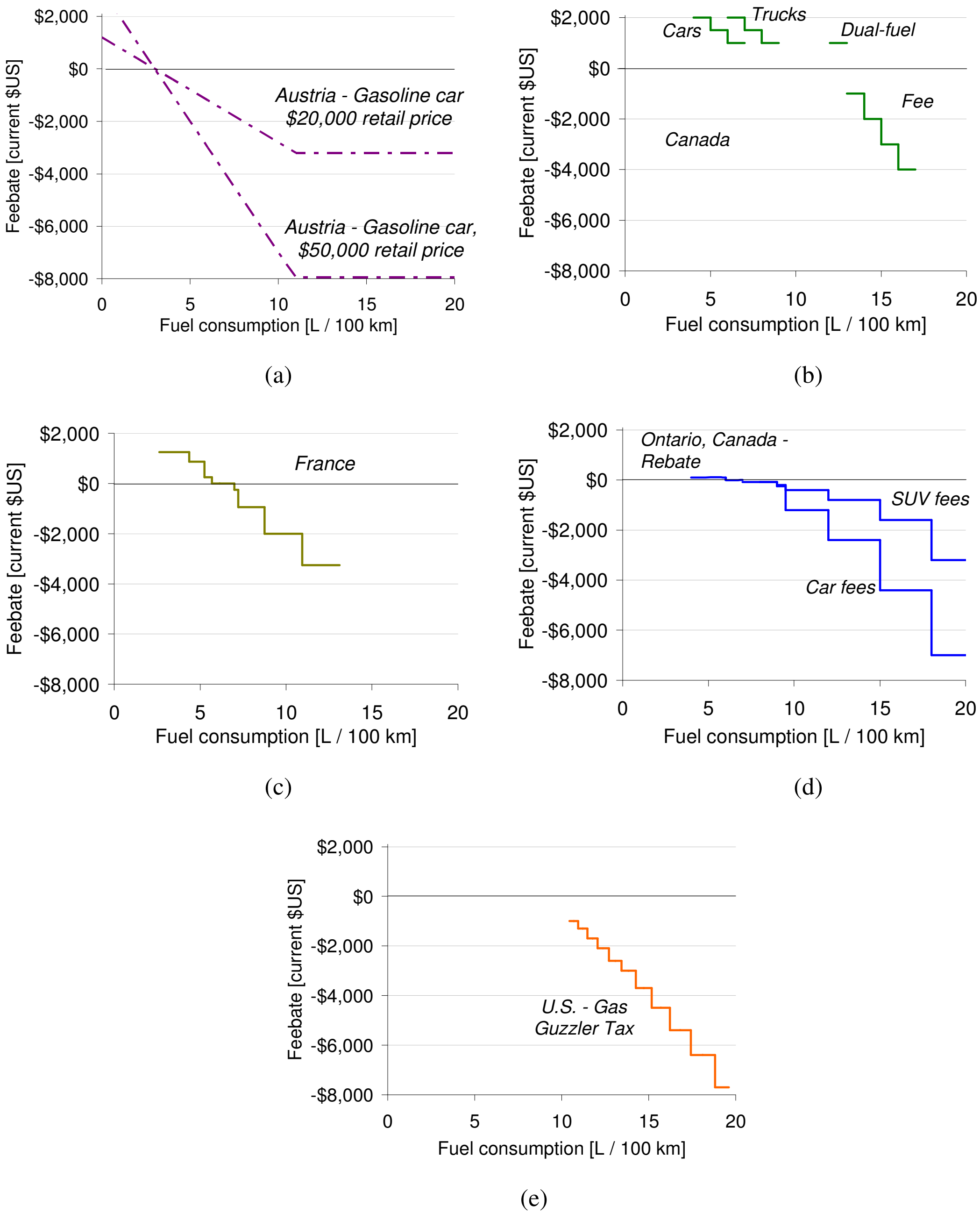


Figure 6: Comparison of international feebate schedules: (a) Austria; (b) Canada (rebate to be phased out in 2009); (c) France (proposed); (d) Ontario, Canada; (e) United States. U.S. and Canada fuel consumption values are based on the U.S. CAFE test cycle; European values are based on the NEDC test cycle.

The Canadian Government announced two measures as part of a Vehicle Efficiency Incentive in the 2007 Budget. The ecoAUTO program establishes rebates for new cars getting 6.5 L / 100 km or better, and new light trucks getting 8.3 L / 100 km or better (Transport Canada, 2007a). An excise tax on fuel cars (dubbed "the Green Levy") applies to new automobiles, but not pick-up trucks, or vans equipped to carry ten or more. The fee is levied according to four tiers, ranging from $1,000 for vehicles that get 13 to 14 L / 100 km to $4,000 for those that consume above 16 L / 100 km (Canada Revenue Agency, 2007).

In 2008, the Canadian Government announced that the ecoAuto Rebate program will be phased out in 2009, two years after its enactment (Parkinson, 2008). This is likely a result of criticism that the program received during its implementation. First, the feebate includes a wide "zero-band" across which no fee or rebate applies. This band straddles a wide range of vehicle models; of 1,040 offerings in the 2007 model year, only 167 are affected by the feebate. Second, the discrete schedule penalized manufacturers over trivial differences in fuel consumption[31]. Finally, the Government has been criticized for implementing the program too quickly without enough consultation or notice given to industry. This may have impacted the ability of manufacturers—particularly North American automakers—to respond to the feebate through supply-side technology improvements (Banerjee, 2007, p. 8). Jaccard and Rivers estimate that the feebate system could reduce Canada's GHG emissions by at most 8 Mt CO_2-equivalent in 2020, or less than one percent of their estimate of Canada's 2020 GHG emissions under business-as-usual (Jaccard & Rivers, 2007, pp. 19,20).

Since 1990, the Government of Ontario, a province of Canada, has imposed a feebate on the sale of new vehicles based on their rate of fuel consumption. The Tax for Fuel Conservation is primarily a revenue-generating tax with a small rebate component for vehicles that with a fuel consumption below 6 L / 100 km. Barg et al. estimate that the feebate has had a small impact on the fuel consumption of vehicles sold in the province, since the rebate and fee amounts are small; 90% of cars fall within the mid-range $75 tax

[31] For the 2008 model year, Honda Canada lowered the Fit's fuel consumption by one-tenth of liter per 100 km in order to qualify for a $1,000 rebate (Keenan, 2007).

bracket, and consumers are not informed of the feebate until after they have purchased a vehicle (2000).

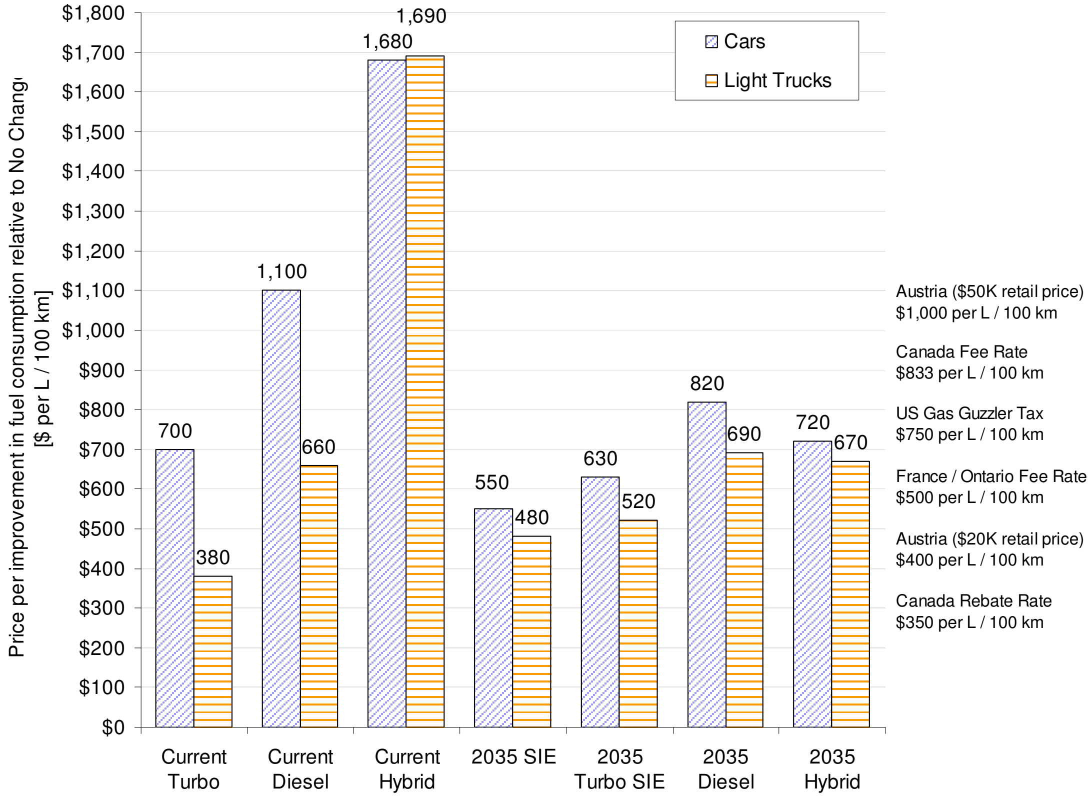


Figure 7: Increase in retail price per unit improvement in fuel consumption for cars and light trucks, compared with rates of fees and rebates in various countries. Results are shown for current and future powertrains relative to No Change in fuel consumption from today. [32]

On December 5, 2007 the French government announced that it would pursue a feebate program for new vehicles based on grams of CO_2 emitted per kilometer. The program adds an extra payment if a vehicle of more than 15 years is scrapped at the same time as a new vehicle is purchased. The program also features a large rebate for vehicles achieving emissions less than 60 gCO_2 per kilometer (2.6 L / 100 km) to promote the adoption of low-emitting, primarily electric, vehicles[33]. French auto manufacturers are well-positioned to benefit from the regulation due to their large share of small car sales,

[32] Note that Canada, Ontario, U.S., and France have been approximated as linear rates from non-linear feebate schedules. Additionally, many of the fee and rebate rates apply only a narrow range of fuel consumption values.
[33] For more information, see Green Car Congress, http://www.greencarcongress.com/2007/12/france-to-insti.html, accessed December 10, 2007.

and the exclusion of consumptive commercial light vehicles, of which two-thirds are French brands (Bussy, 2008).

Figure 7 compares international fee and rebate rates to the estimated retail price increases of various advanced powertrain technologies for cars and light trucks (see Section 5.2.1 for retail price estimate details). The feebate rates are sufficient to offset at least two-fifths of the increase in retail price in future powertrain options. The effectiveness of these feebate systems is reduced by the discrete, non-linear schedules that many schemes use, and by the narrow range of fuel consumption values over which rates for the U.S. Gas Guzzler Tax, the Canadian and Ontario feebates apply.

From a review of the literature on feebates and their international implementation, the following can be suggested:

- Based on modeling studies, feebate rates on the order of $225 per L/100 km to $500 per L/100 km are sufficient to incentivize lower rates of fuel consumption in new vehicles, both in the demand-side response from consumers and the supply-side response from manufacturers.
- Modeling studies of U.S. feebate systems have found that the supply-side response is an order of magnitude greater than the demand-side response triggered by a feebate system, accounting for 90 to 95 percent of the total improvement in vehicle fuel consumption (W. B. Davis, Levine, Train, & DuLeep, 1995, pp. 82-83; Greene, Patterson, Singh, & Li, 2005, pp. 769-770).
- Many of the feebate rates implemented internationally are sufficient to offset estimated retail price increases of various advanced powertrain technologies. The effectiveness of these systems is impaired by the use of discrete, non-linear schedules that often only apply across a small range of fuel consumption values.
- As concerns over energy security and climate change heighten, feebates are being increasingly considered as viable policy instruments. Feebate systems have typically employed much higher levels of fees than rebates. This suggests they are often used as revenue generation taxes rather than revenue-neutral instruments for reducing the fuel consumption of new vehicles.

4.4 Fuel taxes

Fuel taxes are levied on the sale of gasoline, diesel, and other transportation fuels. Taxes of this kind are justified by governments for the following reasons (Parry & Small, 2005):

- They are an efficient way of raising government revenue.
- They directly influence the *price of fuel*, and can correct for externalities such as: the environmental damage from local air pollutants and carbon dioxide emissions produced by the combustion of fuels, and economic losses from dependence upon petroleum-based fuels.
- They indirectly influence the *price of travel*, and can partially correct for externalities such as congestion and traffic-related accidents that consumers might not otherwise take into account in their travel decisions.
- They act as a user-fee for the use of publicly-provided roads and highways (Gordon, 2005, p. 26; Wachs, 2003).

Of these rationale, internalizing the cost of carbon dioxide emissions in the price of fuel is most closely aligned with reducing GHG emissions from light-duty vehicles. This is analogous to the use of carbon taxes as a means of including the costs of climate change impacts into the price of activities that release GHG emissions. Typically, carbon taxes are expressed in terms of dollars per metric ton of carbon dioxide emissions, or simply in terms of dollars per metric ton of carbon. When applied to fuels, carbon taxes can be converted into a dollar per gallon amount which forms a portion of the fuel tax.

The carbon price can be expressed as a fraction of the price of fuel with the following conversion (W. B. Davis, Levine, Train, & DuLeep, 1995, p. 39):

$$Fuel\ Price = Carbon\ Price \times \left[\frac{20\ lbs\ CO_2}{1\ gallon\ gasoline}\right] \times \left[\frac{metric\ ton}{2{,}205\ lbs}\right] \quad \text{-- (4.3)}$$

Where carbon price is the price of one metric ton of GHG emissions in carbon dioxide equivalent and fuel price is expressed in dollars per gallon of gasoline. Using this conversion, a carbon tax of $100 per metric ton of carbon ($27 per ton of carbon dioxide) is equivalent to a fuel tax of $0.25 cents per gallon of gasoline.

The primary advantage of fuel taxes are that they promote reductions in fuel use in a cost-effective manner, particularly relative to vehicle standards (Austin & Dinan, 2005; CBO, 2002). Changes in fuels taxes broadly affect the price of fuel and the cost of driving a given distance across all on-road vehicles. As a result, they have an important impact on the total demand for *both* private vehicle travel and fuel use.

In particular, changes in fuel tax induce two distinct responses. Over the short-term (within one year or so), consumers increase or reduce the amount they travel in response to price changes. Travel can be reduced by eliminating inefficient trips, carpooling, and switching modes of transportation (e.g. shifting from private to public transportation). Recent literature suggests that income growth and improved rates of fuel consumption in vehicles have insulated consumers from short-term increases in fuel price, reducing this effect to as much as one-fifth of what it was in the 1980's (CBO, 2008; Small & Dender, 2007a).

Over the longer-term, consumers alter their purchase decisions with regards to vehicles' rates of fuel consumption. For instance, if fuel price increases are sustained over a longer-term period of five to fifteen years, consumers gradually begin to replace their vehicles with models that have lower rates of fuel consumption. Manufacturers, in turn, respond to this demand by implementing technologies and vehicle designs that emphasize reduced fuel consumption over other attributes. Empirical estimates suggest that this response may be from three to seven times larger than the short-term response from consumers (CBO, 2008, p. xi).

The following elasticities of response are representative of recent studies that have investigated and summarized these effects (CBO, 2008; Small & Dender, 2007a, 2007b):

- For a 10% increase in the fuel cost of travel: consumers respond with a 0.3% decrease in annual vehicle travel over the short term, growing linearly to a 1.0% reduction in travel over 10 years, under sustained fuel price increases. This is the elasticity of annual travel with respect to the fuel cost of travel ($\varepsilon_{travel,\ per\text{-}km\ cost}$).
- For a 10% increase in fuel price (i.e. $ / liter): manufacturers to consumer demand respond by reducing new vehicle fuel consumption to produce a 0.3%

decrease in fuel use over the short-term, growing linearly to a 1.7% reduction within 15 years, and a 3.3% reduction over 30 years, assuming sustained fuel price increases. This is the elasticity of fuel consumption with respect to fuel price ($\varepsilon_{fuel\ consumption,\ price}$).

The elasticity of overall fuel use with respect to fuel price ($\varepsilon_{fuel,\ price}$) is given by (Austin & Dinan, 2005, p. 572):

$$\varepsilon_{fuel,price} = \varepsilon_{travel,per-km\,cost}(1+\varepsilon_{fuel\ consumption,price}) + \varepsilon_{fuel\ consumption,\ price} \quad \text{-- (4.4)}$$

With the values above, this gives a price elasticity of fuel use of -0.25 in 2020 and -0.40 in 2035. These are within the range of values from econometric analyses cited in literature, although there is considerable variation in elasticity estimates (Espey, 1996; Goodwin, Dargay, & Hanly, 2004; Greene, Kahn, & Gibson, 1999; Greening, Greene, & Difiglio, 2000; Small & Dender, 2007a). Section 5.3 provides a sensitivity analysis on a range of elasticity values.

Higher rates of fuel taxation and lower rates of vehicle fuel consumption are correlated internationally. Figure 8 shows gasoline taxes as a percentage of the cost of gasoline across the United States, Japan, Europe, and Canada. European countries apply very high taxes relative to the actual cost of the fuel; Japan and Canada are more moderate, while the U.S. taxes gasoline at the lowest rate in the OECD.

Alongside the high rate of fuel taxation in Europe, new vehicles in France, Germany, Italy, and the United Kingdom have shown a much greater emphasis on reducing fuel consumption relative to the light-duty fleet in the U.S. During the late-1990's, more than half of the efficiency improvements in new cars coming onto the road in these countries were used to reduce fuel consumption (Bodek & Heywood, 2008, p. 22).

Italy is particularly noteworthy, having realized 80% of the total fuel consumption reduction that would have been possible at constant size and performance, even with a lower gasoline tax rate relative to other European countries over the same period. In the U.S., however, very little of the improvements in vehicle efficiency have been used to improve fuel consumption; instead, horsepower increased by nearly 15% while sales-weighted average fuel consumption in U.S. cars remained essentially flat between 1995 and 2006 (EPA, 2007b).

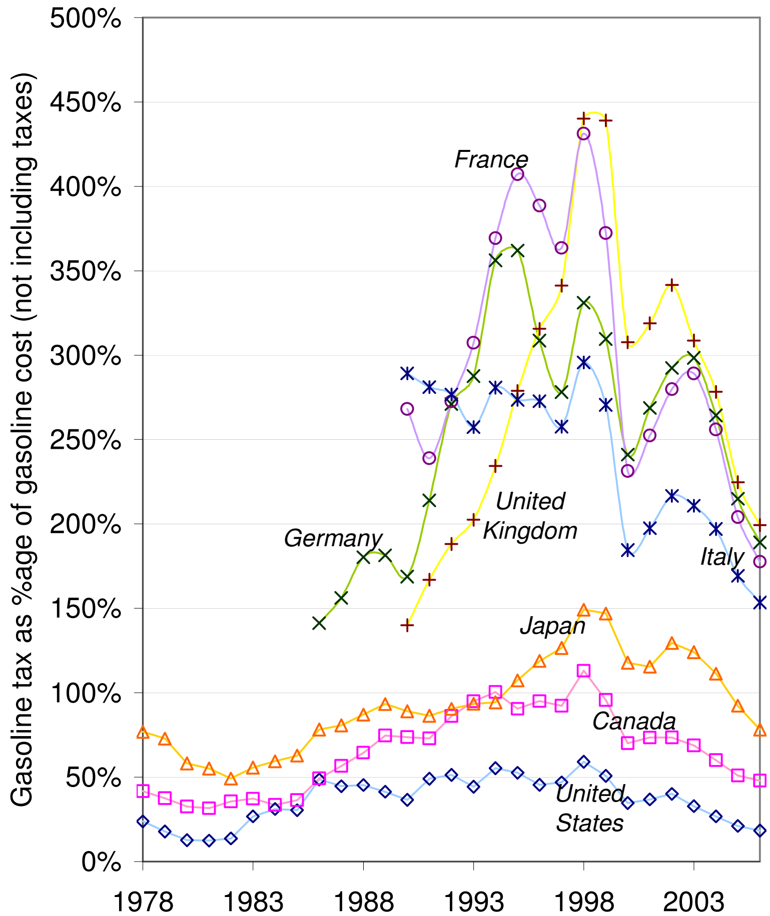


Figure 8: International as a percentage of fuel price from 1978 to 2006 (IEA, 2007 Energy End-Use Prices in US/toe, PPP/unit)

Table 9: Fraction of the potential fuel consumption reduction (at constant size and performance) realized in vehicles across different countries (An & DeCicco, 2007, p. 9; Bodek & Heywood, 2008, p. 23)

COUNTRY	PERIOD	EMPHASIS ON REDUCING FUEL CONSUMPTION[34] [%]
United States	1995 - 2006	8
France	1995 – 2006	68
Germany	1995 – 2006	54
Italy	1995 – 2001[35]	83
United Kingdom	1995 – 2001[35]	52

[34] See Bandivadekar (2008, p. 71). Emphasis on reducing fuel consumption (ERFC) describes the ratio of actual fuel consumption reduction realized on-road to the fuel consumption reduction possible at constant vehicle size and performance.

[35] Due to data availability, the emphasis on reducing fuel consumption could only be calculated over 1995 to 2001 for Italy and the United Kingdom.

While the main benefit of fuel taxes is their cost-effectiveness in reducing fuel use, they are at a disadvantage politically. A broad range of stakeholders are generally aligned against tax increases. In the past, these groups have included the tourism services industry, road contractors, taxicab companies, truckers, farmers, fuel provides, auto makers, labor unions, and general public opinion. A concern is that tax increases will hit low-income and rural groups hardest and transfer large amounts of wealth from consumers to the government (Nivola, 1986, pp. 210-220). As a result, only modest fuel tax increases have been possible within the United States in real dollar terms (Figure 9).

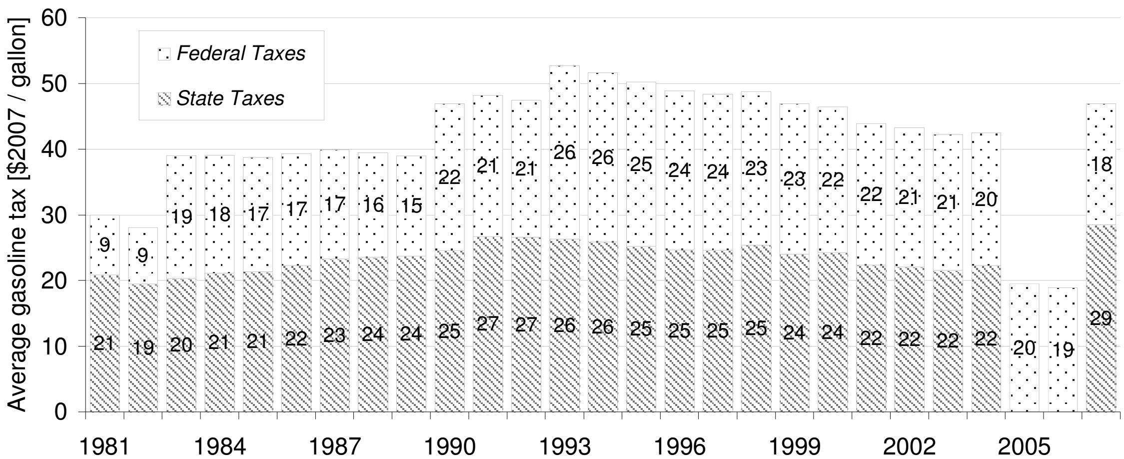


Figure 9: Historical U.S. gasoline tax rates[36] (BLS, 2008; FHWA, 1995; , 2004 Table MF205)

At the same time, the evidence is mounting that too-cheap gasoline is imposing societal costs that will need to be incorporated into the price of fuel—potentially sooner rather than later. First, the external costs of private transportation are not fully internalized in the price of fuel in the United States. This promotes higher rates of fuel consumption and greater vehicle travel than if fuel was taxed at a socially optimal level. Parry and Small (2005) recently examined what level of gasoline tax would be necessary to optimally account for the external costs of congestion, accidents, local air pollution, GHG emissions, and the balance between fuel and labor taxes for revenue generation. Their results, summarized in Table 10 show that the optimal rate of taxation is estimated to be $1.21 in 2007 dollars—over two and a half times the current average fuel tax of $0.47 per gallon[37].

---

[36] Due to a discrepancy in the FHWA data, average state tax rates were not available for 2005 and 2006.
[37] U.S. average of federal, state, and local taxes. See (API, 2008)

Table 10: Components of an optimal gasoline tax in the U.S. (Parry & Small, 2005, p. 1283, Table 1)

COMPONENT	OPTIMAL TAX [2007 cents per gallon]
Congestion[38]	34
Accidents	31
Pollution from NO_x, HC, CO emissions, regulated on a distance basis	19
Pollution from GHG emissions (CO_2 emissions, proportional to fuel use)	6
Revenue generation[39]	31
Total optimal gasoline tax rate	121

Second, fuel tax increases are a straightforward and increasingly essential means of raising revenue to maintain America's highways. From an equity perspective, taxes and fees placed on private vehicle use should balance government expenditures on the infrastructure and services provided for private vehicles (Delucchi, 2007; Wachs, 2003). In the U.S., there is strong evidence that vehicle users do not current pay enough to offset the level of investment required to sustain and improve surface transportation infrastructure.

Nearly all of federal government spending on surface transportation comes through the Highway Trust Fund (HTF), a fund established in 1954 to cover federal highway expenditures. Although HTF revenues swelled in 1997, recent increases in spending have dramatically reduced the balance of the HTF (CBO, 2007, pp. 3-4). As a result, the Highway Account—the portion of the HTF responsible for highway funding—is projected to carry a negative balance beginning in 2009 if no corrective action is taken (see Table 11).

[38] The congestion term includes a one-cent "congestion feedback" effect on labor supply from reduced congestion. See Parry and Small, 2005, p. 1280.

[39] "Revenue generation" here does not suggest the level of taxation necessary to recoup government expenditures on highway infrastructure. Instead, it refers to the optimal level of fuel taxation relative to labor taxes as a source of government revenue.

Table 11: Projected end-of year balances for the Highway Account from 2006 to 2010 (Adapted from CBO, 2007, p. 9, Table 5).

	2006	2007	2008 [billions of dollars]	2009	2010
Estimated outlays	33.9	35.7	39.4	41.5	42.8
Transfer to Mass Transit account	1.4	0.3	0.7	0.9	0.9
Estimated receipts	33.6	35.2	35.9	36.7	37.5
Projected balance	8.9	8.1	3.9	-1.7	-8.1

To keep the Highway Account solvent, a nine-to-three majority on the blue-ribbon National Surface Transportation Policy and Revenue Commission panel recommended an immediate 25 to 40-cent increase in the federal fuel tax between 2008 and 2013. This is more than double the current federal rate of 18.3 cents per gallon (4.8 cents per liter). The Commission estimated that between 2020 and 2050, equivalent increases in the fuel tax would be on the order of 50 to 85 cents per gallon (13.2 to 22.5 cents per liter) in order to improve highway performance measures[40] relative to today (see Table 12).

Table 12: Estimated levels of investment required under High Capital Investment scenario (National Surface Transportation Policy and Revenue Study Commission, 2008, p. 6)

	Currently sustainable	2005 - 2020		2020 - 2035		2035 – 2055	
		Low	High	Low	High	Low	High
Level of capital investment [billions, const. $]	68	207	240	182	250	185	276
Funding gap[41] [billions, const. $]	--	139	172	114	182	117	208
Equivalent fuel tax increase req'd. [const. $ per gallon]	--	0.71	0.88	0.54	0.85	0.49	0.85

The immediate increase in fuel tax recommended by the Surface Transportation Panel corresponds well with Delucchi (2007), who estimated that user payments for vehicle infrastructure and services fall short of government expenditures by roughly 20 cents per gallon (5.3 cents per liter). When indirect government expenditures and general

[40] Highway performance measures considered by the Panel include: average delay on urban principal arteries, total delay on all Federal-aid highways, and the percentage of vehicle travel on roads with an acceptable pavement ride quality.
[41] Calculated by subtracting the currently sustainable level of investment from level required in each future time period.

taxes and fees are included, the total shortfall could be as high as 70 cents per gallon (18.5 cents per liter).

Third, in terms of the burden fuel taxes place on low-income households, studies have shown that these groups *do* spend a higher fraction of their income and expenditures on gasoline. At the same time, the disparity is less pronounced when gasoline spending is compared relative to long-term income or annual expenditures than it is when compared against annual income. It is believed that these measures may be more accurate representations of the gasoline tax burden than annual income (CBO, 2002, p. 30). Additionally, government transfer payments or income tax rebates to low-income households can be used to reimburse extra expenditures on gasoline. For example, Metcalf shows how payroll tax rebates could offset the regressive effects of an economy-wide \$15 per metric ton of CO_2 (\$55 per ton carbon) tax that would increase household gasoline spending by 9% (2007; Table 6, p. 6).

Finally, it should be noted that fuel taxes alone are not the only way to send a signal to consumers through the fuel cost of travel. Pay As You Drive or Pay At the Pump insurance programs (see Section 4.5) are a means of increasing the cost of travel by shifting the up-front costs of insurance to a variable rate. Over the longer-term, road charging and mileage-based user fees that are able to differentiate rates by time of day (i.e. peak versus off-peak hours), location (i.e. congested city center versus rural roads), and perhaps even vehicle type may be the most efficient and equitable solution beyond 2025 to 2030 (National Surface Transportation Policy and Revenue Study Commission, 2008; Wachs, 2003).

The following observations are made from this review of the literature and international experience with fuel taxation:

- Fuel taxes are seen as a cost-effective way to enable a broad range of fuel use reduction strategies in an administratively-simple framework.
- Fuel taxes account directly for the costs of GHG emissions and oil market imperfections. They indirectly account for local air pollution, congestion, and accident costs. Collectively, this second group of externalities have been estimated to be 14 times larger than costs imposed by GHG emissions (Parry & Small, 2005).

- The main disadvantages of increases in the fuel tax are its regressive effect on low-income consumers, and its impact on a broad range of stakeholders are generally aligned against these tax increases.
- At the same time, the need for revenue to offset negative balances in the Highway Account of the HTF may provide an immediate, short-term driver for dramatic increases.
- To some extent, concerns over the distributional impacts of fuel tax increases can be mitigated though appropriate re-distribution of revenue through government transfer payments or income and payroll tax rebates.
- Finally, fuel taxes are not the only measure available; Pay As You Drive or road charging systems similarly reduce vehicle travel and directly account for local air pollution, congestion, and accident-related externalities. Over the long term, transitions to road charging systems that differentiate by time, location, and vehicle type may provide the most effective method of taxation.
- In the short-term: fuel tax increases on the order of 2 to 3 times the current average federal and state tax rate of $0.47 per gallon ($0.12 per liter) are justifiable on grounds of economic efficiency (internalizing costs of fuel use) and equity (private vehicles should pay their way).

4.5 Pay As You Drive

Motorists that drive often are more likely to get into an accident than others who drive less. Currently, automobile insurance is paid in an annual lump-sum amount that has been likened to an "all-you-can-eat buffet" (Bordoff & Noel, 2008). Once the lump-sum amount is paid, people tend to over-consume—in this case by driving further than they would if the price of insurance took into account their amount of travel relative to other consumers.

A Pay As You Drive (PAYD) system would correct this to a certain extent by rolling the up-front costs of annual insurance payments into a price per unit of distance traveled[42]. Under such a system, individuals who drive below-average would pay lower

[42] A similar Pay At The Pump (PATP) system is discussed later and would roll insurance into a fuel surcharge paid at during refueling.

premiums, while those who travel above-average would pay more; the premium of the average driver would remain unchanged. By calculating premiums on a *pay*-as-you-drive basis, rather than a *all*-you-can-drive basis, the approach would provide all drivers with a continuous price incentive to reduce vehicle travel.

There are a number of advantages to PAYD. First, it has been suggested that the impact on low-income groups may be progressive since they drive less than higher-income households (Bordoff & Noel, 2008; Figure 3, p. 9). Second, PAYD insurance allows flexibility in accounting for other insurance risk factors, such as age, driving history, location, and time of day in addition to the annual distance traveled (Parry, 2005). Third, it is a potentially feasible alternative to the fuel tax for incorporating externalities into the cost of private transportation and reducing growth in vehicle travel. Finally, PAYD is a step toward road charging systems that would most effectively account for distance-based externalities (congestion, accidents, air pollution), and that are viewed as a necessary transition for transportation finance in the long-term.

Table 13: Summary of Pay As You Drive studies. All prices in $2007. (veh. = vehicle)

SOURCE	AVERAGE PREMIUM		REDUCTION IN VKT	EQUIV. FEDERAL GAS TAX INCREASE	BENEFITS	
					PRIVATE	SOCIETAL
	[¢ / mi]	[¢ / L][43]	[%]	[%]	[$ billion]	[$ billion]
Bordoff & Noel (2008)[44]	6.6	35.5	8	220	$7.7 ($34 / veh.)	$51.5 ($225 / veh.)
Parry (2005)	6.9	37.1	9.1	150	--	$20.5
Edlin (2003)	5.4	29.3	10	--	$7.2 ($33 / veh.)	$24.75 ($146 / veh.)

Table 13 summarizes three recent studies of PAYD systems. Edlin (2003) developed a model to relate only accident and congestion externalities to a PAYD system using state insurance premium data. Parry (2005) assessed the welfare gains from local

[43] Assumes an light-duty fleet average fuel consumption of 11.8 L / 100 km.
[44] Bordoff & Noel's estimates of the societal benefits of PAYD are high relative to the other studies. One reason is that Parry takes into account the existing tax on gasoline when calculating the external benefits of reducing gasoline use; since the tax is already higher than Parry's estimate of the external costs of gasoline use, reducing consumption is a net *loss* of welfare (2005, p. 290). In contrast, Bordoff & Noel simply multiply the reduction in fuel use by the external cost per gallon for a net societal benefit.

air pollution, GHG emissions, and oil dependence in addition to accident and congestion externalities. Bordoff & Noel (2008) used data from the National Household Transportation Survey to disaggregate premiums and welfare impacts by state, but accounted for a comprehensive set of externalities similar to Parry. Bordoff & Noel were also able to disaggregate welfare effects by income group and location (rural versus urban) in order to analyze the distributional impacts of a PAYD system.

The average premium anticipated across the studies is about 6 cents per mile or 3.8 cents per km. Assuming the average light-duty vehicle fleet fuel consumption is around 11.8 L / 100 km (20 miles per gallon), this is approximately equivalent to $1.20 per gallon ($0.32 per liter). All of the studies find substantial net social benefits from the PAYD system; Bordoff & Noel and Parry estimate that increases on the order of 150 to 220% of the current 18-cent federal fuel tax would be necessary to achieve the same reduction in overall fuel use. Each concludes that PAYD offers a much more efficient alternative to the current system of lump-sum insurance premiums. Bordoff & Noel find that lower-income households pay less on average under PAYD, and that the same share of households pay less in premiums whether urban or rural (2008; 47).

PAYD may offer benefits, but there are also drawbacks. First, a number of state-level insurance regulations explicitly forbid PAYD-type premiums or would require reforms to accommodate these schemes. Second, there are barriers to entry for new firms attempting to launch PAYD insurance systems: regulatory hurdles and over-broad patents on PAYD-like auto insurance arrangements may impair their diffusion (Bordoff & Noel, 2008, pp. 16-19). Third, lower- and middle-income groups may still pay more for insurance (Wenzel, 1995, pp. 39-43). Although premiums will more fairly reflect consumers' use of private travel, this may result in distributional issues among certain groups that will need to be addressed by policymakers (Bordoff & Noel, 2008, p. 46).

A final barrier is that implementation of PAYD suffers from a failure of collective action. Even though the *social* benefits are estimated to be large, benefits for *individual* insurance firms are less than the costs of monitoring vehicle mileage. Spill-over effects make it difficult for first-movers to fully capture the benefits of implementing PAYD (Bordoff & Noel, 2008). Current GPS monitoring systems are priced between $100 to

$250 per vehicle[45]—far larger than the $30 per vehicle benefit that individual insurance companies or consumers are estimated to receive (Table 13). Odometer audits may offer a lower-cost option for monitoring vehicle mileage that would also avoid the privacy concerns over the use GPS monitoring equipment in personal vehicles.

Another option is Pay at the Pump (PATP), which would see lump-sum insurance premiums rolled into the price of gasoline at the pump, rather than a charge based on annual vehicle travel. It would not require mileage monitoring, and would have lower up-front costs than distance-based premiums. Additionally, by levying premiums on the amount of fuel consumed, rather than distance traveled, PATP would affect consumer's vehicle purchase decisions as well as reducing annual vehicle travel.

A drawback to PATP is that it is more difficult to price other risk factors as precisely as traditional insurance programs or PAYD. Second, PATP approaches may have stronger regressive impacts than PAYD since lower-income households are more likely to have older vehicles that consume fuel at a higher rate for the same distance traveled. Third, by basing premiums on the amount of fuel consumed, PATP does not encourage the same reduction in vehicle travel as an equivalent PAYD scheme. As a result, while PATP does encourage lower rates of fuel consumption in vehicles, larger externalities that are related to vehicle travel—such as accidents, congestion, and local air pollution—will not decrease as much as they would under PAYD (Bordoff & Noel, 2008, p. 48).

PATP proposals have been motivated by efforts to reform auto insurance legislation rather than correct the pricing of auto insurance. In California, efforts in the mid-1990's to introduce PATP auto insurance were ultimately unsuccessful (New York Times, 1993). In the meantime, improvements in GPS technology and pilot programs conducted by insurance companies appear to have renewed interest in PAYD relative to surcharges at the pump. Distance-based insurance programs are currently offered by Norwich-Union in the United Kingdom (Norwich Union, 2008), and Hollard Insurace in South Africa (Hollard Insurance, 2008). Progressive, the U.S. auto insurance firm, is planning on launching a PAYD program called MyRate on a pilot basis in six states (Dubner & Levitt, 2008). The company already offers discounts from 5 to 25% on

[45] See Bordoff, 2008; Table 1, p. 14 for a summary of available monitoring systems.

premiums through a voluntary travel monitoring program called TripSense underway in Minnesota, Oregon, and Michigan (Progressive Insurance, 2007). Milemeter, a start-up insurance firm will allow consumers to purchase insurance for a specified odometer range over the internet, with rates adjusted by geography, age, and vehicle risk factors (Milemeter, 2008). There is no data currently available on the performance of these programs to date.

The following suggestions are made based on this review of PAYD and PATP proposals:

- According to economic literature, substantial social benefits (on the order of \$150 to \$225 per insured vehicle) are offered by linking insurance premiums to annual travel or fuel use. Suggested premiums are on the order of 6 cents per mile, or 32 cents per liter.
- There is some disagreement in the literature over whether these reforms would disproportionately impact low-income groups. While the lowest-income households may be better off, mid- and lower-income groups may be disproportionately worse off.
- The implementation of actual PAYD schemes and pilot programs suggest that private insurance companies are becoming increasingly interested in linking premiums to annual vehicle travel. While regulatory and collective action barriers exist, improved mileage tracking technologies and the potential private benefits available have renewed interest in PAYD approaches relative to PATP.
- In terms of reducing GHG emissions and fuel use in light-duty vehicles, these systems offer a less controversial alternative to fuel taxes as a way of incorporating the external costs of private vehicle travel into consumer decision-making.

4.6 Scrappage incentives

At the final stage of vehicle life, scrappage incentives—also known as voluntary vehicle retirement programs—provide rebates to owners who choose to retire aging vehicles rather than re-sell them or keep them on the road. To the extent that retired vehicles lead to new vehicle sales, and that these new vehicles travel further on a liter of fuel, scrappage programs can increase the rate at which the on-road fleet achieves fuel consumption reductions. Interest in scrappage incentive has largely been motivated by their impact on local air pollution emissions, as the oldest vehicles on the road are responsible for a disproportionate share of total emissions. In California, five local air districts offer scrappage incentives as a means of meeting federal ozone standards within the state[46].

Scrappage incentives can be combined with feebates or other differentiated vehicle taxes in order to promote the adoption of vehicles with lower rates of fuel consumption upon retirement of an older vehicle. For example, France's proposed feebate system includes a scrappage incentive for vehicles 15 years or older (see Section 4.3). British Columbia's "Scrap-It" program offers a sliding scale of incentives, from $1,000 towards a new hybrid vehicle purchase, to $500 for the purchase of a used vehicle not older than 1998.

Two drawbacks to scrappage programs are that they may increase the price of used vehicles, which can impact low-income groups who typically purchase older vehicles, and that they may increase the migration of older vehicles into the area where the incentive is offered, thus offsetting some of the policy's benefits. One study in California found the regressive effect of a scrappage incentive to be smaller than expected, with average used car prices increasing by at most 5%, or $300 per vehicle. Local emissions reductions were very dependant upon the assumptions made regarding the age of vehicles which migrate into the area—under a worst-case assumption, the base-case emissions reductions predicted for the incentive were offset by two-thirds (Dixon & Garber, 2001; pp. 63 - 64; Table 7.2, p. 58).

4.7 Summary and discussion

This chapter has qualitatively reviewed the literature and real-world experience with vehicle standards, differentiated vehicle taxes, fuel taxes, pay as you drive programs, and scrappage incentives. Table 15 summarizes the results of this assessment, which suggest that vehicle standards, such as CAFE form an incomplete approach to addressing

[46] See http://www.arb.ca.gov/msprog/avrp/avrpfaq.htm, accessed May 2, 2008.

the full menu of opportunities available for reducing fuel use and GHG emissions from light-duty vehicles for the following reasons:

1. Vehicle standards act directly on manufacturers, but a broad range of stakeholders influence energy use and GHG emissions. Bringing these groups into a coordinated policy framework enables a wide range of reduction opportunities through technological and behavioral change.
2. There is a trend towards mandatory and tighter regulation of vehicle fuel consumption across developed countries in the world. At the same time, fiscal approaches have a role to play in aligning the interests of manufacturers and consumers in achieving reductions without the use of perverse incentives and loopholes.
3. There are numerous opportunities to reduce energy use and emissions along the entire vehicle life-cycle. Policy drivers that influence the choices of manufacturers and consumers can be applied at the time of vehicle design, production, purchase, operation, and retirement. Without addressing these different life-cycle stages, a measure may unintentionally alter the behavior of stakeholders in ways that reduce the effectiveness of policy interventions.

Table 14 integrates the policy options reviewed in this chapter by policy type, stakeholder group, and life-cycle stage. This sample package shows how these options might be combined in a coordinated policy framework.

Table 14: A sample coordinated policy package for reducing the fuel consumption of vehicles.

STAKEHOLDER	VEHICLE LIFE-CYCLE STAGES			
	Production	Purchase	Operation	Retirement
Manufacturers	CAFE	*(Feebates)*	--	--
Consumers	--	*Feebates*	*Pay as you drive / Fuel tax*	*Scrappage Incentive*

Non-italics = regulatory mandate
Italics = fiscal incentive

A mandatory vehicle standard such as CAFE would establish a binding fuel consumption target on manufacturers. At the time of purchase, *feebates* would reward buyers for selecting new vehicles with lower fuel consumption, while providing manufacturers with an incentive to equip vehicles with technologies that reduce the rate of consumption. Customers who elect to pay fees on larger, more powerful and consumptive vehicles would effectively subsidize these improvements.

Following vehicle purchase, increases in the federal fuel tax could encourage consumers to adopt less-consumptive vehicles through a long-term and consistent price signal. Income or payroll tax rebates could be used to mitigate the impact of fuel tax increases on lower income vehicle users. Alternatively, a pay as you drive, or pay at the pump system could be used to increase the fuel cost of travel in a way that is revenue-neutral for the average driver. At the final stage of the vehicle life-cycle, scrappage incentives would provide a rebate to vehicle owners to promote earlier retirement of aging vehicles, increasing the rate of turnover in the fleet and encouraging newer vehicles with lower rates of fuel consumption to hit the road.

The combined effect of these policies is consistent and reinforcing: consumers respond to fiscal incentives in a way that aligns their desire for reduced fuel consumption with regulatory requirements placed on manufacturers. Just as there is no “silver bullet” in the technology options available, it is unlikely that one dominant strategy can satisfy the necessary political and economic constraints while achieving dramatic reductions in energy use and greenhouse gas emissions. The policies outlined above are technology-neutral, in that they are oriented around relative reductions in vehicle fuel consumption rather than the technologies used to achieve these reductions. Finally, they act across the entire vehicle life-cycle, providing incentives to reduce fuel use at the time of purchase, as vehicles are driven, and in deciding when to retire or re-sell old vehicles.

Table 15: Summary of policy measure features

POLICY	GOAL	STAGE	GROUP	ADVANTAGES	DISADVANTAGES	ALONGSIDE CAFE
Vehicle standards	Reduce rates of new vehicle FC / GHG emissions	Production	Manufacturers	Immediate & binding effect on new vehicle FC and GHG emissions; certainty in reduction	Limited to *new* vehicle *FC*; costlier; rebound effect; may need perverse incentives to win favor	--
Differentiated vehicle taxes	Incentivize adoption of vehicles with lower FC / GHG emissions	Purchase / operation	Consumers	Ongoing incentive to reduce FC; stimulates consumer response; administratively simple; transition to road pricing	Double taxation, patch-work systems may reduce effectiveness; revenue generation instead of fuel reduction	Ongoing incentive to reduce FC; aligns consumer demand w/ requirement for lower FC in new vehicles
Feebates	Incentivize adoption of vehicles with lower FC / GHG emissions	Purchase	Consumers (with manufacturer response)	Ongoing incentive to reduce FC; stimulates consumer response; possibly revenue-neutral; progressive	Disproportionate impact on manufacturers (size-based system can help); rebound effect; discrete rates harm effectiveness	Incentive for lower FC eases burden of manufacturer's internal pricing strategy; demand response helps
Fuel tax / carbon tax	Correct fuel use externalities; efficiently raise revenue; charge for use of infrastructure	Operation	Consumers (with manufacturer response)	Cost-effective; lowers travel, FC; stimulates consumer response; administratively simple; can price externalities	Impacts broad range of interests aligned against tax increases; regressive; large wealth transfer to government	Offset rebound effect by reducing travel; aligns consumer demand with requirement for lower FC in new vehicles
Pay As You Drive / Pay At The Pump (PATP)	Charge insurance on an equitable basis; remove incentive to over-consume private travel	Operation	Consumers	Does not increase fuel price; tends to be progressive; cost-neutral for avg. driver; helps shift to road pricing	Collective action failure, regulations, & overbroad patents act as barriers; no affect on new vehicle FC.	Offset rebound effect by reducing travel; PATP can align consumer demand w/ requirement for lower FC
Scrappage incentives	Reduce length of time that oldest vehicles are kept on the road; improve fleet FC	Retirement	Consumers	Increases fleet rate of turn-over; improves fleet FC; reduces local air pollution.	Has regressive impacts, but may be small; benefits may be offset by migration of older vehicles.	Speeds penetration of lower FC vehicles into fleet.

FC = Fuel consumption

5.0 Analysis of a coordinated policy approach

Chapter 5 illustrates how a coordinated fiscal policy option interacts with a regulatory fuel consumption standard. Using a model of the U.S. light-duty vehicle fleet, the first section compares the impact of fuel tax increases in comparison to CAFE standards. For each instrument, a stringent policy case out to 2035 is compared against a case where political will weakens by 2020 and results in a less aggressive effort to reduce fuel consumption in new vehicles. A final case coordinates a fuel tax policy alongside CAFE to show how the two policy options interact.

The second section presents estimates of the cost and benefits obtained by using future technologies to reduce vehicle fuel consumption. Using a plausible scenario of technology penetration, estimates of the extra costs, fuel savings, and GHG emission reductions across new light-duty vehicles are developed for the 2020 and 2035 model years. The role that feebates might play in offsetting a portion of these costs is examined. The third section varies sensitive parameters to verify the robustness of the conclusions drawn from the preceding sections.

5.1 Policy cases

This section describes the development of two illustrative policy scenarios relative to a No Change baseline: CAFE legislation, and a fuel tax policy. Based on profiles of new vehicle fuel consumption developed for each scenario, the U.S. light-duty vehicle fleet model described in Chapter 3 is used to determine the changes vehicle travel, fuel use and GHG emissions. The potential for coordinating CAFE and fuel tax increases is discussed, highlighting specific features of each instrument and the role that they each may play alongside on another.

5.1.1 CAFE policy cases

Section 4.1 described the CAFE standards legislated by the Energy Independence and Security Act (EISA) of 2007. Title I of the bill requires cars and light trucks to achieve a combined average fuel consumption rate of at most 6.72 L / 100 km (or at least

35 mpg) by 2020. This corresponds to an on-road fuel consumption of 8.20 L / 100 km, assuming a 22% adjustment factor between fuel consumption rates measured by the EPA and rates experienced in on-road driving[47]. Beyond 2020, CAFE standards must be set at the "maximum feasible average fuel economy" (EISA, 2007). If reducing fuel consumption remains a political priority beyond 2020, NHTSA may continue to set stringent standards between 2020 and 2035. It is equally possible that the political will for reducing fuel consumption will subside, and that only modest improvements will be achieved after 2020[48].

The CAFE policy cases developed in this section illustrate the impact of the new legislation on light-duty vehicle GHG emissions in 2020 and 2035. Due to uncertainty in how the standards will be set beyond 2020, two different cases are examined:

1. A *CAFE* case where the political will and demand for reducing fuel consumption fades by 2020, similar to the period when standards remained largely constant between 1985 and 2007. Under this scenario, standards remain constant and there is no further improvement in the rate of fuel consumption from 2020 to 2035.
2. A *CAFE High* case where political will and consumer demand for reduced fuel consumption remain strong beyond 2020, enabling NHSTA to prescribe stringent increases in CAFE standards.

Table 16: Annual rates of improvement in new car and light truck on-road fuel consumption assumed for the CAFE, CAFE High policy cases. The EIA's projections for new light duty vehicles under the new CAFE legislation are also shown for comparison (EIA, 2008a).

PERIOD	CAFE [% per year]	CAFE High [% per year]	EIA Annual Energy Outlook 2008 [% per year]	
	Cars and Light Trucks	Cars and Light Trucks	Cars	Light Trucks
2010 – 2015	3.7	3.7	2.2	3.1
2015 – 2020	2.1	2.1	3.7	2.6
2020 – 2035	0.0	2.3	0.2	0.5

[47] This is the same factor used by the World Business Council on Sustainability's Sustainable Mobility Project. See Fulton, Eads (2004, p. 21).

[48] Although NHSTA was charged with establishing standards at the "maximum feasible [level]" for light trucks under the original CAFE legislation, only modest improvements were achieved during the early 1990's, and standards were frozen by Congress between 1996 and 2002. See Section 4.1 for details.

Table 16 shows the annual rates of improvement in fuel consumption for both new cars and light trucks under the CAFE and CAFE High policy cases. For both policy cases, the rate of improvement between 2010 and 2020 is roughly 2.9%, which achieves the target on-road fuel consumption of 8.20 L / 100 km by 2020 (equivalent to a test cycle fuel economy of 35 mpg). After 2020, fuel consumption remains constant under the CAFE case. The CAFE High policy case assumes an annual improvement rate of 2.3% per year in new vehicle fuel consumption, which nearly halves fuel consumption in new cars and trucks from 2010 levels by 2035. Figure 10 shows the projected on-road fuel consumption of new cars and light trucks under CAFE and CAFE High.

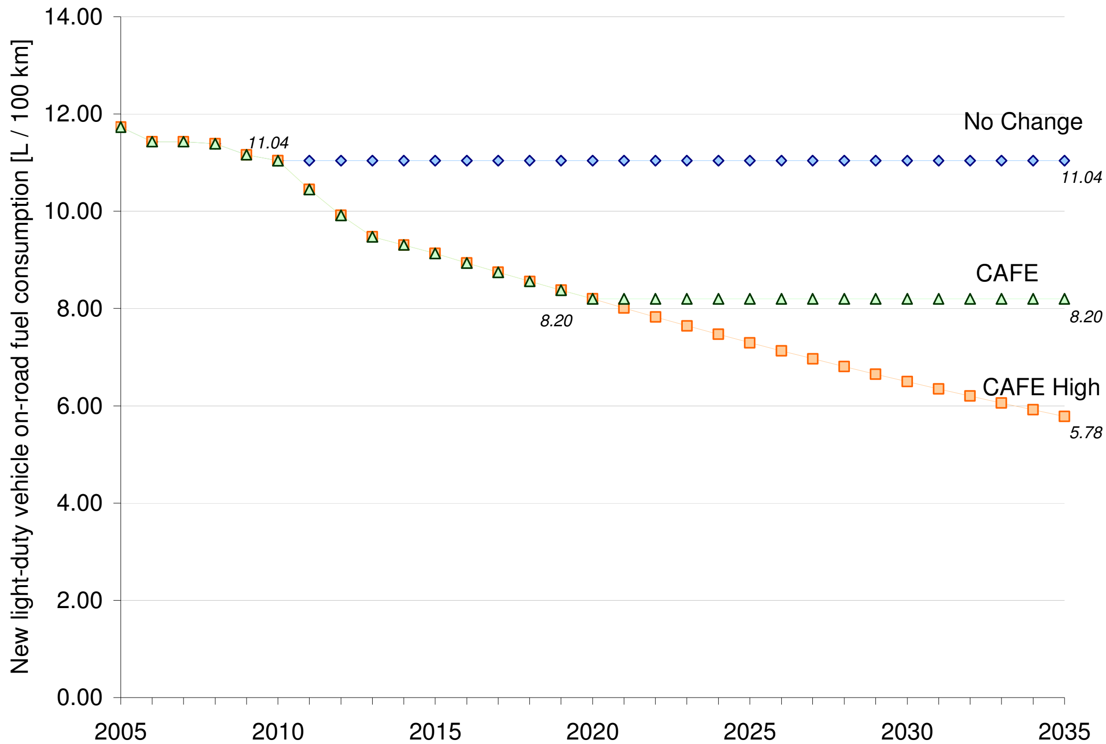


Figure 10: Average on-road fuel consumption of new light-duty vehicles under CAFE and CAFE High policy cases relative to No Change[49].

If the price of fuel remains relatively constant between 2010 to 2035, the reduced rates of vehicle fuel consumption will lower the fuel cost of travel and incentivize consumers to drive new vehicles further. The impact of the CAFE policy cases on vehicle

[49] On-road fuel consumption values are obtained by adjusting the CAFE test cycle fuel consumption by a factor of 1.22.

travel is shown by Figure 11. From the literature reviewed in Section 4.4, the elasticity of annual vehicle travel relative to a change in the fuel cost of travel is assumed to be -0.03 over the short-term and increasing linearly to a long-term maximum of -0.10 by 2015. These elasticities are implemented using the methodology described in Section 3.0.

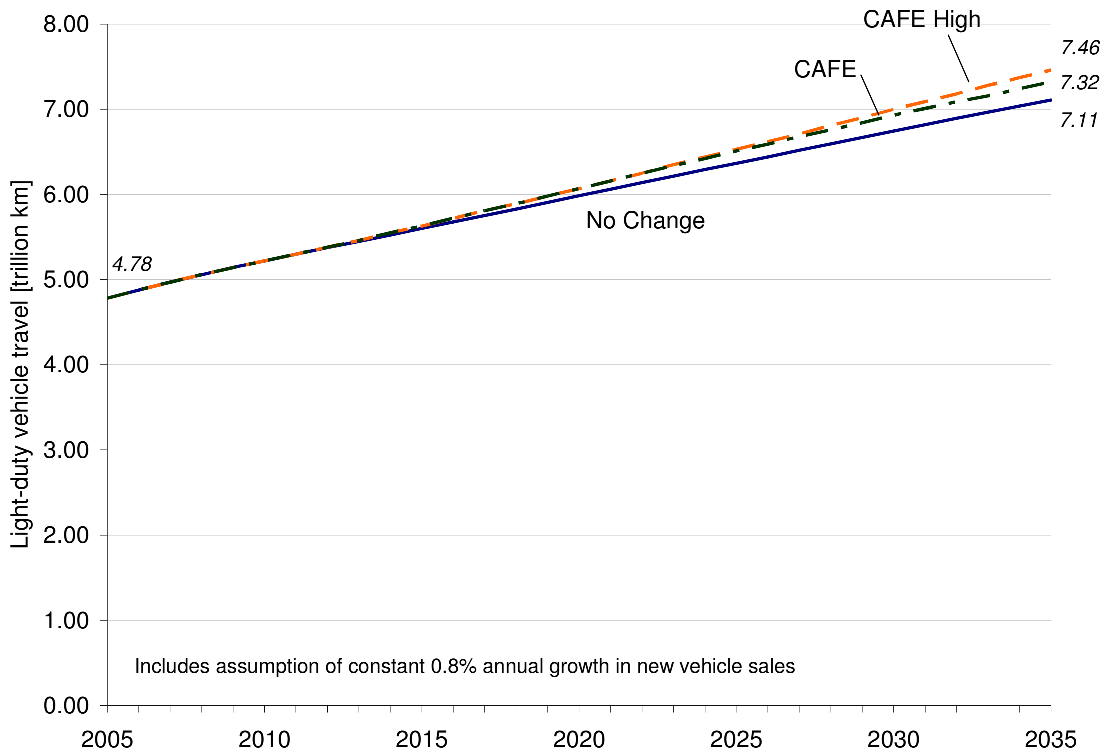


Figure 11: Light-duty vehicle travel under the CAFE policy cases relative to No Change. Assumes a constant fuel price of $2.50 per gallon ($0.66 per liter) between 2010 and 2035, including state and local taxes.

The CAFE High policy case results in an increase in vehicle travel of 5% relative to No Change by 2035. This increase in travel is caused by the lower rates of fuel consumption in new cars and light trucks that enter the fleet between 2010 and 2035. Assuming a constant fuel price of $2.50 starting in 2010, the fuel cost of travel for new vehicles entering the fleet gradually decreases, resulting in slightly higher rates of travel. The increase in vehicle travel is nearly the same in the CAFE case, although reduced by a small amount since the average new fleet fuel consumption does not improve between 2020 to 2035. Even so, vehicle travel remains 3% higher in 2035 under CAFE relative to No Change.

The total GHG emissions from the light-duty fleet under the CAFE policy cases are show in Figure 12. Total emissions include GHGs produced during vehicle operation (tank-to-wheels), upstream extraction, refining and transport (well-to-tank), and vehicle material lifecycle. Under No Change, emissions increase by 40% in 2035 relative to 2005. Unsurprisingly, both the CAFE and CAFE High policy cases achieve the same 11% reduction of in GHG emissions from No Change in 2020—a 6% increase from 2005 emissions. By 2035, the CAFE High policy case reduces GHG emissions by 32% relative to the No Change baseline (or 4% relative to 2005 levels). The CAFE case achieves about two-thirds of this reduction, dropping GHG emissions by 21% relative to No Change in 2035 (an 11% increase relative to 2005 emissions).

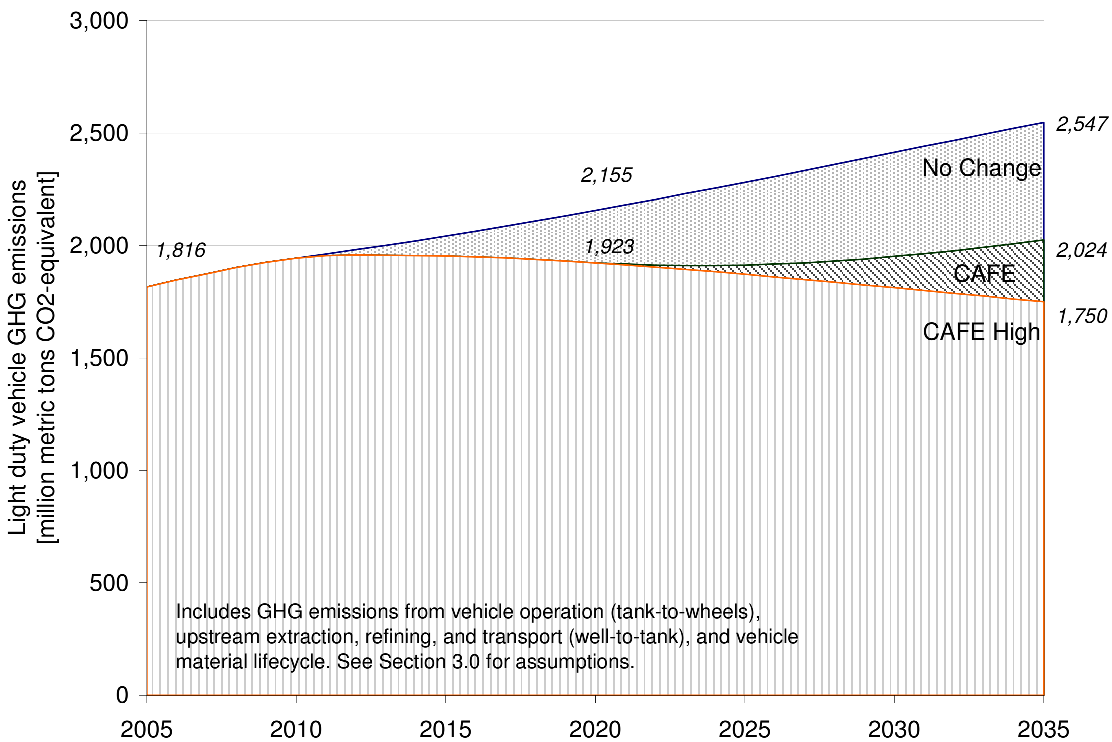


Figure 12: Light-duty vehicle GHG emissions under CAFE policy cases relative to No Change.

More importantly, under the CAFE case, GHG emissions are 5% *higher* in 2035 than in 2020. The trajectory of emissions is once again increasing under this scenario: with no improvement in fuel consumption after 2020, growth in vehicle sales and travel begin to offset a portion of the reduction achieved in the previous 10 years. As a result of this trajectory, further reductions in light-duty vehicle fuel consumption will be required just to again slow the growth in GHG emissions. This result stresses the importance of continuous and long-term improvements in fuel consumption in order to overcome rates of growth in vehicle sales and travel.

5.1.2 Fuel tax policy cases

Fuel tax increases are an administratively simple way of increasing the fuel cost of travel. This section develops two fuel tax policy cases to illustrate the effects that higher fuel prices could have on vehicle fuel consumption, annual travel, and GHG emissions. In this section, two different fuel tax cases are examined:

1. A *Fuel Tax* case where fuel tax increases in real 2007 dollars by $0.15 per gallon ($0.04 per liter) annually between 2010 until 2020. Beyond 2020, there are no increases in the real price of fuel tax. By 2020, the price of a gallon of fuel is $4.00 ($1.06 per liter) and remains at this level through 2035. This is a total tax increase of $1.50 per gallon ($0.40 per liter), assuming a base fuel price of $2.50 that includes federal state and local taxes of 40 cents on average.
2. A *Fuel Tax High* case where fuel tax increases by $0.15 per gallon in real 2007 dollars between 2010 to 2020, and continues to rise at this rate until 2035. By 2035 the price of a gallon of fuel is $6.25 ($1.65 per liter). This is a tax increase of $3.75 per gallon ($1.00 per liter) by 2035.

The level of taxation under the Fuel Tax policy case is at the higher bound of increases in the fuel tax that were justified in Section 4.4. At the same time, the price of GHG emissions is expected to rise over time, and externalities such as congestion, accidents, and equitable financing of highway infrastructure provide a strong rationale for increases that are on the order of the Fuel Tax case, alongside the need to reduce fuel use and emissions.

This analysis assumes the same elasticity of vehicle travel with respect to the fuel cost of travel as for the CAFE policy case, namely -0.03 over the short-term, linearly increasing to -0.10 by 2015. The change in new vehicle fuel consumption with respect to fuel price is assumed to be -0.03 in the short term, linearly increasing to -0.33 by 2035 (see Section 4.4). These elasticities were employed using the methodology outlined in Section 3.2.

As described in Section 4.4, increases in the price of fuel will stimulate consumer demand for lower rates of fuel consumption in new vehicles. The improvement in new vehicle fuel consumption generated by this demand under the Fuel Tax and Fuel Tax High cases is shown in Figure 13. Both policy cases provide the same pricing incentive to reduce fuel consumption until 2020, resulting in an on-road light duty fleet average of 10.28 L / 100 km (23 mpg). Beyond 2020, fuel price increases under the Fuel Tax High case gradually reduce fuel consumption to a fleet average of 8.14 L / 100 km (29 mpg) in 2035.

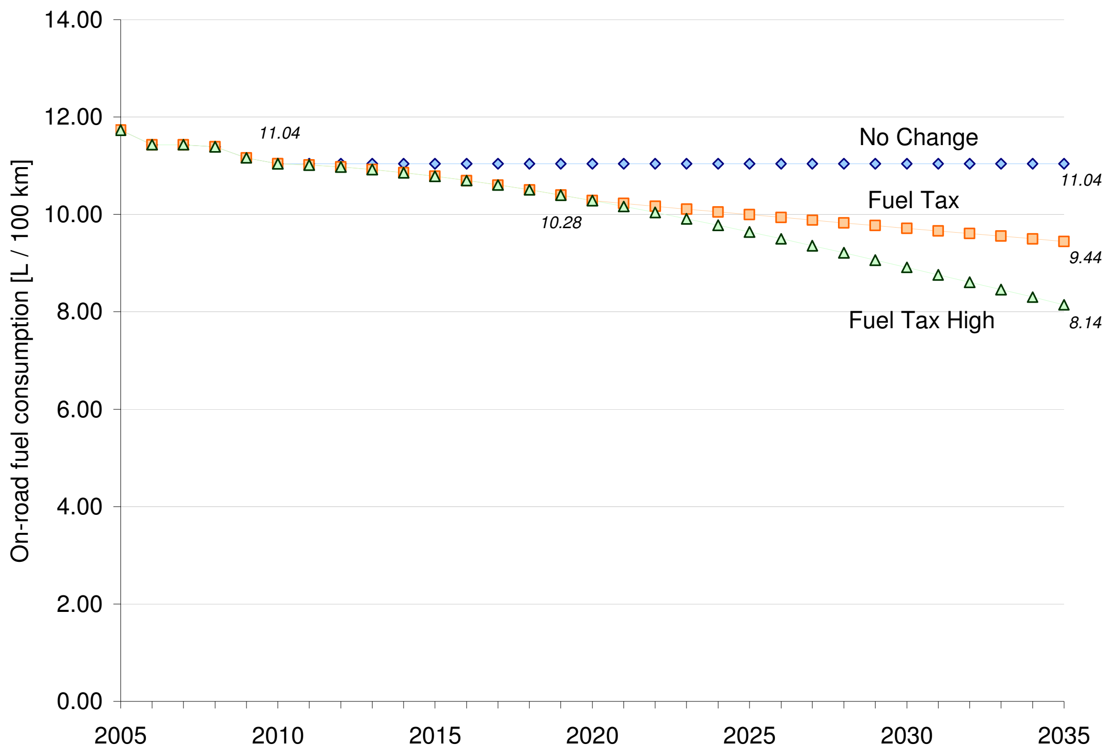


Figure 13: Average on-road fuel consumption of new light-duty vehicles under Fuel Tax and Fuel Tax High policy cases relative to No Change

Under the Fuel Tax case, fuel prices remain constant in real terms between 2020 to 2035. Even so, vehicle fuel consumption continues to drop due to the assumption that the elasticity of fuel consumption with respect to fuel price continues to increase until 2035. That is, even though the fuel price remains constant beyond 2020, the model assumes that consumers continue to adjust to the price changes between 2020 and 2035 as a result of slow turnover rates in the fleet that are on the order of 15 years.

Figure 14 shows the changes in vehicle travel for the Fuel Tax and Fuel Tax High policy cases relative to No Change. There are two important differences between the fuel tax policy cases and CAFE. First, vehicle travel is *reduced* relative to the No Change case; second, the overall change in vehicle travel occurs earlier and is larger in magnitude than under CAFE.

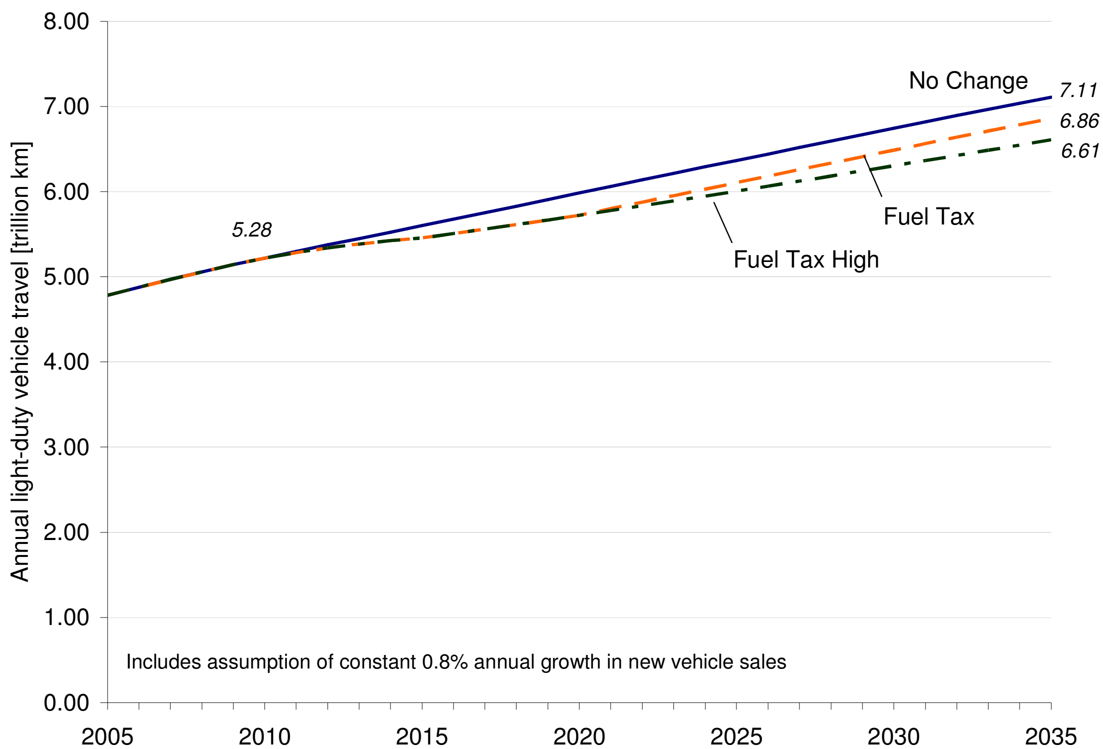


Figure 14: Annual vehicle travel under Fuel Tax and Fuel Tax High policy cases relative to No Change

These differences stems from important features of the fuel tax policies. First, they *increase* the fuel cost of travel relative to No Change, which offsets the rebound effect to achieve an overall reduction in vehicle travel. Second, tax increases impact the *entire in-use fleet*—both old and new vehicles are affected by the increased fuel cost of travel. In fact, older vehicles with higher rates of fuel consumption are affected to a greater extent than new, less consumptive models. Under the Fuel Tax High case, the fuel cost of travel for the average car made in 2020 is 15 cents per km in 2035—this is 15% higher than that of a brand-new car coming onto the road in the 2035 model year.

The total GHG emissions from light-duty vehicles under the fuel tax policy cases are shown in Figure 15. Under the Fuel Tax policy case, the GHG emissions are reduced by 13% compared to No Change. The Fuel Tax High policy reduces GHG emissions by 21% relative to the No Change baseline. Of this reduction, roughly three-quarters is attributable to reductions in vehicle fuel consumption, while the remaining portion is achieved through lower vehicle travel. Similar to the CAFE policy case, without further increases in the price of fuel beyond 2020, GHG emissions continue to rise between 2020 and 2035 under the Fuel Tax policy case.

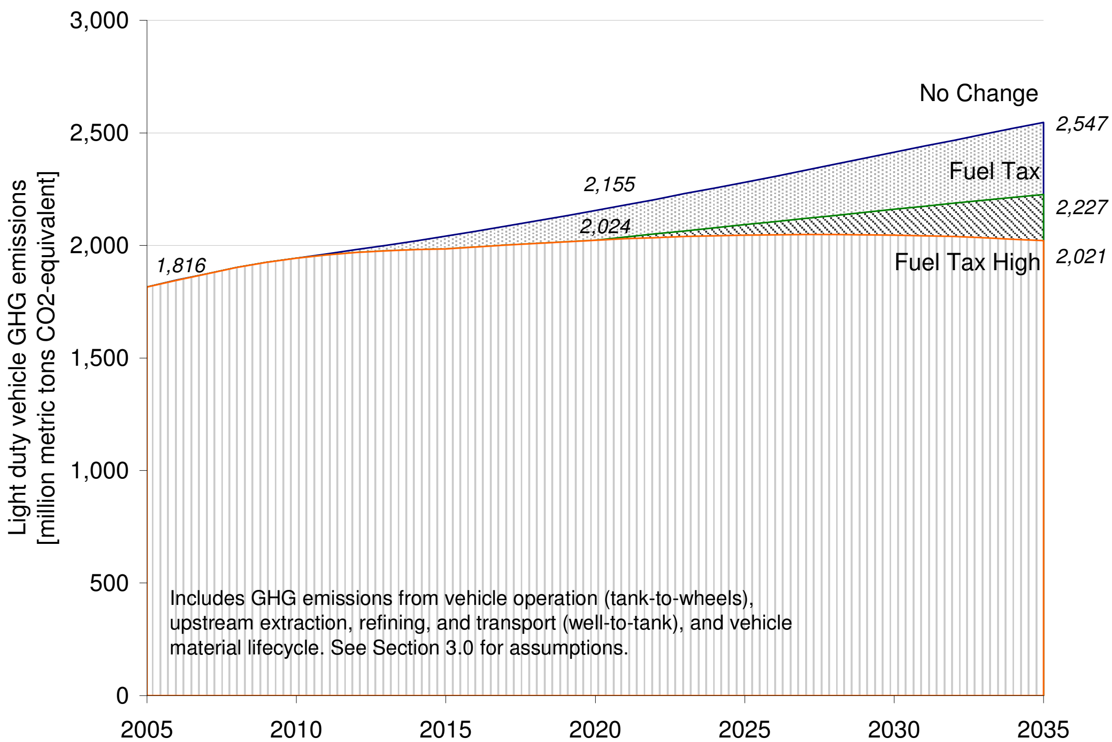


Figure 15: Light-duty vehicle GHG emissions under Fuel Tax and Fuel Tax High policy cases relative to No Change

5.1.3 Coordinating the policy cases

The results of the CAFE, fuel tax, and the coordinated policy cases are shown by Table 17. The CAFE and CAFE High policy cases achieve reductions of roughly 20 to 35% in both fuel use and GHG emissions, while the Fuel Tax and Fuel Tax High cases achieve reductions of 15 to 23% relative to No Change in 2035.

Table 17: Summary of CAFE, fuel tax, and coordinated policy cases

Policy Case	Price of fuel [$ / gallon]		Avg. new vehicle on-road fuel consumpt'n [L / 100 km]		Vehicle travel [trillion km]		Fuel use [billion liters]		GHG Emissions[50] [$MtCO_2e$]	
	2020	2035	2020	2035	2020	2035	2020	2035	2020	2035
No Change	2.50	2.50	11.04	11.04	5.98	7.11	661	777	2,155	2,547
CAFE	2.50	2.50	8.20	8.20	6.07	7.32	583	600	1,923	2,024
CAFE High	2.50	2.50	8.20	5.78	6.07	7.46	583	508	1,923	1,750
Fuel Tax	4.00	4.00	10.28	9.44	5.72	6.86	617	669	2,024	2,227
Fuel Tax High	4.00	6.25	10.28	8.14	5.72	6.61	617	599	2,024	2,021
CAFE + Fuel Tax	4.00	4.00	8.20	8.20	5.79	6.98	556	573	1,843	1,942
CAFE + Fuel Tax High	4.00	6.25	8.20	5.78	5.79	6.80	556	463	1,843	1,617

A key difference between the two sets of policy instruments, however, is the mechanism by which fuel use and GHG emissions are reduced. Under CAFE, reductions come about by the adoption of technologies and alternative powertrains that provide efficiency gains that are used to reduce the fuel consumption of vehicles. Manufacturers are required to implement the technologies in this fashion regardless of the market demand for reductions in fuel consumption. With these new technologies, the retail price of vehicles will increase for the same size and performance. In response, consumers may sales mix shift to smaller vehicles. Since the new CAFE standards proposed by NHTSA are normalized across vehicle size, smaller vehicles will be required to improve fuel consumption as well; manufacturers will not necessarily be able to fulfill their CAFE requirements through sales mix shifts alone. Thus, while CAFE provides a means of achieving dramatic reductions in new vehicle fuel consumption over a relatively short timeframe (10 years), it may well fight an uphill battle if market forces continue to show a strong preference for other vehicle attributes.

In contrast, under the Fuel Tax policy cases, manufacturers are not required to direct efficiency gains to reductions in fuel consumption. Instead, as the price of fuel

[50] Includes well-to-tank, well-to-wheel, and material cycle GHG emissions.

increases, consumers begin to place more value on lower rates of fuel consumption relative to other vehicle attributes. Manufacturers gradually respond to this demand by using efficiency improvements to downsize engines and other vehicle components rather than increasing the size and power of vehicles. These changes occur over a longer timeframe (15 to 25 years) than under CAFE. Some level of sales mix shifting to smaller vehicles is likely under the Fuel Tax policy cases, since consumers may elect to purchases smaller vehicles that get better rates of fuel consumption. At the same time, consumers will also reduce the amount of private vehicle travel they undertake. This can be done in various ways, such as shifting from private vehicles to public transportation, reducing the number of trips taken, or increasing the number of passengers per vehicle through carpooling.

To illustrate these interactions, the CAFE and CAFE High policy cases were combined with the Fuel Tax and Fuel Tax High cases respectively. Since the CAFE policy cases examined here achieve lower rates of fuel consumption than the Fuel Tax policies provide (see Figure 10 and Figure 13), it was assumed that CAFE remained a binding limit on fuel consumption. Alongside CAFE, however, the Fuel Tax policies work to offset the rebound effect, reducing vehicle travel and achieving further reductions in GHG emissions and fuel use as shown in Figure 16 and Figure 17. The result is a dramatic increase in new vehicle fuel consumption through CAFE, with an additional contribution from the fuel tax through reduced vehicle travel.

Finally, although it is harder to quantify, coordination of CAFE with fuel tax policies aligns consumer demand with the regulatory fuel consumption requirements. The fuel tax policies *pull* reductions in vehicle fuel consumption into the market at an increasing rate, though more gradually than the regulatory *push* of CAFE manufacturers to supply less-consumptive vehicles. To provide some quantitative estimate of this effect, the *degree of consumer alignment* can be measured using the following relation:

$$Degree\ of\ Consumer\ Alignment\ [\%] = \frac{FC_{No\ Change} - FC_{FuelTax}}{FC_{No\ Change} - FC_{CAFE}} \times 100$$

This ratio of the fuel consumption (*FC*) benefit under a fuel tax policy relative to the benefit under CAFE is a measure of the degree to which market-driven demand for lower rates of fuel consumption contributes to the overall reduction mandated by CAFE.

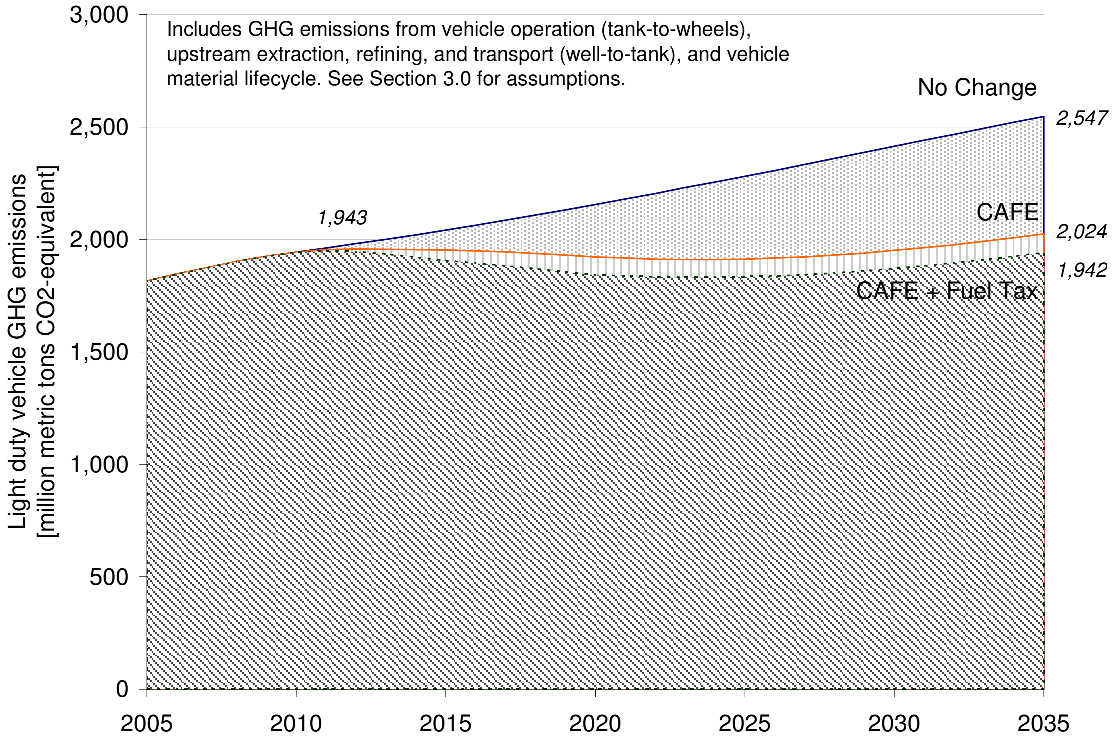


Figure 16: Light-duty vehicle GHG emissions under "CAFE + Fuel Tax" relative to No Change

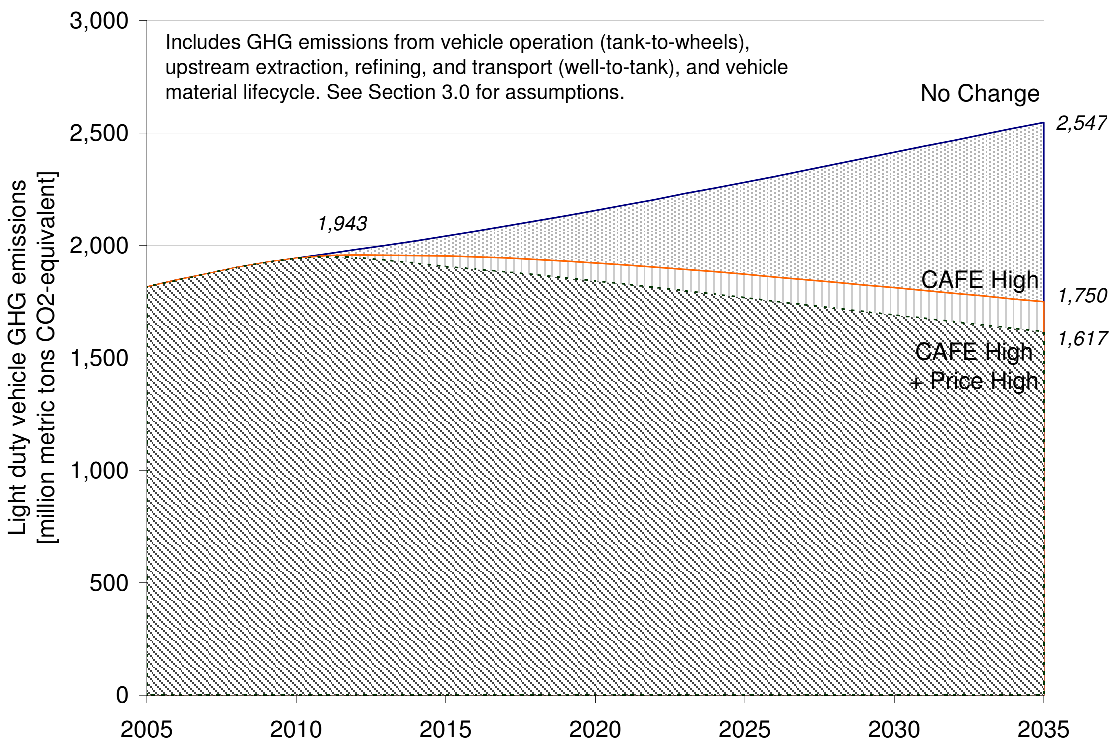


Figure 17: Light-duty vehicle GHG emissions under "CAFE High + Fuel Tax High" relative to No Change

The degree of consumer alignment for the combined policy cases is shown in Table 18. Due to symmetry in how the policy scenarios were developed, the degree of consumer alignment is the same for both the CAFE and Fuel Tax combined policy case, and the CAFE High and Fuel Tax High combined policy case. In the 2020 model year, consumer demand accounts for around a quarter of the regulated reductions in new vehicle fuel consumption. By the 2035 model year, the increased responsiveness in consumers accounts for half of the required reductions in fuel consumption under the CAFE policies. Balancing consumer demand for lower rates of fuel consumption against the mandated targets enables manufacturers to meet their CAFE obligations with vehicles that are more attractive to buyers.

Table 18: Fuel cost of travel and degree of consumer alignment with fuel consumption regulations under both the CAFE and Fuel Tax combined policy case, and the CAFE High and Fuel Tax High combined policy case. All dollar amounts are in real 2007 dollars.

POLICY CASE	MODEL YEAR	
	2020	2035
No Change		
Fuel cost of travel [cents / km]	7.5	7.3
Fuel consumption (FC) [L / 100 km]	11.04	11.04
CAFE with Fuel Tax		
Fuel cost of travel [2007 cents / km]	10.7	8.9
FC demanded under fuel tax [L / 100 km]	10.28	9.44
FC required by CAFE [L / 100 km]	8.20	8.20
Degree of consumer alignment [%]	27%	55%
CAFE High with Fuel Tax High		
Fuel cost of travel [cents / km]	10.7	12.0
FC demanded under fuel tax [L / 100 km]	10.28	8.14
FC required by CAFE [L / 100 km]	8.20	5.78
Degree of consumer alignment [%]	27%	55%

Table 18 also includes the average changes in the fuel cost of travel (in $ per km) that consumers will face under the combined CAFE and fuel tax policy cases. Under the CAFE and Fuel Tax case, the fuel cost of travel increases by 43% relative to No Change by 2020, declining to 22% above No Change in 2035 as the fuel tax remains constant and new vehicle fuel consumption improves slightly. Under the CAFE High and Fuel Tax

High case, the fuel cost of travel continues to increase, and is 64% higher relative to No Change in 2035.

5.2 Engineering costs and changes in vehicle retail price

The purpose of this section is to quantify the magnitude and cost of introducing technologies that can reduce vehicle fuel consumption at a rate roughly equivalent to the CAFE policy cases developed in the preceding section. First, cost estimates of future vehicle technologies relative to today are provided. Next, using a plausible scenario of alternative powertrain technology penetration, aggregate costs across the light-duty fleet are developed. Changes in vehicle production costs and retail price increases are discussed, as well as the cost of reducing GHG emissions. Finally, the potential for a feebate policy to offset increases in production costs and retail prices is briefly examined.

5.2.1 Future vehicle cost estimates

The incremental retail price increases of different propulsion systems relative to current and future gasoline vehicles are shown in Table 19. These retail prices were based on production cost estimates summarized in Table 21 and Table 22[51]. Production costs describe those costs associated with producing a vehicle at the manufacturing plant gate; they include vehicle manufacturing, corporate overhead, and production overhead. To account for distribution costs and manufacturer and dealer profit margins, production costs were multiplied by a factor of 1.4 to provide the retail price estimates[52]. This is a representative retail price estimate, but does not represent the actual retail price that would be arrived at in a competitive auto market.

If efficiency improvements provided by these technologies are directed towards reducing the rate of fuel consumption, vehicles will provide benefits by using less fuel and emitting less GHG emissions over a given amount of travel. The relative fuel consumption of individual vehicle types is shown in Table 20.

[51] The production cost estimates are based on earlier work done by Kromer & Heywood (2007, pp. 117-118) and Kasseris & Heywood (2007). This work extends their assessments by updating the estimate of future improvements to a conventional gasoline spark-ignition engine, and by expanding the cost estimates to include current cars and light trucks as well as future light trucks.
[52] The retail price factor of 1.4 is was taken from Vyas et al. (2000) based on the assumption that production costs include vehicle manufacturing, and corporate and production overhead.

Table 19: Incremental retail price increase of current and future propulsion technologies

VEHICLE TYPE	CARS		LIGHT TRUCKS	
	Relative to current gasoline ICE	Relative to 2035 gasoline ICE	Relative to current gasoline ICE	Relative to 2035 gasoline ICE
Current Gasoline	$0	--	$0	--
Current Diesel	$1,700	--	$2,100	--
Current Turbo Gasoline	$700	--	$800	--
Current Hybrid	$4,900	--	$6,300	--
2035 Gasoline	$2,000	$0	$2,400	$0
2035 Diesel	$3,700	$1,700	$4,500	$2,100
2035 Turbo Gasoline	$2,700	$700	$3,200	$800
2035 Hybrid	$4,500	$2,500	$5,600	$3,200
2035 Plug-in Hybrid	--	$5,900	--	$8,300
2035 Battery Electric	--	$14,400	--	$22,100
2035 Fuel Cell	--	$5,300	--	$7,400

Table 20: Fuel consumption of current and future vehicle powertrains. Bandivadekar, 2008, p. 75.

VEHICLE TYPE	CARS			LIGHT TRUCKS		
	Fuel consumption [L / 100 km]	Relative to current gasoline vehicle	Relative to 2035 gasoline vehicle	Fuel consumption [L / 100 km]	Relative to current gasoline vehicle	Relative to 2035 gasoline vehicle
Current Gasoline	8.8	1.00	--	13.6	1.00	--
Current Diesel	7.4	0.84	--	10.1	0.74	--
Current Turbo	7.9	0.90	--	11.3	0.83	--
Current Hybrid	6.2	0.70	--	9.5	0.70	--
2035 Gasoline	5.5	0.63	1.00	8.6	0.63	1.00
2035 Diesel	4.7	0.53	0.85	6.8	0.50	0.79
2035 Turbo	4.9	0.56	0.89	7.3	0.54	0.85
2035 Hybrid	3.1	0.35	0.56	4.8	0.35	0.56
2035 Plug-in[53]	1.5	0.18	0.28	2.4	0.18	0.28

[53] 0.65 L / 100 km in gasoline equivalent terms of electricity use in addition to liquid fuel consumption not shown for cars; 1.01 L / 100 km for light trucks

Table 23 and Table 24 provide a summary of the savings in fuel use and GHG emissions of each vehicle type over an assumed 15-year lifetime of 240,000 km vehicle travel. It is important to note that a negative "net price" in Table 23 and Table 24 does not imply that a technology is "zero cost". Instead of lowering fuel consumption, efficiency improvements can also be used to increase the size and power of vehicles. The full cost of reducing fuel consumption would account for how changes in vehicle attributes such as fuel consumption, power, and size affect the value that consumers derive from these products (CBO, 2003; Box 2-1, p. 8).

The results from the future vehicle cost assessment show that alternative powertrains entering the fleet today, such as improved gasoline and diesel engines, turbocharged gasoline engines and hybrid powertrains, cost from 10 to 30% more than a baseline gasoline vehicle. This price increase is estimated to drop to 5 to 15% in the future. Longer-term options such as plug-in hybrid and fuel-cell vehicles are estimated to cost between 25 to 30% more than a future gasoline vehicle. Battery electric vehicles remain costly, approaching double the cost of a future gasoline vehicle.

Retail price increases from technologies that reduce fuel consumption are largely offset by fuel savings provided over the vehicle lifecycle, but not in all cases. Relative to a current vehicle, turbocharged gasoline engines fully pay-back the retail price increase in fuel savings, assuming a fuel price of $2.50 per gallon and a 5% discount rate over 15 years of vehicle operation. Hybrid and diesel powertrains pay-back 60 and 90% of the up-front retail price increase respectively. Reductions in the price of future hybrid systems will allow these vehicles to break even, while diesel engines may loose ground relative to future gasoline vehicles. Longer-term options such as plug-in hybrid and fuel cell vehicles are estimated to pay-back 50 to 70% of the increase in retail price at $2.50 per gallon. At higher fuel prices of $4.00 to $6.25 per gallon—equivalent to the Fuel Tax policy cases used in the previous section—all technologies fully pay-back the initial retail price increase, except diesel cars below prices of $5.25 per gallon, and the battery electric vehicle.

Table 21: Incremental production cost and vehicle weight reduction cost assumptions by powertrain type for cars. All costs in $US 2007.[54]

CARS	Current Gasoline	Current Diesel	Current Turbo Gasoline	Current Hybrid	2035 Gasoline	2035 Diesel	2035 Turbo Gasoline	2035 Hybrid	2035 Plug-in Hybrid	2035 Battery Electric	2035 Fuel Cell
Engine											
NA SI	$3,000	--	$3,000	$3,000	$3,700	--	$3,700	$3,700	$3,700	--	--
Diesel	--	$3,700	--	--	--	$4,400	--	--	--	--	--
Turbo	--	--	$500	--	--	--	$500	--	--	--	--
Motor / controller[55]	--	--	--	$1000	--	--	--	$600	$800	$1,500	$1,600
Fuel cell	--	--	--	--	--	--	--	--	--	--	$3,000[56]
Downsizing	--	--	--	-$100	--	--	--	-$100	-$200	--	--
Transmission											
Hybrid trans. & integration	--	--	--	$400	--	--	--	$300	$300	--	--
1-spd. trans.	--	--	--	--	--	--	--	--	--	$200	$200
Energy storage											
Battery[57]	--	--	--	$2,000	--	--	--	$800	$2,700	$12,000	$1,000
H_2 Storage[58]	--	--	--	--	--	--	--	--	--	--	$1,800[56]
Miscellaneous											
Exhaust	$300	$800[59]	$300	$300	$300	$800[59]	$300	$300	$300	--	--
Wiring	--	--	--	$200	--	--	--	$200	$200	$200	$200
Charger	--	--	--	--	--	--	--	--	$400	$400	--
Vehicle weight reduction[60]	--	--	--	--	$700	$700	$700	$700	$700	$700	$700
TOTAL[61]	$3,300	$4,500	$3,800	$6,800	$4,700	$5,900	$5,200	$6,500	$8,900	$15,000	$8,500

[54] Production cost assumptions in this table adapted from Kromer (2007,Tables 51-53, pp. 117, 118) based on sources noted by Kromer in Table 51, p. 117.
[55] $200 + $30 per kW for current hybrid vehicle; $200 + $15 per kW for 2035 vehicles (Kromer, 2007, Table 51, p, 117).
[56] Assumes fuel cell costs $50 per kW; hydrogen storage costs $15 / kWh (Kromer, 2007, Table 51, p, 117).
[57] Assumes $2000 / kWh for current hybrid vehicle. For 2035 vehicles, assumptions range from $250 / kWh for high energy batteries to $750 / kWh for high power batteries. Assumes 2035 hybrid battery costs $750 / kWh, 2035 plug-in hybrid battery costs $320 / kWh, 2035 fuel cell battery costs $750, 2035 battery electric vehicle costs $250 / kWh (Kromer, 2007, Table 52, p. 117).
[58] Assumes $15 / kWh storage (Kromer, 2007, Table 51, p. 117).
[59] Includes NO_x after-treatment and diesel particulate filter (DPF).
[60] Assumes 20% weight reduction in 2035 vehicles; roughly 14% of weight reduction is achieved through material substitution at $3 / kg; the remainder is secondary reduction at no cost.
[61] Total incremental production cost relative to a baseline vehicle cost of $10,700. Total production cost of current gasoline car is therefore: $10,700 + $3,300 = $14,000.

Table 22: Incremental production cost and vehicle weight reduction cost assumptions by powertrain type for trucks. All costs in $US 2007.

TRUCKS	Current Gasoline	Current Diesel	Current Turbo Gasoline	Current Hybrid	2035 Gasoline	2035 Diesel	2035 Turbo Gasoline	2035 Hybrid	2035 Plug-in Hybrid	2035 Battery Electric	2035 Fuel Cell
Engine											
NA SI[62]	$3,900	--	$3,900	$3,900	$4,700	--	$4,700	$4,700	$4,700	--	--
Diesel[62]	--	$4,800	--	--	--	$5,600	--	--	--	--	--
Turbo[62]	--	--	$600	--	--	--	$600	--	--	--	--
Motor / controller[63]	--	--	--	$1,200	--	--	--	$800	$1,100	$1,900	$2,000
Fuel cell	--	--	--	--	--	--	--	--	--	--	$3,900[64]
Downsizing	--	--	--	-$100	--	--	--	-$100	-$200	--	--
Transmission											
Hybrid trans. & integration	--	--	--	$600	--	--	--	$400	$400	--	--
1-spd. trans.	--	--	--	--	--	--	--	--	--	$300	$300
Energy storage											
Battery[65]	--	--	--	$2,600	--	--	--	$1,000[66]	$4,000[67]	$18,000[67]	$1,200[66]
H_2 Storage	--	--	--	--	--	--	--	--	--	--	$2,700[68]
Miscellaneous											
Exhaust	$300	$900[69]	$300	$300	$300	$900[69]	$300	$300	$300	--	--
Wiring	--	--	--	$200	--	--	--	$200	$200	$200	$200
Charger	--	--	--	--	--	--	--	--	$400	$400	--
Vehicle weight reduction[70]	--	--	--	--	$900	$900	$900	$900	$900	$900	$900
TOTAL[71]	$4,200	$5,700	$4,800	$8,700	$5,900	$7,400	$6,500	$8,200	$11,800	$21,700	$11,200

[62] Gasoline, diesel and turbo engine costs roughly scaled by a factor of 1.3 relative to gasoline/diesel cars, the ratio of current gasoline car to truck (1620 kg to 2,140 kg) vehicle weight (EPA, 2007).
[63] $200 + $30 for current hybrid vehicle; $200 + $15 per kW for 2035 vehicles (Kromer, 2007, Table 51, p, 117). Motor power calculated by holding power to curb weight ratio constant relative to car of same powertrain type; curb weight scaled relative to car by a factor of 1.3; share of power provided by engine and motor determined by degree of hybridization.
[64] Fuel cell power scaled relative to fuel cell car by a factor of 1.3.
[65] Assumes $2,000 / kWh for current hybrid vehicle. For future vehicles, assumed battery costs range from $250 / kWh for high energy batteries to $750 / kWh for high power batteries. Assumes 2035 hybrid battery costs $750 / kWh, 2035 plug-in hybrid battery costs $320 / kWh, 2035 fuel cell battery costs $750 / kWh, 2035 battery electric vehicle costs $250 / kWh (Kromer, 2007, Table 52, p. 117).
[66] Battery energy storage sized by a factor of 1.3 relative to 2035 hybrid car using a factor of 1.3; same ratio of hybrid energy storage for trucks to cars determined by Kasseris (2006, pp. 180, 184).
[67] Battery energy storage scaled by a factor of 1.5 relative to 2035 car of same powertrain type. This is the ratio of energy required at the wheel by hybrid truck versus cars, based on ratio of fuel consumptions of hybrid light truck and car from Kasseris, 2006.
[68] Assumes $15 / kWh storage (Kromer, 2007, Table 51, p. 117). Hydrogen energy storage scaled relative to car by 1.5, ratio of energy required at the wheel by trucks versus cars; see footnote 67.
[69] Includes NO_x after-treatment and diesel particulate filter (DPF).
[70] Assumes 20% weight reduction in 2035 vehicles; roughly 14% of weight reduction is achieved through material substitution at $3 / kg; the remainder is secondary reduction at no cost.

Table 23: Fuel and GHG emission savings of cars with alternative propulsion technologies relative to current and future gasoline cars. Assumes 15 years of vehicle operation over 240,000 km[72].

CARS	RELATIVE TO CURRENT GASOLINE VEHICLE					RELATIVE TO 2035 GASOLINE VEHICLE					
	Current Gasoline	Current Diesel	Current Turbo Gasoline	Current Hybrid	2035 Gasoline	2035 Diesel	2035 Turbo Gasoline	2035 Hybrid	2035 Plug-in Hybrid	2035 Battery Electric	2035 Fuel Cell
Tank-to-wheel fuel consumption[73] [MJ / km]											
Petroleum	0.00	-0.47	-0.31	-0.87	-1.08	-0.24	-0.20	-0.78	-1.27	-1.77	-1.77
Electricity	--	--	--	--	--	--	--	--	0.21	0.57	--
Hydrogen	--	--	--	--	--	--	--	--	--	--	0.74
Total	0.00	-0.47	-0.31	-0.87	-1.08	-0.24	-0.20	-0.78	-1.06	-1.20	-1.03
Tank-to-wheel fuel cost[74] [$]											
@ $2.50 / gallon	0	-1,539	-1,008	-2,855	-3,566	-806	-647	-2,568	-3,725	-4,556	-2,363
@ $5.00 / gallon	0	-3,077	-2,016	-5,709	-7,131	-1,613	-1,295	-5,136	-7,917	-10,381	-8,189
Net price [$][75]											
@ $2.50 / gallon	0	161	-308	2,045	-1,566	894	53	-68	2,175	9,444	2,937
@ $5.00 / gallon	0	-1,377	-1,316	-809	-5,131	87	-595	-2,636	-2,017	3,619	-2,889
Well-to-wheel GHG emissions[76]											
Emitted [tCO_2e]	0	-9	-7	-19	-24	-5	-4	-17	-18	-11	-18
Price of abatement [$\$/tCO_2e$]	--	184	103	256	83	360	161	145	333	1,312	300

[71] Total incremental production cost relative to a baseline vehicle cost of $10,800. Total production cost of current gasoline light truck is therefore: $10,800 + $4,200 = $15,000.
[72] Vehicle travel is taken from NHSTA (2006, Tables 7 and 8, pp. 22, 25) as the average of car and light truck weighted yearly travel miles, over the first 15 years of vehicle life.
[73] Change in tank-to-wheel (TTW) rate of fuel consumption for each propulsion system relative to current and future gasoline vehicles.
[74] Change in TTW fuel cost is calculated using a 7% discount rate (r), an electricity cost of $0.05 / kWh, and a hydrogen cost of $3.50 / kg (NRC, 2004). Change in fuel cost is calculated for two gasoline and diesel prices: $2.50 / gallon and $5.00 / gallon.
[75] Net price equals retail price increase (see Table 19) minus TTW fuel cost. A negative result implies that the fuel savings provided by the propulsion technology are greater than its original cost.
[76] Well-to-wheel (WTW) greenhouse gas (GHG) emissions in metric tons of carbon dioxide equivalent (CO_2e). Includes emissions from upstream fuel production and downstream vehicle operation. Does not include vehicle material cycle.

Table 24: Fuel and GHG emission savings of trucks with alternative propulsion technologies relative to current and future gasoline trucks. Assumes 15 years of vehicle operation over 240,000 km[77].

TRUCKS	RELATIVE TO CURRENT GASOLINE VEHICLE					RELATIVE TO 2035 GASOLINE VEHICLE					
	Current Gasoline	Current Diesel	Current Turbo Gasoline	Current Hybrid	2035 Gasoline	2035 Diesel	2035 Turbo Gasoline	2035 Hybrid	2035 Plug-in Hybrid	2035 Battery Electric	2035 Fuel Cell
Tank-to-wheel fuel consumption[78] [MJ / km]											
Petroleum	0.00	-1.13	-0.74	-1.31	-1.61	-0.58	-0.42	-1.22	-2.00	-2.77	-2.77
Electricity	--	--	--	--	--	--	--	--	0.32	0.89	--
Hydrogen	--	--	--	--	--	--	--	--	--	--	0.74
Total	0.00	-1.13	-0.74	-1.31	-1.61	-0.58	-0.42	-1.22	-1.68	-1.88	-2.03
Tank-to-wheel fuel cost[79] [$]											
@ $2.5 / gal.	0	-3,714	-2,441	-4,330	-5,306	-1,910	-1,380	-4,032	-5,880	-7,136	-3,701
@ $5.0 / gal.	0	-7,428	-4,881	-8,659	-10,612	-3,820	-2,759	-8,065	-12,480	-16,262	-12,827
Net price [$][80]											
@ $2.5 / gal.	0	-1,614	-1,641	1,970	-3,106	190	-580	-832	2,420	14,964	3,699
@ $5.0 / gal.	0	-5,328	-4,081	-2,359	-8,412	-1,720	-1,959	-4,865	-4,180	5,838	-5,427
Well-to-wheel GHG emissions[81]											
Emitted [tCO_2e]	0	-23	-16	-29	-36	-12	-9	-27	-28	-17	-28
Abatement price [$/tCO_2e$]	--	89	49	217	62	177	86	118	294	1,322	268

[77] Vehicle travel is taken from NHSTA (2006, Tables 7 and 8, pp. 22, 25) as the average of car and light truck weighted yearly travel miles, over the first 15 years of vehicle life.
[78] Change in tank-to-wheel (TTW) rate of fuel consumption for each propulsion system relative to current and future gasoline vehicles.
[79] Change in TTW fuel cost is calculated using a 7% discount rate, an electricity cost of $0.05 / kWh, and a hydrogen cost of $3.50 / kg (NRC, 2004). Change in fuel cost is calculated for two gasoline and diesel prices: $2.50 / gallon and $5.00 / gallon.
[80] Net price equals retail price increase (see Table 19) plus TTW fuel cost. A negative result implies that the fuel savings provided by the propulsion technology are greater than its original cost.
[81] Well-to-wheel (WTW) greenhouse gas (GHG) emissions in metric tons of carbon dioxide equivalent (CO_2e). Includes emissions from upstream fuel production and vehicle operation. Does not include vehicle material cycle.

5.2.2 Integrated fleet cost scenarios

By combining the vehicle cost estimates in Section 5.2.1 with rates at which these different technologies are likely to penetrate into the vehicle fleet, integrated cost estimates can be developed for new light-duty vehicles that enter the market in a given year. Bandivadekar (2008, pp. 108-109) developed three scenarios for market penetration of advanced propulsion systems including turbocharged gasoline engines, diesel engines, hybrids, and plug-in hybrids:

> The *market mix* scenario represents a muddling through into the future as no particular propulsion system dominates the light-duty vehicle market over the next three decades. The *turbocharged ICE future* represents a continuing dominance of internal combustion engines, but with an increasing emphasis on turbocharged gasoline engines as well as advanced diesels. The *hybrid strong* scenario presents the possibility that gasoline hybrids and plug-in hybrids emerge as the dominant powertrain combinations.

Assuming vehicles maintain constant size and performance relative to today[82], the improvement in new vehicle fuel consumption under the Hybrid Strong scenario is similar to the CAFE High policy case developed in Section 5.1.1. The Market Mix and Turbocharged ICE Future realize less aggressive reductions in new vehicle fuel consumption between 2010 and 2035. Of the three scenarios, Hybrid Strong therefore provides a representative case of aggressive technology penetration that approaches the stringency of the CAFE High policy case.

The shares of powertrain technologies that enter the light-duty fleet under the Hybrid Strong scenario (shown in Figure 18) can be combined with the future vehicle cost estimates to determine the extra costs of reducing fuel use and GHG emissions relative to No Change in fuel consumption from today. Integrated costs and retail price increases across the light-duty fleet for the 2020 and 2035 model years are developed in Table 25. The reductions in fuel use and GHG results assume a constant fuel price of $2.50 per gallon and account for the rebound effect using the same vehicle travel elasticity assumptions as in Section 5.1.1.

[82] This is equivalent to a 100% “emphasis on reducing fuel consumption” (ERFC), using the terminology developed in Bandivadekar (2008, pp. 70-71).

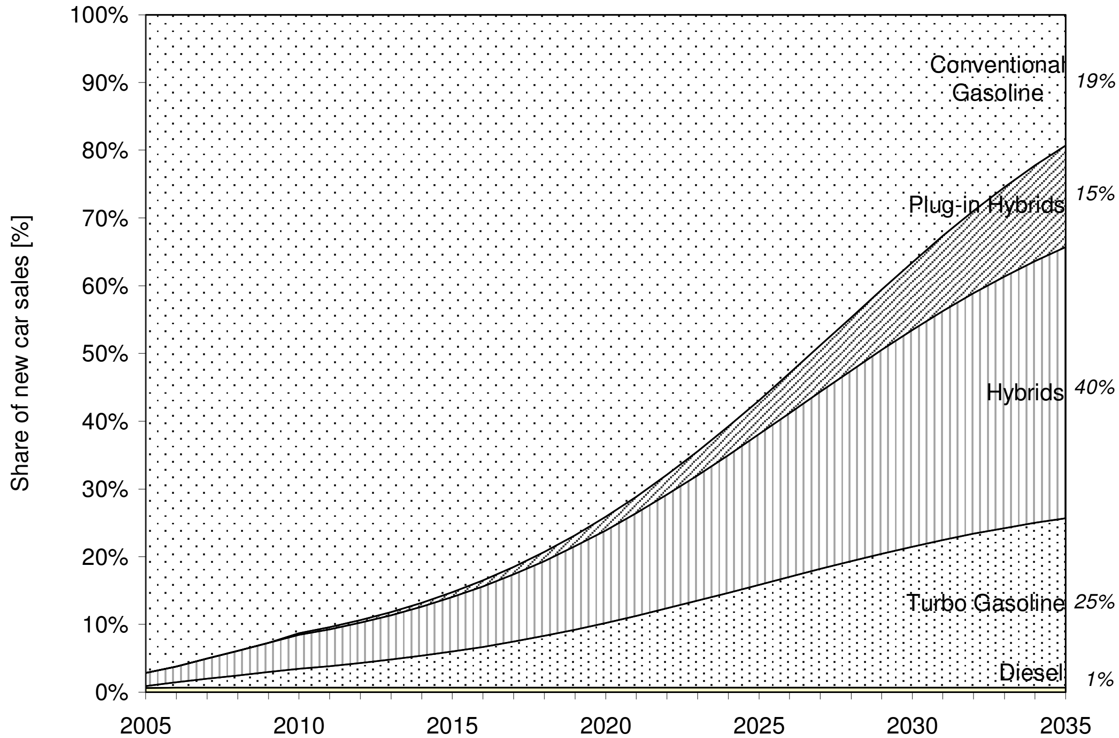


Figure 18: Market shares of advanced powertrain technologies under Hybrid Strong scenario. Italics represent market share in 2035.(Bandivadekar, 2008, p. 115).

The results show that the production cost of improvements that reduce fuel consumption is $20 billion in 2020, growing to $70 billion by 2035. This is roughly an additional 8% of the baseline production cost in 2020 if fuel consumption remained constant from today, and 21% of the baseline cost in 2035. In terms of retail price, the average vehicle is roughly $1,600 more expensive in 2020, and $4,500 more in 2035.

Under the Hybrid Heavy penetration scenario, production costs would increase by 8% in 2020 relative to the baseline cost if fuel consumption remained constant from today; this share would grow to 21% of the baseline cost by 2035. The payback period in either model year relative to the No Change baseline is 4 years using a discount rate of 5% and a constant fuel price of $2.50 per gallon; at $4.00 per gallon this period drops to 2 years.

Without accounting for the value of fuel savings, the cost of reducing a ton of GHG emissions in either model year is roughly $75 per metric ton of CO_2 equivalent ($275 per ton of carbon). For comparison, the Intergovernmental Panel on Climate Change estimates that GHG reductions costing between of $20 to $80 per ton of CO2e

($70 to $300 per ton of carbon) before 2030, and between $30 to $150 ($110 to $550 per ton of carbon) by 2050, will be required in order to stabilize atmospheric GHG emissions at 550 ppm CO2-equivalent by 2100 (IPCC, 2007; Working Group III, SPM, p. 19).

Table 25: Cost and benefits of hybrid strong scenario for 2020 and 2035 model years, relative to No Change in new light-duty vehicle fuel consumption. All prices are in $2007.

Model Year		2020	2035
Total extra production cost [$ billion]		20	70
Percentage of baseline production cost [%]		8%	21%
Increase in retail price of avg. vehicle [$ / vehicle]	Cars	1,430	4,000
	L-T	1,700	4,900
Retail price increase in cents per km[83] (r = 7%) [¢ / km]	Cars	0.9	2.6
	L-T	1.0	3.0
Fuel savings [billions L]		130	440
GHG emission savings [$MtCO_2e$]		350	1,300
Payback period (r = 7%) [years]	$2.50 / gal.	4	
	$4.00 / gal.	2	
Price of GHG reduction [$ / ton CO_2e] (does not include fuel savings)		75	
Price of FC benefit [$ per L / 100 km] (does not include fuel savings)		700	

L-T = Light truck

The increase in price of reducing fuel consumption by one liter per 100 kilometers in either model year is approximately $700 relative to the No Change baseline. Under a feebate system, Section 4.3 concluded that rates on the order of $225 to $500 per L / 100 km have been implemented in various countries around the world. This range would offset one-third to two-thirds of the average vehicle retail price increase under the Hybrid Heavy scenario. For cost-effective technologies, such as conventional improvements in gasoline engines and turbocharging, the feebate incentive would entirely neutralize the retail price increase. Other, more expensive options such as diesel and hybrid engines would have their retail price increase reduced by one-half and a third respectively.

[83] Assumes a 15 year lifetime for cars and light trucks. Vehicle travel is representative of today's cars and light trucks, and was taken from (NHTSA, 2006b); likely gives a conservative estimate of extra retail price per kilometer since travel per vehicle is expected to increase from today until 2020 and 2035.

5.3 Sensitivity analysis

The fuel tax policy cases are especially sensitive to the elasticities assumed with respect to fuel price and the fuel cost of travel. It is important to verify that conclusions drawn from the behavior of the fuel tax policies are robust across a range of elasticity values. This section uses a range of values used to test the sensitivity of the fuel price cases. The variation in parameters is shown in Table 26.

Table 26: Range of fuel use and vehicle travel elasticities used to test the sensitivity of the fuel tax policy cases

		ELASTICITY VALUES	
		Short term	Long term
Change in vehicle travel with respect to a change in fuel cost of travel	*Less* responsive	-0.02	-0.05
	Assumed value	-0.03	-0.10
	More responsive	-0.05	-0.20
Change in new vehicle fuel consumption with respect to a change in fuel price	*Less* responsive	-0.02	-0.17
	Assumed value	-0.03	-0.33
	More responsive	-0.05	-0.50

The results in Table 27 show that the fuel tax policy cases are sensitive to the elasticity inputs, particularly the rates of new vehicle fuel consumption. Note that the variation in vehicle travel under the Fuel Tax case remains relatively constant between 2020 to 2035; this is due to the fact that the fuel tax does not increase after 2020 while vehicle fuel consumption continues to improve slightly, causing the vehicle travel to rebound. It is also important to note that the reductions in fuel use and GHG emissions are not the same because the GHG emissions include emissions generated from producing the materials embodied within new vehicles; these emissions increase over time, as new technologies and lightweight materials are implemented in future vehicles to reduce fuel consumption[84].

Small variations in the assumed elasticities result in large changes in the estimates of future fuel use and GHG emissions from light-duty vehicles. For the Fuel Tax case, the reductions in fuel use and GHG emissions range from 7 to 20% across the variation in the

[84] The material cycle includes material extraction and processing steps, but does not include transportation of materials nor manufacturing or assembly of vehicles. See Section 3.1 for details on the material lifecycle assumptions used in the fleet model.

elasticity assumptions. This sensitivity is even greater under the Fuel Tax High case, where the reductions from No Change vary from 11 to 30%. At the same time, the results of this study are intended to quantitatively *illustrate* the effects and interaction of fuel tax increases alongside CAFE—they are not meant to *forecast* the future fuel use and GHG emissions from light-duty U.S. vehicles.

Table 27: Sensitivity of changes in elasticity values. Reductions in new vehicle fuel consumption, light-duty fleet vehicle travel, light-duty fuel use and GHG emissions relative to No Change are shown for the Fuel Tax and Fuel Tax High Policy cases.

RELATIVE TO NO CHANGE	Avg. on-road new vehicle fuel consumption [L / 100 km]		Vehicle travel [trillion km]		Fuel use [billion liters]		GHG emissions[85] [$MtCO_2e$]	
	2020	2035	2020	2035	2020	2035	2020	2035
Fuel Tax Case								
Less responsive	-3%	-8%	-2%	-2%	-3%	-8%	-3%	-7%
Assumed value	-7%	-14%	-4%	-4%	-7%	-14%	-6%	-13%
More responsive	-10%	-21%	-8%	-6%	-12%	-21%	-11%	-19%
Fuel Tax High Case								
Less responsive	-3%	-14%	-2%	-4%	-3%	-13%	-3%	-11%
Assumed value	-7%	-26%	-4%	-7%	-7%	-23%	-6%	-21%
More responsive	-10%	-37%	-8%	-12%	-12%	-33%	-11%	-30%

For these purposes, the behavior of the fuel tax policy measures is consistent. The magnitude of the impact that a fuel tax policy might have on fuel use and GHG emissions is highly sensitive to the assumed elasticities values, however. As a result, it is not possible to accurately determine the extent to which a fuel tax would reduce fuel use and GHG emissions. The results of the sensitivity analysis suggest reductions on the order of 7 to 30% below the No Change baseline, given the fuel tax policies implemented.

A second assumption that the fuel tax policy cases are sensitive to is the starting price of fuel. The assumed price of $2.50 per gallon in 2010 was drawn from the EIA's Annual Energy Outlook 2008. Recent trends in world oil prices, however, have shown that fuel prices are subject to considerable uncertainty even in the short- to near-term. As a result, two different starting price cases were evaluated. First, a higher starting fuel price of $4.00 per gallon was chosen to reflect current trends in elevated fuel prices.

[85] Includes well-to-tank, tank-to-wheel, and material cycle GHG emissions.

Second, a lower starting price of $1.70 per gallon was evaluated. This value was chosen as the average fuel price between 1988 and 2002—a period of relative stability in world oil prices. In this way, the higher starting price captures recent trends towards higher prices, while the lower price evaluates changes in the light duty fleet relative to what has been a stable price equilibrium for over a decade.

Table 28: Sensitivity to changes in starting fuel price. Reductions in new vehicle fuel consumption, light-duty fleet vehicle travel, light-duty fuel use and GHG emissions relative to No Change are shown for the Fuel Tax and Fuel Tax High Policy cases.

RELATIVE TO $2.50 / gallon STARTING FUEL PRICE	Avg. on-road new vehicle fuel consumption [L / 100 km]		Vehicle travel [trillion km]		Fuel use [billion liters]		GHG Emissions [$MtCO_2e$]	
	2020	2035	2020	2035	2020	2035	2020	2035
Fuel Tax High Case								
$1.50 / gallon	-9%	-32%	-6%	-9%	-9%	-28%	-8%	-25%
$2.50 / gallon	-7%	-26%	-4%	-7%	-7%	-23%	-6%	-21%
$4.00 / gallon	-5%	-20%	-3%	-5%	-5%	-17%	-4%	-15%

The results are shown in Table 28. The Fuel Tax High policy case was evaluated for starting fuel prices of $1.70 and $4.00 per gallon by adding $0.15 per gallon annually to each starting price until 2035. The sensitivity results show that the variations in new vehicle fuel consumption, fuel use, and GHG emissions are on the order of +/- 10% by 2035. Under a higher starting fuel price of $4.00 per gallon, the light-duty fleet is *less* responsive to fuel tax increases. Since fuel prices are already high, the annual $0.15 per gallon fuel tax increases are smaller in percentage terms, and therefore stimulate less of a response in reduced fuel consumption and vehicle travel. Under a lower starting fuel price of $1.50 per gallon, the light-duty fleet is more responsive to changes in fuel price. As a result, the annual $0.15 per gallon tax increases stimulate greater reductions in new vehicle fuel consumption and vehicle travel.

5.4 Summary and discussion

This chapter has illustrated how fuel tax and feebate policies could play a role alongside CAFE as a means of reducing fuel use and GHG emissions in light-duty vehicles. In particular, the following insights are offered:

- *Continuous* and *long-term* improvements in fuel consumption, ideally accompanied by reduced rates of growth in vehicle travel, are necessary to maintain a downward trajectory in fuel use and GHG emissions in the light-duty fleet. Without sustained effort, growth in vehicle sales and travel can reverse short-term reductions in consumption and emission rates.
- If feasible, the improvements mandated by the new CAFE legislation will enable dramatic reductions in new vehicle fuel consumption over a relatively short timeframe (10 years). Increasing the cost of travel reduces fuel consumption gradually over a much longer timeframe (15 to 20 years).
- Based on the assumed fuel prices and response in travel with respect to per-kilometer costs, the overall rebound effect under CAFE is smaller compared to the improvement in fleet fuel consumption, as it only affects new vehicles entering the fleet. Fuel taxes have a larger impact on reducing vehicle travel since they impact the entire in-use fleet. This effect is greater on older vehicles with higher rates of fuel consumption; as lower-income groups typically own older vehicles, policy makers will have to address this potentially regressive impact, perhaps through equitable tax revenue distribution.
- An important effect of coordinating CAFE with policies that increase the fuel cost of travel is the alignment of consumer demand with regulatory requirements for reduced fuel consumption. Policies that influence consumer behavior can *pull* reductions in fuel consumption into the market, although at a more gradual rate than required by the *push* of current regulatory fuel consumption standards in the United States. Under the policy cases evaluated, consumer demand was found to contribute to a quarter of the fuel consumption reductions required under CAFE by 2020, increasing to half by 2035.
- Fuel tax increases shift some of the costs onto consumers. Relative to No Change, the fuel tax policies evaluated here would increase the fuel cost of travel by 43% in 2020 under a 15-cent annual increase per gallon until 2020, declining to 22% above No Change by 2035. If the fuel tax increases were sustained beyond 2020, the fuel cost of travel would continue to increase by 64% relative to the No Change case in 2035.

- Turbocharged gasoline engines, diesel engines, and hybrids entering the fleet today are estimated to cost from 5 to 30% more than a baseline gasoline vehicle. Longer-term options such as plug-in hybrids and fuel cell vehicles would cost 25 to 35% more than a future gasoline vehicle. Battery electric vehicles are even more costly.
- The retail price increases of technologies that reduce fuel consumption are largely offset by fuel savings provided over the vehicle lifecycle at prices of $2.50 per gallon, but not in all cases. At higher fuel prices of $6.00 per gallon, all technologies, except the battery-electric vehicle, fully pay-back the initial retail price increase in fuel savings. Consumers may pay from $1,500 to $4,500 more for vehicles with dramatically lower rates of fuel consumption, but similar size and performance as today.
- Under technology penetration scenarios approaching the stringency of Congress' legislated CAFE target, the average price of GHG reduction is on the order of \$75 / metric ton of CO_2e. This is in the range of IPCC carbon price forecasts necessary for stabilization of atmospheric CO_2 concentrations at 550 ppm by 2100.
- Feebate incentives on the order of $225 to $500 per L / 100 km can offset one- to two-thirds of the average vehicle retail price increase under aggressive advanced technology penetration scenarios. The exact level of the incentive will vary across different vehicle powertrains. Alongside CAFE, these incentives help subsidize the penetration of new technologies into the fleet.
- The impact that fuel tax increases may have on fuel consumption, vehicle travel, and overall fuel use and GHG emissions is uncertain and highly sensitive to assumptions of price elasticities and starting fuel prices. With low elasticity assumptions, the reductions under aggressive fuel tax policies are very modest—on the order of 7 to 13%. Under higher elasticity assumptions, reductions in fuel use and GHG emissions may be as large as 20 to 33% under an aggressive fuel tax policy.

6.0 Conclusion

All the while at the South Elgin Marathon, the tanker trucks come and go, disgorging their liquid tales into the ground. [...] As usual, the fuel's stories went unheard. They were expelled from countless tailpipes.

- Paul Salopek, *A tank of gas, a world of trouble*

This report has attempted to address the challenging question of how policies can achieve dramatic reductions in fuel use and greenhouse gas emissions from light-duty vehicles in the United States. In its review of policy options, this report considered vehicle standards (or fuel consumption standards), vehicle tax systems and feebates, fuel and carbon taxes, pay as you drive arrangements, and scrappage incentives. It concluded that fiscal policies, coordinated alongside CAFE, can achieve reductions more effectively by acting on key stakeholders in the system, through behavioral as well as technological changes, and by impacting multiple stages of vehicle purchase, operation, and retirement. The report found that fiscal options may align the interests of manufacturers and consumers to overcome resistance in ways that do not require perverse incentives that reduce the overall effectiveness of policies.

By developing illustrative policy scenarios, this report has demonstrated the role that fuel tax increases might play in collaboration with CAFE fuel consumptions standards. It noted two important effects: that fuel taxes align consumer demand for lower rates of fuel consumption with regulatory requirements placed on manufacturers, and that fuel taxes achieve reductions alongside CAFE standards by promoting alternatives to private transport and reducing vehicle travel.

Finally, with engineering cost estimates of future technology options, the report addressed the costs and benefits of reducing vehicle fuel consumption. It found that the costs were on the order of an additional 8 to 20% of baseline costs if there was no change in fuel consumption from today. It estimated that consumers could expect to pay between $1,500 to $4,500 more on average for vehicles with dramatically lower fuel consumption, but roughly the same size and performance as today. The report also found that these significant costs were largely offset by the benefits of fuel savings, and that the costs (not including fuel savings) of reducing greenhouse gas emissions were within estimates of the global prices necessary to stabilize atmospheric concentrations of carbon dioxide at what are considered safe levels.

At the same time, this report leaves many questions unaddressed. It focused on the role that fuel taxes could play alongside CAFE, but other fiscal arrangements may be better suited towards achieving reductions in fuel consumption over the long term. While this report suggested economic, equity, and political grounds for increases in the fuel tax, barriers will likely persist in achieving significant and sustained increases over the near-term. Another question is how the revenue from fiscal options could be spent; whether to counter regressive impacts on low-income households, finance highway infrastructure investment, or perhaps even speed research and development of more efficient automotive technologies.

It is likely that in the next few years, the United States will enact climate legislation that may require reductions of up to 80% of greenhouse gas emissions from current levels across all sectors of the economy. In the face of these stringent reduction targets, it is critical to better understand the magnitude of reductions from transportation that have the best chance of yielding the highest net societal benefits, and what the price tag will be. Further study will be necessary to determine the role that transportation—and light-duty vehicles in particular—can play out to 2050 and beyond in achieving GHG reductions efficiently and in a cost-effective manner.

7.0 Bibliography

AAA. (2008). Your Driving Costs. AAA Association Communication, Heathrow, United States. Retrieved April 24, 2008, from http://www.aaapublicaffairs.com/Main/Default.asp?CategoryID=16&SubCategoryID=76&ContentID=353

An, F., & DeCicco, J. (2007). Trends in Technical Efficiency Trade-Offs for the U.S. Light Vehicle Fleet. *SAE Technical Paper Series, 2007-01-1325*.

API. (2008). State Motor Fuel Excise Tax Rate Report. Retrieved April 15, 2008, from http://www.api.org/policy/tax/stateexcise/index.cfm

Austin, D., & Dinan, T. (2005). Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes. *Journal of Environmental Economics and Management, 50*(3), 562-582.

Bandivadekar, A. P. (2006). Coordinated Policy Measures for Reducing Fuel Use of the U.S. Light Duty Vehicle Fleet. In D. Sperling & J. S. Cannon (Eds.), *Driving Climate Change: Cutting Carbon from Transportation* (pp. 312). Amsterdam: Elsevier.

Bandivadekar, A. P. (2008). Evaluating the Impact of Advanced Vehicle and Fuel Technologies in U.S. Light-Duty Vehicles. Retrieved March 3, 2008

Bandivadekar, A. P., Bodek, K., Cheah, L., Evans, C. W., Groode, T., Heywood, J. B., et al. (2008). On the Road in 2035: Reducing transportation's petroluem consumption and GHG emissions. Laboratory for Energy and the Environment, Massachusetts Institute of Technology, forthcoming.

Banerjee, R. (2007). Deals on Wheels: An Analysis of the New Federal Auto Feebate. Retrieved December 21, 2008, from http://www.cdhowe.org/pdf/backgrounder_108.pdf

Barg, S., Duraiappah, A., & Exan, S. V. (2000). Research Paper #2: Economic Instruments for Environmental Policy Making in Ontario. Retrieved February 24, 2008, from http://www.ene.gov.on.ca/envision/ergreport/downloads/report_paper2.htm

BLS. (2008). Average Consumer Price Index, All Urban Consumers - (CPI-U), U.S. city average, All items. Bureau of Labor Statistics. Retrieved April 22, 2008, from ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

Bodek, K., & Heywood, J. B. (2008). Europe's Evolving Passenger Vehicle Fleet: Fuel Use and GHG Emissions Scenarios through 2035. Publication No. LFEE 2008-03 RP. Laboratory for Energy and the Environment. Massachusetts Insitute of Technology. Cambridge, United States. Retrieved April 18, 2008, from http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/Europe's%20Evolving%20Passenger%20Vehicle%20Fleet.pdf

Bordoff, J. E., & Noel, P. J. (2008). Pay-As-You-Drive Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity. The Hamilton Project, The Brookings Institution. Preliminary draft subject to revision; final draft to be released July 17 2008. Retrieved April 27, 2008, from http://www.brookings.edu/papers/2008/0417_payd_bordoff.aspx

Branden, T. V., Knight, P., Potter, S., Enoch, M., & Ubbels, B. (2000). FAIR AND EFFICIENT PRICING IN TRANSPORT – THE ROLE OF CHARGES AND TAXES. Retrieved October 11, 2007, from http://www.thepep.org/ClearingHouse/docfiles/EU%20taxing%20transport.pdf

Bussy, P. (2008). French CO2 Regulation: Opportunity for National Makes? *PriceWaterhouseCoopers Automotive Institute Analyst Note.* Retrieved January 17, 2008, from http://www.globalautoindustry.com/article.php?id=2200&jaar=2008&maand=1&target=Euro

California Air Resources Board. (2004). Climate Change Emission Control Regulations. California Environmental Protection Agency. Retrieved 4 January 2007, from http://www.arb.ca.gov/cc/factsheets/cc_newfs.pdf

California Code of Regulations. (2005). Exhaust Emission Standards and Test Procedures - 2004 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles, Title 13, Section 1961.1. from http://government.westlaw.com/linkedslice/search/default.asp?tempinfo=find&RS=GVT1.0&VR=2.0&SP=CCR-1000

Canada Revenue Agency. (2007). Excise Tax on Fuel Inefficient Cars. Retrieved Feburary 24, 2008, from http://www.cra-arc.gc.ca/agency/budget/2007/excise-e.html

CAR. (2007). How Automakers Plan Their Products. Center for Automotive Research, July 2007. Retrieved May 7, 2008, from http://www.cargroup.org/documents/ProductDevelopmentFinalReport7-30.a_000.pdf

CBO. (2002). Reducing Gasoline Consumption: Three policy options. Congressional Budget Office, November 2002. Retrieved April 23, 2008, from http://www.cbo.gov/doc.cfm?index=3991

CBO. (2003). The Economic Costs of Fuel Economy Standards Versus a Gasoline Tax. Congressional Budget Office. Retrieved March 2, 2008, from http://www.cbo.gov/ftpdocs/49xx/doc4917/12-24-03_CAFE.pdf

CBO. (2007). Status of the Highway Trust Fund: 2007. Congressional Budget Office, Testimony before the Subcommittee on Highways and Transit, Committee on Transportation and Infrastructure, U.S. House of Representatives. Retrieved April 15, 2008, from http://www.cbo.gov/doc.cfm?index=7909

CBO. (2008). Effects of Gasoline Prices on Driving Behavior and Vehicle Markets. Congressional Budget Office. Retrieved January 15, 2008, from http://www.cbo.gov/ftpdocs/88xx/doc8893/01-14-GasolinePrices.pdf

Cheah, L., Evans, C. W., Bandivadekar, A. P., & Heywood, J. B. (2007). Factor of Two: Halving the Fuel Consumption of New U.S. Automobles by 2035. Laboratory for Energy and the Environment, Cambridge, Massachusetts. Retrieved May 13, 2008, from http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/cheah_factorTwo.pdf

Chosun Ilbo. (2007). Korea to Tighten Fuel Efficiency Standards by 2012. Retrieved March 26 2008, from http://english.chosun.com/w21data/html/news/200712/200712260008.html

COWI. (2002). Fiscal Measures to Reduce CO2 Emissions from New Passenger Cars - Main Report. *Report no. 4, issue no. 3*, from http://ec.europa.eu/environment/co2/pdf/cowi_finalreport.pdf

Davis, S. C., & Diegel, S. W. (2007). Transportation Energy Data Book. Retrieved 19 October 2007, from http://cta.ornl.gov/data/index.shtml

Davis, W. B., Levine, M. D., Train, K., & DuLeep, K. G. (1995). Effects of feebates on vehicle fuel economy, carbon dioxide emissions and consumer surplus. *DOE / PO - 0031* Retrieved 31 July 2007, from http://eetd.lbl.gov/ea/teepa/pdf/DOE-PO-0031.html

DeCicco, J., Fung, F., & Scrafford, R. (2007). Automakers Corporate Carbon Burdens: Update for 1990 - 2005. Retrieved September 5, 2007

Delucchi, M. A. (2007). Do motor-vehicle users in the US pay their way? *Transportation Research Part A: Policy and Practice, 41*(10), 982-1003.

Department of Transportation. (2002). REPORT TO CONGRESS: Effects of the Alternative Motor Fuels Act CAFE Incentives Policy. Retrieved October 17, 2007, from http://www.nhtsa.dot.gov/cars/rules/rulings/CAFE/alternativefuels/index.htm#content

Dixon, L. S., & Garber, S. (2001). *Fighting air pollution in southern California by scrapping old vehicles*. Santa Monica, CA: Rand.

Dubner, S. J., & Levitt, S. D. (2008). Not-So-Free Ride: The trouble with negative externalities. New York Times Freakonomics Blog. Retrieved May 14, 2008, from http://www.nytimes.com/2008/04/20/magazine/20wwln-freakonomics-t.html?ex=1367380800&en=58bdcb115326f7e1&ei=5124&partner=permalink&exprod=permalink

Edlin, A. S. (2003). Per-Mile Premiums for Auto Insurance. In R. Arnott, B. Greenwald, R. Kanbur & B. Nalebuff (Eds.), *Economics for an Imperfect World: Essays in Honor of Joseph E. Stiglitz*. Cambridge, Massachusetts: The MIT Press.

EIA. (1998). Annual Energy Outlook 1998 with Projections to 2020. Energy Information Administration. Retrieved April 22, 2008, from http://www.eia.doe.gov/oiaf/archive/aeo98/homepage.html

EIA. (2007). Annual Energy Review 2006. Energy Information Administration. Retrieved April 22, 2008, from http://www.eia.doe.gov/emeu/aer/overview.html

EIA. (2008a). Annual Energy Outlook 2008: With projections for 2030, revised early release. Energy Information Administration. #:DOE/EIA-0383(2008). Retrieved April 22 2008, from http://www.eia.doe.gov/oiaf/aeo/

EIA. (2008b). Short-Term Energy Outlook Supplement: Motor Gasoline Consumption 2008. Energy Information Administration, April 2008. Retrieved April 22, 2008, from http://www.eia.doe.gov/emeu/steo/pub/special/2008_sp_02.html

EISA. (2007, December 19th, 2007). Energy Independence Act of 2007, H.R. 6 § 101 - 1601. 110th Congress. Retrieved March 27 2008, from http://www.govtrack.us/congress/bill.xpd?bill=h110-6

Energy Conservation Center Japan. (2006). Top Runner Program: Developing the world's best energy-efficient appliances. Retrieved 16 January 2007, from http://www.eccj.or.jp/top_runner/index.html

EPA. (2007a). America Receives a National Solution for Vehicle Greenhouse Gas Emissions. Retrieved February 7, 2008, from http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/41b4663d8d3807c5852573b6008141e5!OpenDocument
EPA. (2007b). Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2006. Retrieved 13 April 2007, from http://www.epa.gov/otaq/fetrends.htm
Espey, M. (1996). Explaining the variation in elasticity estimates of gasoline demand in the United States: A meta. *Energy Journal, 17*(3), 49.
European Commission. (1999). Commission Recommendation of 5 February 1999 on the reduction of CO2 emissions from passenger cars, 1999/125/EC. Retrieved February 8, 2008, from http://ec.europa.eu/environment/co2/99125/en.pdf
European Commission. (2000a). Commission Recommendation of 13 April 2000 on the reduction of CO2 emissions from passenger cars (JAMA), 2000/304/EC. Retrieved February 8, 2008, from http://ec.europa.eu/environment/co2/00304/en.pdf
European Commission. (2000b). Commission Recommendation of 13 April 2000 on the reduction of CO2 emissions from passenger cars (KAMA), 2000/303/EC. Retrieved February 8, 2008, from http://ec.europa.eu/environment/co2/00303/en.pdf
European Commission. (2005). *Proposal for a COUNCIL DIRECTIVE on passenger car related taxes*. Retrieved 11 January 2007. from http://ec.europa.eu/environment/co2/pdf/taxation_com_2005_261.pdf.
European Commission. (2007). Proposal for a Regulation of the European Parliament and of the Council: Setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles. Retrieved January 7, 2008, from http://ec.europa.eu/environment/co2/pdf/co2_cars_proposal.pdf
European Conference of Ministers of Transport. (2007). *Cutting transport CO2 emissions : what progress?* Paris: European Conference of Ministers of Transport : Distributed by OECD Pub.
FHWA. (1995). Highway Statistics Summary To 1995. Federal Highway Administration. Retrieved April 22, 2008, from http://www.fhwa.dot.gov/ohim/summary95/section1.html
FHWA. (2004). Highway Statistics 2003. Federal Highway Administration. Retrieved April 22, 2008, from http://www.fhwa.dot.gov/policy/ohim/hs03/mf.htm
Fuel Taxation Inquiry. (2001). Background Paper: Fuel Taxation- international experience. Retrieved 17 January 2007, from http://fueltaxinquiry.treasury.gov.au/content/backgnd/003.asp
Fulton, L., & Eads, G. C. (2004). IEA/SMP Model Documentation and Reference Case Projection. International Energy Agency / World Business Council on Sustainable Developpment. Sustainable Mobility Project. Retrieved May 13, 2008, from http://www.wbcsd.org/plugins/DocSearch/details.asp?type=DocDet&ObjectId=MTE0Njc
Gallagher, K. S., Collantes, G. O., Holdren, J. P., Lee, H., & Frosch, R. (2007). Policy Options for Reducing Oil Consumption and Greenhouse-Gas Emissions from the

U.S. Transportation Sector. ETIP Discussion Paper. Cambridge, Mass.: Energy Technology Innovation Policy research group, Belfer Center for Science and International Affairs. Retrieved April 19, 2008, from http://belfercenter.ksg.harvard.edu/files/policy_options_oil_climate_transport_final.pdf

Gerard, D., & Lave, L. B. (2003). The Economics of CAFE Reconsidered: A response to CAFE critics and a case for fuel economy standards. AEI-Brookings Joint Center for Regulatory Studies, Regulatory Analysis 03-10, September 2003. Retrieved April 21, 2008, from http://www.aei-brookings.org/publications/abstract.php?pid=394

Goodwin, P., Dargay, J., & Hanly, M. (2004). Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. *Transport Reviews, 24*(3), 275-292.

Gordon, D. (2005). Fiscal Policies for Sustainable Transport: International Best Practices. *Fiscal Policies for Promoting Cleaner and More Efficient Vehicle Technologies* Retrieved 9 May 2007, from http://www.theicct.org/documents/Gordon_background_doc_2005_en.pdf

Greene, D. L. (1991). Short-run pricing strategies to increase Corporate Average Fuel Economy. *Economic Inquiry, 29*(1), 101-114.

Greene, D. L. (1998). Why CAFE worked. *Energy Policy, 26*(8), 595-613.

Greene, D. L., & Ahmad, S. (2005). Costs of U.S. Oil Dependence: 2005 Update. Retrieved September 26, 2006, from http://www-cta.ornl.gov/cta/Publications/Reports/CostsofUSOilDependence.pdf

Greene, D. L., Kahn, J. R., & Gibson, R. C. (1999). Fuel economy rebound effect for US household vehicles. *Energy, 20*(3), pp. 1 - 31.

Greene, D. L., Patterson, P. D., Singh, M., & Li, J. (2005). Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy. *Energy Policy, 33*, 757-775.

Greene, D. L., & Schafer, A. (2003). Reducing Greenhouse Gas Emissions from U. S. Transportation: Pew Center on Global Climate Change.

Greening, L. A., Greene, D. L., & Difiglio, C. (2000). Energy Efficiency and consumption - the rebound effect - a survey. *Energy Policy, 28*(2000), pp. 389 - 401.

Hanna, T. H. (1990). Fuel Economy and Auto Safety Don't Mix. Retrieved October 17, 2007, from http://query.nytimes.com/gst/fullpage.html?res=9C0CE1DF1F3EF930A35753C1A966958260

HLB Decision Economics Inc. (1999). Assessment of a Feebate Scheme for Canada. Retrieved 13 January 2007, from http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/vehicle_technology/study4/final_report/final_report.htm

Hollard Insurance. (2008). About PAYD: Paying Insurance Premiums. Retrieved May 14, 2008, from http://www.payasyoudrive.co.za/paying_premiums.html

ICCT. (2007). Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update. Retrieved 31 July 2007, from http://www.theicct.org/documents/ICCT_GlobalStandards_2007.pdf

IEA. (2007). Energy Prices and Taxes Database. Retrieved March 2, 2008

IEA, & OECD. (2000). *The road from Kyoto : current CO2 and transport policies in the IEA*. Paris: OECD : IEA.

IPCC. (2007). Fourh Assessment Report: Change Change 2007. Intergovernmental Panel on Climate Change, United Nations. Retrieved April 18, 2008, from http://www.ipcc.ch/ipccreports/assessments-reports.htm

Jaccard, M. K., & Rivers, N. (2007). Estimating the Effect of the Canadian Government's 2006-2007 Greenhouse Gas Policies. Retrieved Feburary 24, 2007, from http://www.cdhowe.org/pdf/workingpaper_5.pdf

JAMA. (2003). Auto Tax Reform in Japan. *Japan Auto Trends.* Retrieved April 19, 2008, from http://www.jama.org/AutoTrends/detail1d69.html?id=224

Kasseris, E., & Heywood, J. B. (2007). Comparative Analysis of Automotive Powertrain Choices for the Next 25 Years. *SAE Technical Paper Series, 2007-01-1605, SP-2091*.

Keenan, G. (2007). Honda squeaks through Ottawa's green gates. *The Globe and Mail* Retrieved April 4, 2008, from http://www.theglobeandmail.com/servlet/story/LAC.20071017.RFEEBATE17/TPStory/?query=rebate

Kleit, A. N. (1990). The Effect of Annual Changes in Automobile Fuel Economy Standards. *Journal of Regulatory Economics,, 2*, 151-172.

Kleit, A. N. (2004). Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard. *Economic Inquiry, 42*(2), 279-294.

Kromer, M., & Heywood, J. B. (2007). Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet. Laboratory for Energy and the Environment. Massachusetts Institute of Technology. LFEE 2007-03 RP. Retrieved March 27, 2008, from http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/kromer_electric_powertrains.pdf

Kunert, U., & Kuhfeld, H. (2006). The Diverse Structures of Passenger Car Taxation in Europe and the EU Commissions Proposal for Reform. Retrieved October 23, 2007, from http://ideas.repec.org/p/diw/diwwpp/dp589.html

Levenson, L., & Gordon, D. (1990). DRIVE+: Promoting Cleaner and More Fuel Efficient Motor Vehicles through a Self-Financing System of State Sales Tax Incentives. *Journal of Policy Analysis and Management, 9*(3), 409-415.

Mackenzie, D., Bedsworth, L., & Friedman, D. (2005). Fuel Economy Fraud: Closing the loopholes that increase U.S. oil dependence. Union of Concerned Scientists, August 2005. Retrieved April 22, 2008, from http://www.ucsusa.org/clean_vehicles/fuel_economy/fuel-economy-fraud-closing-the-loopholes-that-increase-us-oil-dependence.html

Metcalf, G. (2007). A Green Employment Tax Swap: Using a Carbon Tax to Finance Payroll Tax Relief. Retrieved 7 July 2007, from http://www.wri.org/climate/pubs_description.cfm?pid=4278

Milemeter. (2008). Milemeter Website: Insurance by the mile. Retrieved May 14, 2008, from http://www.milemeter.com/index.html

Ministry of the Environment. Government of Japan. (1999). Report on Auto-Related Environmental Taxes. Retrieved 17 January 2007, from http://www.env.go.jp/en/policy/tax/auto/

National Research Council. (2002). *Effectiveness and impact of corporate average fuel economy (CAFE) standards*. Washington, D.C.: National Academy Press.

National Surface Transportation Policy and Revenue Study Commission. (2008). Transportation for Tomorrow: Report of the National Surface Transportation Policy and Revenue Study Commission. Retrieved March 15, 2008, from http://www.transportationfortomorrow.org/final_report/

Natural Resources Canada. (2005). Memorandum of Understanding between the Government of Canada and the Canadian Automotive Industry Respecting Automobile Greenhouse Gas Emissions. *The Newsroom: Natural Resource Canada's News Source* Retrieved 5 January 2007, from http://www.nrcan-rncan.gc.ca/media/mous/2005/20050405_e.htm

New York Times. (1990). The Second-Best Way to Save Gas. The New York Times, Opinion, September 20, 1990. Retrieved April 25, 2008, from http://query.nytimes.com/gst/fullpage.html?res=9C0CEED7163CF933A1575AC0A966958260&sec=&spon=&partner=permalink&exprod=permalink

New York Times. (1993). California Lawmakers Reject 'Pay at the Pump' Insurance. The New York Times, May 27, 1993. Retrieved May 14, 2008, from http://query.nytimes.com/gst/fullpage.html?res=9F0CE4DB173FF934A15756C0A965958260

NHTSA. (2006a). Average Fuel Economy Standards for Light Trucks Model Years 2008-2011. National Highway Traffic Safety Administration, Department of Transportation. 49 CFR Parts 523, 533 and 537 [Docket No. 2006- 24306] RIN 2127-AJ61. Retrieved April 1, 2008, from http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/2006FinalRule.pdf

NHTSA. (2006b). Vehicle Survivability and Travel Mileage Schedules. National Highway Traffic Safety Administration (NHTSA). DOT HS 809 952, Technical Report. Retrieved May 5, 2008, from http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2006/809952.pdf

NHTSA. (2007). Summary of fines collected. National Highway Traffic Safety Administration. Updated December 13, 2007. Retrieved April 24, 2008, from http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/Rulemaking/Articles/Associated%20Files/CAFE_Fines.pdf

NHTSA. (2008). Average Fuel Economy Standards Passenger Cars and Light Trucks Model Years 2011-2015. National Highway Traffic Safety Administration, Deparment of Transportation. 49 CFR Parts 523, 531, 533, 534, 536 and 537, Docket No. NHTSA-2008 -0089. Retrieved April 24, 2008, from http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_11-15_NPRM_April_21.pdf

Nivola, P. S. (1986). *The Politics of Energy Conservation*. Washington, D.C.: The Brookings Institution.

Nivola, P. S., & Crandall, R. W. (1995). *The Extra Mile: Rethinking Energy Policy for Automotive Transportation*. Washington, D.C.: The Brookings Institution.

Norwich Union. (2008). 'Pay as you drive' insurance. Retrieved May 14, 2008, from http://www.norwichunion.com/pay-as-you-drive/

NRC. (2002). *Effectiveness and impact of corporate average fuel economy (CAFE) standards.* . Washington, D.C.: National Research Council, National Academy Press.

Office of the Governor. State of California. (2008). Governor Schwarzenegger Announces EPA Suit Filed to Reverse Waiver Denial. Retrieved February 7, 2008, from http://gov.ca.gov/index.php?/print-version/press-release/8400/

Parkinson, D. (2008). Slim pickings for auto makers. *The Globe and Mail* Retrieved April 4, 2008, from http://www.theglobeandmail.com/servlet/story/RTGAM.20080226.wparkinsonbudget0226/BNStory/budget2008/home

Parry, I. W. H. (2005). Is Pay-as-You-Drive Insurace a Better Way to Reduce Gasoline than Gasoline Taxes? *American Economic Review Papers and Proceedings, 95*(2), 288-293.

Parry, I. W. H. (2006). Are the Costs of Reducing Greenhouse Gases from Passenger Vehicles Negative? Retrieved October 13, 2007, from http://www.rff.org/documents/RFF-DP-06-14-REV.pdf

Parry, I. W. H., & Small, K. A. (2005). Does Britain or the United States Have the Right Gasoline Tax? *American Economic Review, 95*(4), 1276-1289.

politics.co.uk. (2007). Vehicle Excise Duty: What is Vehicle Excise Duty. Retrieved October 10, 2007, from http://www.politics.co.uk/issue-briefs/public-services/road/vehicle-excise-duty/vehicle-excise-duty-$366609.htm

Portney, P. R., Parry, I. W. H., Gruenspecht, H. K., & Harrington, W. (2003). The Economics of Fuel Economy Standards. Retrieved September 29, 2006, from http://www.rff.org/Documents/RFF-DP-03-44.pdf#search=%22parry%20%22the%20economics%20of%20fuel%20economy%22%22

PR Newswire. (2003). Japan's Automakers Call for Tax Reform in Japan; Consumers Face Nine Automobile-Related Taxes. Retrieved April 19, 2008, from http://cars.ign.com/articles/390/390918p1.html

Progressive Insurance. (2007). Use Less, Pay Less: A Simple Concept That Reduces the Cost of Car Insurance Now Available to Michigan and Oregon Drivers. Retrieved May 14, 2008, from http://newsroom.progressive.com/2007/January/Tripsense-mich-ore.aspx

Salopek, P. (2006). A tank of gas, a world of trouble. Retrieved March 27 2008, from http://www.chicagotribune.com/chi-oil-email,1,3687917.story

Sauer, A., & Wellington, F. (2004). TAKING THE HIGH (FUEL ECONOMY) ROAD: WHAT DO THE NEW CHINESE FUEL ECONOMY STANDARDS MEAN FOR FOREIGN AUTOMAKERS? Retrieved February 8, 2008, from http://pdf.wri.org/china_the_high_road.pdf

Small, K. A., & Dender, K. V. (2005). The effect of improved fuel economy on vehicle miles traveled: Estimating the rebound effect using U.S. state data 1966 - 2001. *Working paper no. 05-06-03* Retrieved 31 July 2007, from http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1026&context=ucei

Small, K. A., & Dender, K. v. (2007a). Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. *The Energy Journal, 28*(4).

Small, K. A., & Dender, K. V. (2007b). If Cars Were More Efficient, Would We Use Less Fuel? *Access #31* Retrieved March 27 2008, from http://www.uctc.net/access/31/Access%2031%20-%2003%20-%20Cars%20More%20Efficient.pdf

Sterner, T. (2003). *Policy instruments for environmental and natural resource management*. Washington, DC: Resources for the Future : World Bank ; Swedish International Development Cooperation Agency.

Tabo, E., Yoshina, T., Sekine, Y., & Saito, R. (2006). Technology Status and Future of Clean-Energy Vehicles. Retrieved October 9, 2007, from http://www.mitsubishi-motors.com/corporate/about_us/technology/review/e/pdf/2006/18e_02.pdf

Tellus Institute. (2002). Program Design Features for Feebate Initiative: Survey of Existing Feebate Programs. Retrieved October 19, 2007, from http://righg.raabassociates.org/Articles/Tellus_FeebateMemo_Nov25.doc

The City of Milan. (2008). Ecopass: Useful Information. Information Brochure., April 19, 2008, from http://www.comune.milano.it/dseserver/ecopass/images/ECOPASSbrochureinglese.pdf

The White House. (2007). Fact Sheet: Energy Independence and Security Act of 2007 Retrieved Feburary 7, 2008, from http://www.whitehouse.gov/news/releases/2007/12/print/20071219-1.html

Train, K. E., Davis, W. B., & Levine, M. D. (1997). Fees and rebates on new vehicles: Impacts on fuel efficiency, carbon dioxide emissions, and consumer surplus. *Transportation Research Part E: Logistics and Transportation Review, 33*(1), 1-13.

Transport Canada. (2007a). ecoAUTO Rebate Program. Retrieved February 24, 2008, from http://www.tc.gc.ca/programs/environment/ecotransport/ecoauto.htm

Transport Canada. (2007b). MOTOR VEHICLE FUEL CONSUMPTION STANDARDS ACT PROCLAIMED, News Release. Retrieved February 8, 2008, from http://www.tc.gc.ca/mediaroom/releases/nat/2007/07-h215e.htm

Transport Canada. (2008). CANADA'S FIRST MOTOR VEHICLE FUEL CONSUMPTION REGULATIONS: CONSULTATIONS BEGIN, News Release. Retrieved February 8, 2008, from http://www.tc.gc.ca/mediaroom/releases/nat/2008/08-h006e.htm

U.S. Court of Appeals for the Ninth Circuit. (2007). Center for Biological Diversity v. NHTSA. No. 06-71891, November 15, 2007. Retrieved April 24, 2008, from http://www.ca9.uscourts.gov/ca9/newopinions.nsf/775202DBA504085C88257393007B9729/$file/0671891.pdf

Vyas, A., Santini, D., & Curenca, R. (2000). Comparison of indirect cost multipliers for vehicle manufacturing: Technical memorandum in support of electric and hybrid electric vehicle cost estimation studies. Retrieved 17 July, 2007, from http://www.transportation.anl.gov/pdfs/TA/57.pdf

Wachs, M. (2003). Improving Efficiency and Equity in Transportation Finance. *Transportation Reform Series*, from http://www.brookings.edu/es/urban/publications/wachstransportation.htm

Wald, M. L. (2006, December 24, 2006). New Federal Fuel Economy Ratings Set a Double Standard. *New York Times*.

Wenzel, T. (1995). Analysis of National Pay-As-You-Drive Insurance Systems and Other Variable Driving Charges. Lawrence Berkley Laboratory, University of California. Prepared for the U.S. Department of Energy, July 1995.