

**Setting the Standard:
How Cost-Effective Technology Can
Increase Vehicle Fuel Economy**

Jim Kliesch

*Union of Concerned Scientists
April 2008*

© 2008 Union of Concerned Scientists
All rights reserved

Jim Kliesch is a senior engineer in the UCS Clean Vehicles Program.

The Union of Concerned Scientists is the leading science-based nonprofit working for a healthy environment and a safer world.

The UCS Clean Vehicles Program develops and promotes strategies to reduce the adverse environmental impact of the U.S. transportation system.

More information about the Union of Concerned Scientists and the Clean Vehicles Program is available on the UCS website at www.ucsusa.org.

The full text of this report is available online (in PDF format) at www.ucsusa.org/clean_vehicles or may be obtained from:

UCS Publications
Two Brattle Square
Cambridge, MA 02238-9105

Or, email pubs@ucsusa.org or call (617) 547-5552.

Table of Contents

Figures and Tables	iv
Acknowledgments	v
Executive Summary	1
Chapter 1. A Nation of Drivers	6
<i>Sidebar: Recent Fuel Economy Rulemakings</i>	8
Environmental Consequences.....	9
Economic Consequences.....	10
Geopolitical Consequences.....	10
An Urgency for Action.....	13
Chapter 2. Vehicle Technologies: Yesterday, Today, and Tomorrow	14
<i>Sidebar: The Invisible Muscle of Contemporary Cars</i>	14
<i>Sidebar: Fueling the Future</i>	17
Chapter 3. Fuel-saving Technologies: Potential and Costs	18
<i>Sidebar: Studies Assessed in Setting the Standard</i>	18
The Potential of Fuel Economy Technology.....	18
The Cost of Fuel Economy Technology.....	19
Chapter 4. Setting Fuel Economy Standards	22
Putting a Price Tag on Benefits.....	23
<i>Sidebar: Federal Court Finds NHTSA Analysis Flawed</i>	23
Types of Cost-Benefit Analysis.....	25
Chapter 5. Assessing the Benefits	28
Chapter 6. Securing a Strong Fuel Economy Future	31
References	33
Appendices	
Appendix A. Fuel-Efficient Technologies Currently on the Market.....	37
Appendix B. Studies and Assessment Methodology.....	41
Appendix C. Cost-Benefit Assessment Assuming \$3.00/gallon Gasoline.....	50

Figures and Tables

Figures

Figure ES-1. Fleet Average Fuel Economy Potential (TCTB Analysis) by Study and Technology	2
Figure 1. U.S. Population and Passenger Vehicle Trends, 1950-2005	6
Figure 2. U.S. Vehicles in Operation, 1950-2006.....	7
Figure 3. The Impact of CAFE Standards on Gasoline Consumption.....	8
Figure 4. CO ₂ Emissions from Fossil Fuels by Sector and Fuel, 2006.....	9
Figure 5. Top Five Global Warming Polluters from Fossil Fuel Combustion, 2004	10
Figure 6. The Economic Consequences of Oil Consumption, 1975-2006	11
Figure 7. U.S. Gasoline Expenditures and Price, 1978-2007	12
Figure 8. Total U.S. Petroleum Production and Net Petroleum Imports, 1970-2006.....	12
Figure 9. Average Vehicle Fuel Economy, Weight, and Performance, 1975-2007	15
Figure 10. Vehicle Energy Use in a Typical Passenger Car	16
Figure 11. Midsize Car Fuel Economy Potential by Study and Technology.....	20
Figure 12. Vehicle Technology Assessments: Fuel Economy Potential vs. Retail Price Increase	21
Figure 13. Fleet Average Fuel Economy Potential (TCTB Analysis) by Study and Technology.....	26
Figure 14. Fleet Average Fuel Economy Potential (MCMB Analysis with Externalities) by Study and Technology	27
Figure 15. The Impact of Increased Fuel Economy on Oil Consumption	29
Figure C-1. Fleet Average Fuel Economy Potential (TCTB Analysis, \$3.00/gal Gasoline) by Study and Technology	50
Figure C-2. Fleet Average Fuel Economy Potential (MCMB Analysis, \$3.00/gal. Gasoline, with Externalities) by Study and Technology.....	50

Tables

Table ES-1. Cumulative Benefits from Increased Fuel Economy Standards	3
Table 1. Yesterday's Muscle Car, Today's Family Car	14
Table 2. Cost-Effective Fuel Economy Potential by Study and Analysis Type	28
Table 3. Cumulative Benefits from Increased Fuel Economy Standards	30
Table B-1. Vehicle Class Mappings.....	47

Acknowledgments

This report was made possible through the generous support of Foundation M, The Energy Foundation, The Pew Charitable Trusts, The William and Flora Hewlett Foundation, and Wallace Global Fund, with additional support from NoraLee and Jon Sedmak.

The author would like to express sincere thanks to the entire UCS Clean Vehicles team for their helpful comments and detailed editorial suggestions during the preparation of this report. Special thanks are extended to David Friedman for his wealth of insight and feedback. The author also extends heartfelt thanks to Heather Tuttle, Bryan Wadsworth, and Rob Catalano for their editing and layout talents, an undertaking made all the more challenging by a tight deadline; their efforts are sincerely appreciated. Finally, gratitude is expressed to Jason Mark of The Energy Foundation for his valuable feedback, and to the authors of the cost and performance studies upon which this analysis is based: Feng An, John DeCicco, K.G. Duleep, David Friedman, David Greene, John Heywood, Matthew Kromer, Northeast States Center for a Clean Air Future, Steve Plotkin, and Malcolm Weiss and colleagues.

The opinions expressed in this report do not necessarily reflect those of the foundations that supported this work, nor of the other authors listed above. Both the information and opinions presented here are the sole responsibility of the author.

Executive Summary

The United States is a nation of drivers. Americans own about 250 million passenger vehicles today, and they are driving these vehicles more and more every year. These trends, combined with stagnant vehicle fuel economy standards and a market shift toward less fuel-efficient SUVs, pickups, and minivans have resulted in a dramatic increase in our nation's oil consumption and global warming emissions.

Over the past few years, concerns about global climate change, energy security, and economic stability have brought U.S. transportation policy to the forefront of the national agenda. After decades of inaction, some progress is finally being made to reduce the environmental and economic impact of passenger vehicles. In 2007 alone, ground-breaking legislation (the Energy Independence and Security Act of 2007) was signed into law, requiring cars and trucks to achieve a minimum fleet average fuel economy of 35 miles per gallon (mpg) by 2020; several landmark legal decisions cleared the way for action on reducing global warming pollution from vehicles; and the automotive industry acknowledged that cost-effective technical solutions to boost car and light truck fuel economy exist today.

While the 2007 energy bill should lead to substantial improvements in fuel economy over the next 10 to 15 years, simply meeting the minimum fleet average of 35 mpg by 2020 will not cure our nation's oil addiction or sufficiently reduce heat-trapping emissions to avoid the most harmful effects of global warming. To evaluate how much farther our cars and trucks could go on a gallon of fuel, the Union of Concerned Scientists (UCS) analyzed several studies on fuel economy technology potential and costs and found that, by multiple accounts, cars and trucks could cost-effectively reach an average of about 40 mpg by 2020 with conventional technology alone, and more than 50 mpg by 2030 with the additional deployment of hybrid-electric technology. Combined with policies aimed at reducing vehicle miles traveled and increasing low-carbon fuel use, these higher fuel economy standards can be the cornerstone of a more efficient, climate-friendly transportation sector.

Harnessing Cost-Effective Technology

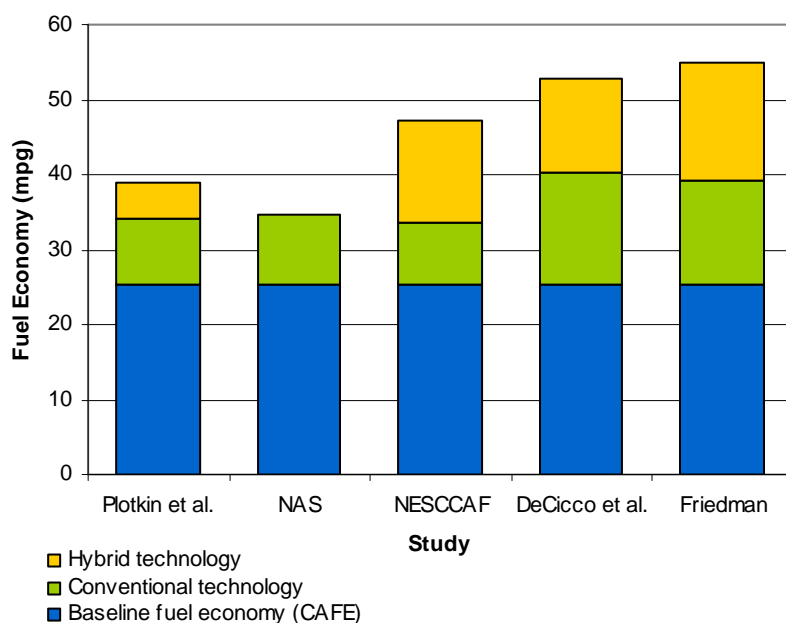
Automotive engineers have a number of technologies at their disposal to make cars and trucks more fuel-efficient, including those that improve engine and drivetrain efficiency, reduce auxiliary loads,¹ and reduce aerodynamic drag or rolling resistance. Packaging these technologies together can offer additional and often synergistic design benefits. These technologies vary, however, in price and ease of implementation. Conventional technologies, which offer modest to mid-level fuel economy improvements, can be implemented in the near term at relatively low cost, while advanced technologies such as hybrid powertrains are more expensive and take longer to fully penetrate the market, but deliver even greater fuel savings and emissions reductions (when combined with conventional technologies). In most cases, these technology packages are cost-effective for consumers because they result in fuel savings over the lifetime of the vehicle that more than offset the technology's upfront cost.

¹ Auxiliary loads are the energy demands for power steering, water pumps, air conditioning, and other common non-motive vehicle equipment.

To determine maximum feasible fuel economy targets, regulators often conduct cost-benefit analyses that weigh the cost of fuel-saving technologies against the economic and societal benefits associated with their implementation. Using several recent studies by experts in the private, government, academic, and nonprofit sectors that examine the relationship between various technologies’ fuel economy potential and cost, UCS conducted its own cost-benefit analyses to determine how high fleet average fuel economy standards can—and should—be set by regulators and legislators.

The studies offer differing perspectives on how high fuel economy can go with conventional and hybrid technologies. This is due in large part to varied assumptions about the potential benefits of hybrid technology and the use (or lack thereof) of high-strength, lightweight materials. The studies also vary in their assumptions about the costs of the various technologies. The results of the cost-benefit analyses performed by UCS thus represent a range of potential that can be provided by fuel-saving technologies.

Figure ES-1. Fleet Average Fuel Economy Potential (TCTB Analysis) by Study and Technology



Notes: Assumes a baseline "CAFE" fuel economy of 25.3 mpg (20.2 mpg in real-world operating conditions), 15,600 year-one base miles with a diminishing travel each year of 4.5%, discount rate of 7%, rebound effect of 10%, and a retail gasoline price of \$2.61 per gallon (2006 dollars) minus a combined federal and state gasoline tax of 40 cents per gallon. (Gasoline taxes are excluded from the analysis because they are considered a "transfer" from taxpayers to pay for road repairs and to support public transit.) Externalities such as reduced global warming pollution and increased energy security are excluded from this TCTB analysis.

The most transparent approach to determining fuel economy standards is to simply ask the question, “How high can we raise the standards so that we can cut our oil addiction while making sure consumers will be at least as well off economically as they are today?” This analysis forms the basis of a total cost-total benefit (TCTB) analysis. UCS conducted a TCTB analysis on the studies described above, and found that a fleet average fuel economy of 39 to 55 mpg would be

both achievable and cost-effective (see Figure ES-1). Compared with the minimum fleet average of 35 mpg specified in the 2007 energy bill, these studies suggest potential for up to an 11 percent increase in fuel economy using conventional technology alone, and up to a 57 percent increase when combined with fully deployed hybrid technology.

Of course, it will take time for automakers to deploy these technologies. UCS estimates that it could take roughly 10 years (2010 to 2020) to fully deploy conventional fuel-efficient vehicle technologies to achieve a fleet average fuel economy of up to 40 mpg, and another 10 years (2020 to 2030) to fully deploy hybrid technology and achieve up to 55 mpg. These should be regarded as conservative estimates, since this assumes that hybrid technology—which is gaining a steady market interest *today*—will not be used until after 2020. Since we are already seeing rapid adoption of hybrid technologies, higher fuel economy standards could certainly be achieved sooner. For example, if hybrids represented 25 percent of the new vehicle market in 2020, fuel economy could reach as high as 42 mpg from vehicle improvements alone.

Assuming this conservative technology deployment timetable, these higher fuel economy standards can also yield significant environmental benefits compared with a baseline scenario that assumes no fuel economy progress other than laws that were on the books as of 2006 (see Table ES-1). As the table shows, the benefits vary substantially depending on the assessment. The 2007 energy bill, for example, could save more than 350 billion gallons of gasoline and reduce global warming emissions by more than 4,000 tons by 2030, while more aggressive technology deployment has the potential to increase these savings by more than 60 percent.

Table ES-1. Cumulative Benefits from Increased Fuel Economy Standards

Policy/Study	Fuel Economy Standard (mpg)		Oil Savings (billion gallons gasoline)		Avoided Global Warming Pollution (MMT CO ₂ -equiv)	
	Through 2020	Through 2030	Through 2020	Through 2030	Through 2020	Through 2030
2007 Energy Bill Minimum	35	35	61	367	681	4,071
Plotkin/NAS	35	39	61	396	681	4,390
NESCCAF	35	47	61	445	681	4,937
Friedman	39	55	87	572	964	6,347

Notes: UCS calculation based on the policy and studies referenced in the table above. Estimated benefits are based on full deployment of conventional technology by 2020 and full deployment of hybrid technology by 2030. (The 2020 assessment includes no hybrids and is thus a very conservative estimate.) Cumulative benefits are compared with a baseline scenario in which fuel economy policies in place as of 2006 remain in effect and fuel economy does not change significantly after 2011. The Plotkin and NAS studies, which have similar modeling foundations and similar conventional technology findings, were combined to facilitate inclusion of hybrid technologies; hybrid vehicles were not assessed in the original NAS study.

The Road Ahead

In spring 2008, the National Highway Traffic Safety Administration (NHTSA) will begin the rule-making process for interim (model year 2011–2015) vehicle fuel economy standards—the first step toward the minimum goal of 35 mpg by 2020. Whether passenger vehicle fuel economy

ultimately reaches or even surpasses this goal, however, will hinge upon how NHTSA drafts this rule. The agency's cost-benefit analysis approach and assumptions about technology potential, costs, and benefits will substantially affect how high it sets maximum feasible fuel economy standards. The decisions NHTSA makes will not only have important legal and policy implications, but have lasting impacts on both the energy demand and carbon footprint of our future transportation sector.

Historically, NHTSA has taken a very conservative approach to setting fuel economy standards. Rather than using a TCTB analysis, which assesses how high standards can be set while making sure consumers are no worse off than they are today, the agency has used a marginal cost-marginal benefit (MCMB) analysis, which asks, "How high can we raise the standards such that the benefits of each additional mile per gallon in fuel economy outweigh the cost of the technology to get that additional fuel economy boost?"

These two analyses have subtle differences in framing, yet an MCMB analysis produces noticeably more conservative findings for maximum cost-effective fuel economy levels. The MCMB approach is also very sensitive to different valuations of the benefits, making it more error prone. It is therefore critical to accurately identify and account for the benefits associated with fuel-saving technologies. An MCMB analysis that excludes or undervalues even some of the benefits—such as avoided carbon emissions, reduced oil dependence, or increased consumer fuel savings at high gas prices—is fundamentally flawed. Unfortunately, NHTSA has already shown a tendency to use flawed MCMB analyses. In 2006, when setting light truck fuel economy standards for model years 2008–2011, the agency placed a monetary value of reduced heat-trapping emissions at zero dollars, effectively taking the position that global warming does no harm to our environment or economy. NHTSA also used very low gasoline costs in its assumptions, which vastly underestimated consumers' economic savings from reduced fuel use.

At a minimum, UCS suggests that NHTSA use a TCTB analysis to determine maximum feasible U.S. fuel economy standards. Such an analysis would reduce the need for NHTSA to accurately monetize the benefits of reduced fuel consumption, such as improved energy security and reduced heat-trapping emissions, and ensure that the agency is doing the most possible to address these issues without negative consequences to U.S. consumers. If NHTSA continues to use the more conservative MCMB analysis, the agency should use more realistic gasoline prices and, at a minimum, include more realistic values for costs of global warming pollution and oil security. In the analysis conducted for this report, UCS assumed a value of approximately \$41 per ton of carbon dioxide-equivalent emissions avoided (equal to \$0.49 per gallon,² in 2006 dollars)—a conservative assessment for a near-future carbon-constrained market—and \$0.35 per gallon (in 2006 dollars) for improved oil security³ (excluding both military program costs and the impacts of oil reliance on U.S. foreign policy). Similar valuations should be employed by NHTSA in its cost-benefit analyses as well.

² Assuming full life cycle emissions of 24 pounds of CO₂-equivalent per gallon.

³ Making vehicles more fuel-efficient can reduce our dependence on imported oil, which lowers not only global demand pressure, but also the financial risks of potential supply disruption and market price spikes, and the strategic costs of attempting to avoid them.

Given the urgency of addressing global warming and oil dependence, our cars and trucks must go well beyond the 35 mpg minimum fleet average outlined in the 2007 energy bill. By adopting the steps suggested in this report, NHTSA can ensure that the promising potential of fuel-saving vehicle technology is fully realized in tomorrow's cars and trucks.

Based on our analysis, we recommend that NHTSA:

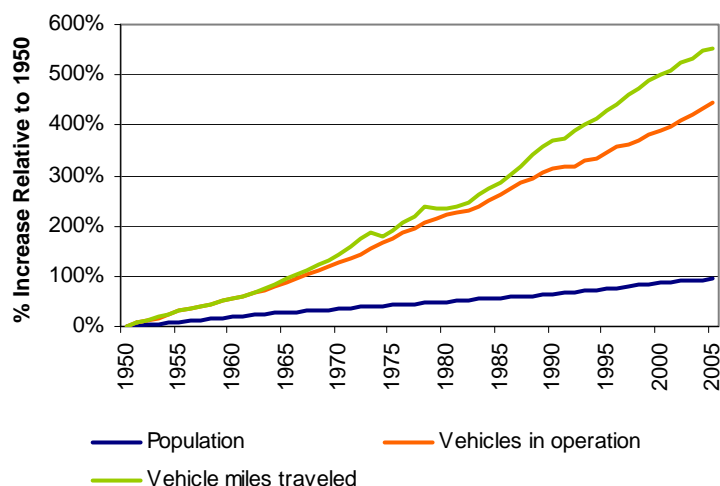
- Regard the 35 mpg fleet average fuel economy level as a bona fide *minimum* standard for 2020.
- Include analysis of data from a broad number of studies when considering maximum feasible fleet average fuel economy targets for 2020. Multiple studies assessed in this report indicate an ability to cost-effectively achieve fleet average fuel economies of around 40 mpg *with conventional technology alone*. A combination of conventional and hybrid vehicle technology could achieve even higher fuel economy levels; if hybrids represented a modest 25 percent of the new vehicle market in 2020, fuel economy could cost-effectively reach up to 42 mpg.
- Target a fleet average fuel economy of *at least* 50 mpg in 2030, reflecting an achievable, cost-effective fuel economy level based on conventional and hybrid vehicles.

These recommendations serve as a critical first step in the process of seeking solutions to the environmental, economic, and national security challenges posed by our nation's oil dependence. While fully realizing U.S. transportation goals will require a concerted, long-term effort from policy makers, consumers, and industry alike, the severity of consequences associated with inaction underscores the critical need to initiate this effort today.

Chapter 1. A Nation of Drivers

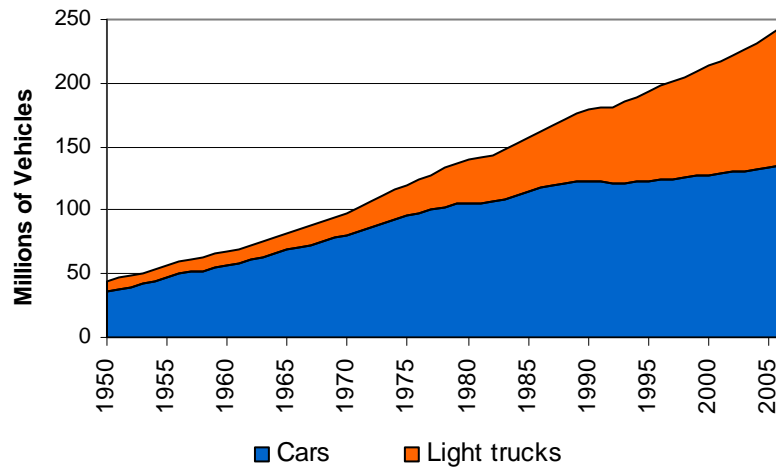
Since the 1950s, when President Eisenhower championed a coast-to-coast grid of interstate highways, Americans' fascination with personal travel has grown dramatically. Between 1950 and 2005, the United States population approximately doubled, yet in the same time period, the number of vehicles on the road more than quintupled, from roughly 43 million to 237 million. Moreover, since the early 1970s, Americans have been driving their cars and trucks more, with total vehicle miles traveled (VMT) outpacing the increase in both population *and* the number of vehicles on the road (Figure 1).

Figure 1. U.S. Population and Passenger Vehicle Trends, 1950-2005



Source: UCS calculation based on Davis and Diegel 2007.

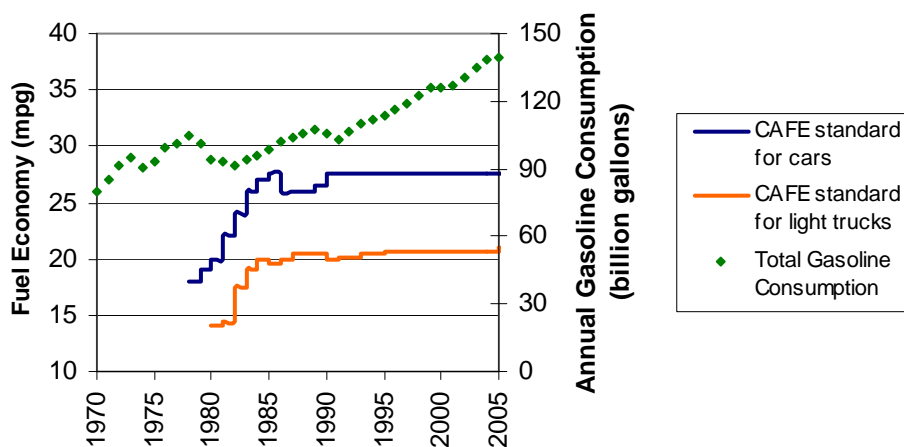
Meanwhile, amidst this growth, the type of vehicles Americans drive has shifted significantly. From the 1950s to the mid-1970s, fuel-inefficient trucks, which were primarily used by individuals needing to haul commercial goods, accounted for less than 20 percent of vehicles on the road. Since then, “light trucks”—which not only include pickups but also minivans, sport utility vehicles (SUVs) and, in recent years, “crossover” vehicles that combine the functionality of trucks with the design and handling of cars—have become a common staple of our nation’s highways and byways. These vehicles, which are subject to weaker fuel economy requirements than passenger cars, now account for roughly 50 percent of vehicles on the road (Figure 2).

Figure 2. U.S. Vehicles in Operation, 1950-2006

Source: Ward's Automotive Group 2007.

The compounding effects of changing driving patterns and a more truck-heavy personal vehicle market have caused a troubling increase in the amount of petroleum needed to feed our nation's driving habit. Between 1970 and 2005, the amount of gasoline used by American drivers grew 74 percent. Today, drivers pump more than 140 billion gallons of gasoline into their vehicles each year—a staggering figure that prompted President Bush to acknowledge in his 2006 State of the Union address, “America is addicted to oil” (White House 2006).

How exactly did we get here? The road to this addiction has, in fact, been a circuitous one. In 1975, fresh out of the 1973–1974 Arab oil embargo, the federal government enacted Corporate Average Fuel Economy (CAFE) standards with the goal of roughly doubling passenger car efficiency to 27.5 miles per gallon (mpg) over a 10-year period. At the same time, the National Highway Traffic Safety Administration (NHTSA) was granted authority to set fuel economy standards for light trucks, which then accounted for less than 20 percent of personal vehicle sales. These CAFE standards worked remarkably well at reining in gasoline fuel consumption; however, regulators did not increase the standards to keep pace with the subsequent increase in travel and number of passenger vehicles on the road, and by the early 1990s consumption was once again on the rise (Figure 3).

Figure 3. The Impact of CAFE Standards on Gasoline Consumption

Source: NHTSA 2004; Davis and Diegel 2007.

Fuel economy standards remained almost unchanged between 1985 and 2004. More recently, NHTSA made small changes to light truck fuel economy standards (see box), but today's cars are still subject to the same 27.5 mpg standard first applied to them in 1985. This will soon change as a result of the Energy Independence and Security Act of 2007, a new law enacted as part of the 2007 energy bill that increases the fleet average fuel economy for both cars and trucks (minus certain exemptions such as large pickup "work trucks") to a combined minimum of 35 mpg by 2020. NHTSA will craft the specifics of the new standards, which take effect starting in 2011, in consultation with other agencies such as the U.S. Environmental Protection Agency (the agency responsible for implementing vehicle global warming pollution standards).

While the 2007 energy bill should lead to substantial improvements in fuel economy over the next 10 to 15 years, it is important that, moving forward, we retain perspective on the implications of congressional and regulatory inaction. There is no single reason for America's addiction to oil, but a significant share of the blame can be attributed to the fact that energy policies of the day were not sufficiently attentive to either the changing vehicle market or Americans' changing driving behaviors. In short, fuel economy policy stagnated precisely when it was most urgently needed—and the consequences of that mistake are today more visible and troubling than ever.

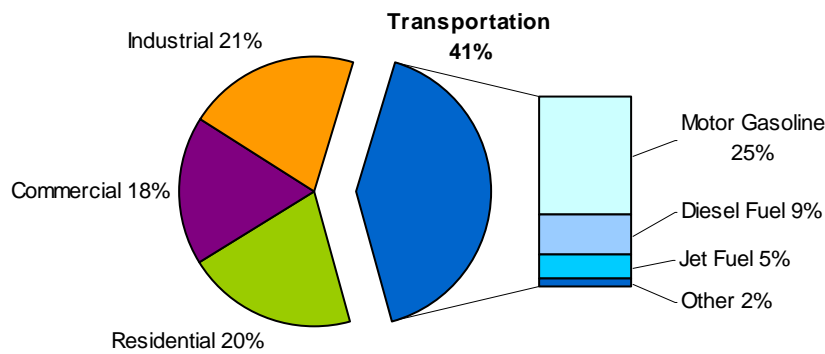
Recent Fuel Economy Rulemakings

In April 2003, NHTSA issued a rule calling for a very small (1.5 mpg) increase to light truck fuel economy between model years 2005 and 2007. Three years later, in 2006, NHTSA increased fuel economy standards for SUVs, minivans, and certain pickup trucks between model years 2008 and 2011. However, these increases set by NHTSA were marginal (averaging less than 0.5 mpg per year) and, moreover, subsequently determined by the Ninth Circuit Court of Appeals to be set using approaches "arbitrary and capricious and contrary to the [Energy Policy and Conservation Act of 1975]" (*CBD v. NHTSA* 2007).

Environmental Consequences

The cars, pickups, SUVs, and minivans on our nation's roads consume nearly all gasoline in the transportation sector and are responsible for a quarter of our nation's fossil fuel-related emissions of carbon dioxide (CO₂)—the primary heat-trapping gas responsible for global warming (Figure 4). Passenger vehicles alone are responsible for emitting more CO₂ emissions than any other sector of the U.S. economy. In fact, as of 2004, the cars and trucks on U.S. roadways accounted for more global warming pollution than the entire economies of all but two other countries in the world (Figure 5). The sheer magnitude of CO₂ levels from U.S. passenger vehicles underscores the critical importance of developing mitigation plans for this sector that support broader efforts to reduce global warming pollution.

Figure 4. CO₂ Emissions from Fossil Fuels by Sector and Fuel, 2006



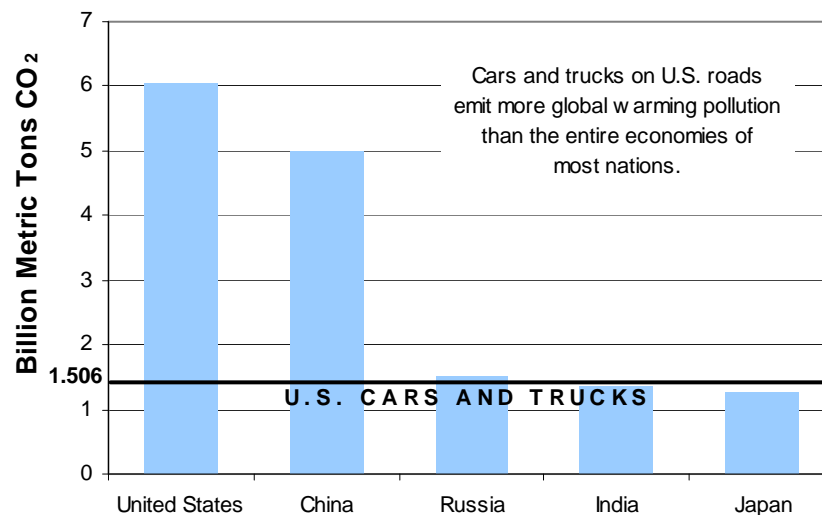
Source: UCS calculation based on EPA 2006 and EIA 2007a. Data include "upstream" emissions associated with extracting, refining, and transporting fuel from the well head to the fuel pump.

From a policy standpoint, lowering a vehicle's carbon footprint can be achieved through one or more of the following strategies:

- (1) Deploying technology to improve vehicle fuel economy and air conditioning systems
- (2) Reducing the life cycle global warming pollution associated with vehicle fuels⁴
- (3) Reducing the amount of vehicle miles traveled

While the focus of this report lies primarily in the area of fuel economy, it cannot be overemphasized that a comprehensive mitigation strategy portfolio would employ all three of the above strategies. A stronger emphasis on public transit infrastructure development by the Department of Transportation and state and local governments, for example, could help reduce VMT and congestion in urban centers. Similarly, the Environmental Protection Agency must exercise its authority under the Clean Air Act to establish global warming pollution standards for vehicles and fuels if U.S. transportation's role in climate change is to be adequately addressed.

⁴ A life cycle assessment of a fuel's global warming pollution accounts for heat-trapping emissions generated by a given fuel from the time it is grown or extracted to its ultimate release from the tailpipe, including fuel refinement and transport to a fueling station. For plant-based fuels (biofuels), the life cycle assessment also accounts for emissions related to feedstock source, production processes, and land use effects (UCS 2007a).

Figure 5. Top Five Global Warming Polluters from Fossil Fuel Combustion, 2004

Source: Country emissions from Marland, Boden, and Andres 2007. U.S. passenger vehicle emissions calculation based on EPA 2006 and EIA 2007a. Passenger vehicle data include upstream emissions.

Economic Consequences

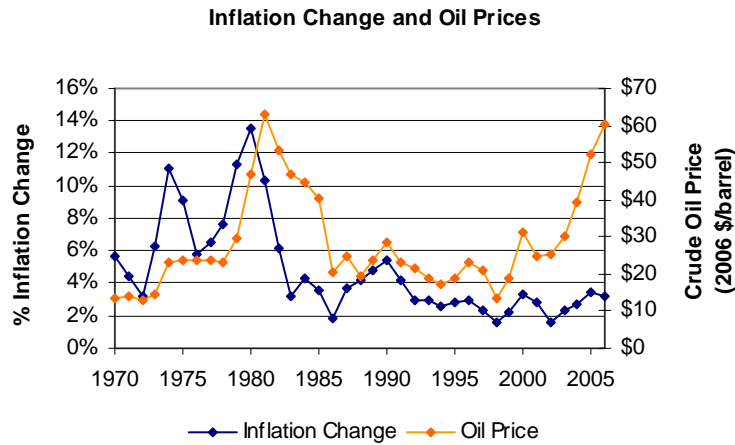
Our nation's dependence on oil has been an important factor in shaping the United States' economic well being, especially over the past few decades. As Figure 6 shows, oil prices have historically been closely correlated with inflation—a fact that is not surprising since higher energy prices translate to higher production costs and commodity prices, which in turn are passed on to the consumer as more expensive goods and services. And when inflation spikes, the economy falls into economic slowdown or, worse, a recession. Over the past few years, our economy has done a better job protecting itself from inflation in the face of high oil prices, yet as housing and other areas of the market now make downward turns, our economy is becoming more fragile and expensive oil may have a more pronounced impact.

As noted in November 2007 by Federal Reserve Chairman Ben Bernanke to the U.S. Congress, “Further sharp increases in crude oil prices have put renewed upward pressure on inflation and may impose further restraint on economic activity” (Bernanke 2007). Such economic warnings are understandable; in 2007, gasoline prices again exceeded \$3.00 per gallon, and in March 2008 both crude oil and gasoline prices reached record high levels. Gasoline prices have more than doubled since November 2003 (EIA 2007b); combined with continued growth in fuel demand, this has resulted in record consumer expenditures on gasoline, approaching \$400 billion in 2007 (Figure 7).

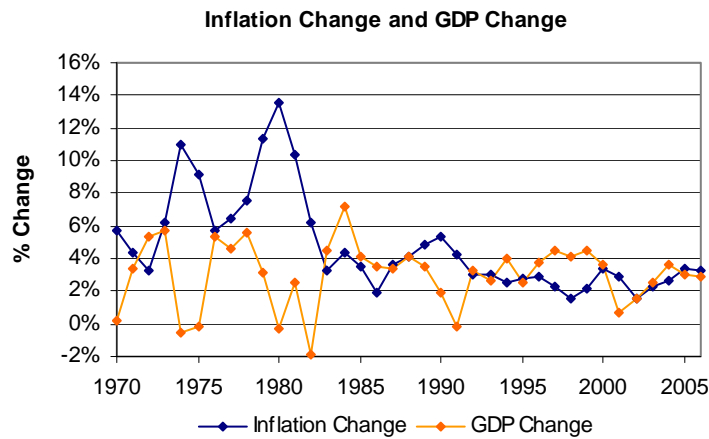
Geopolitical Consequences

An additional disconcerting consequence of our nation's oil addiction is our increased reliance on oil imported from foreign countries. Today, nearly 60 percent of the oil we consume is imported (Figure 8). As of early 2008, crude oil prices still hovered over \$100 per barrel; purchasing this oil to meet our growing demand has resulted in a billion-dollar-a-day spending deficit for the United States (UCS 2007b).

Figure 6. The Economic Consequences of Oil Consumption, 1975-2006



Source: BLS 2007, EIA 2007d Table 5.18.



Source: BEA 2007, BLS 2007.

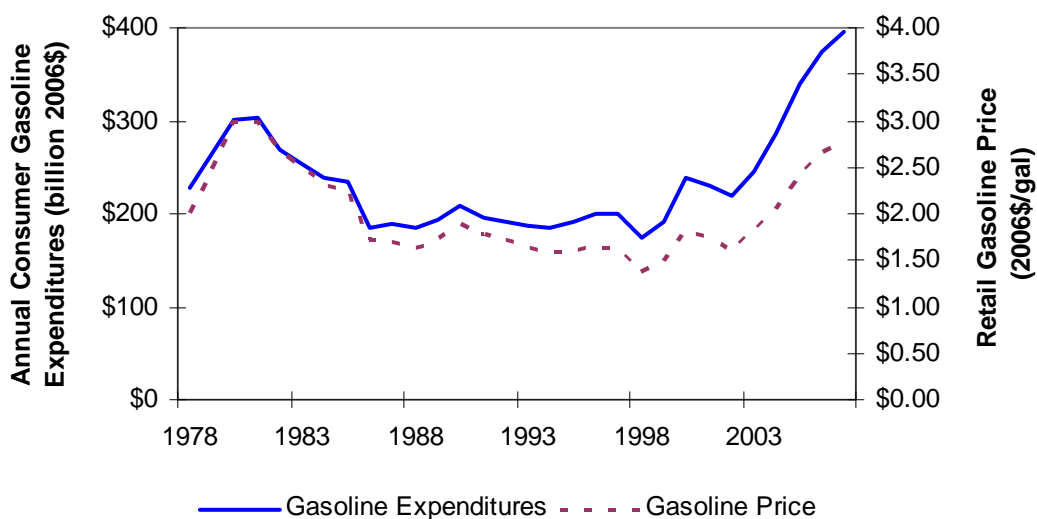
While Canada and Mexico are currently the two largest suppliers of oil to the United States, more than 40 percent of the United States’ net oil imports are from members of the Organization of the Petroleum Exporting Countries (OPEC); of this total, 40 percent comes from Persian Gulf countries⁵ (EIA 2007c). Maintaining a secure, steady supply of oil from this region, which includes a number of hostile or politically unstable countries, has posed significant challenges for the United States. Protecting U.S. oil interests has led to significant American military expenditures, as well as thousands of lives lost by the U.S. military alone. Supply concerns due to political instability have resulted in frequent and unpredictable market price spikes, adversely affecting the U.S. economy even more. In fact, a recent study has estimated that between 1970

⁵ Persian Gulf nations consist of Bahrain, Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates. Bahrain is the only Persian Gulf country that is not a member of OPEC; U.S. oil imports from Bahrain are negligible.

and 2004, U.S. oil dependence cost the nation \$3.6 trillion (in constant 2000 dollars), a figure *excluding* military expenditures and lives lost (Greene and Ahmad 2005).

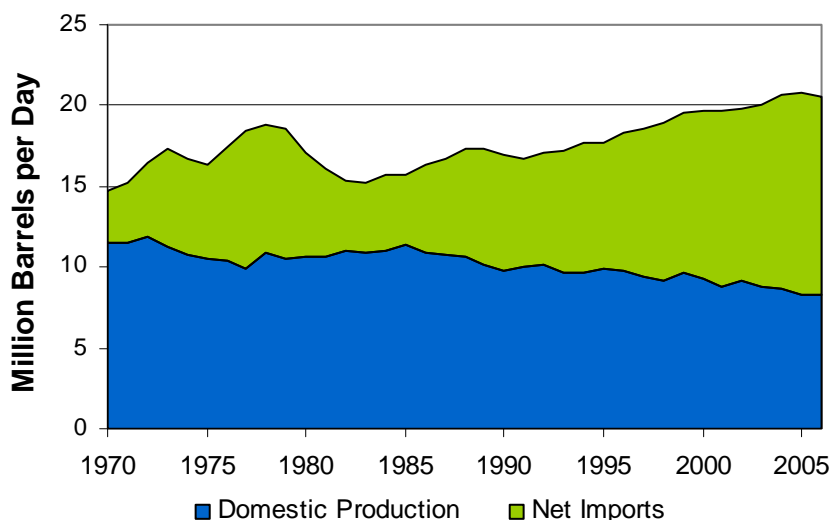
Outside the Middle East, only a few areas of the world are experiencing growth in oil production, meaning the United States will need to continue relying on the Middle East for oil in the years ahead. With brisk demand for petroleum products from industrializing countries like China and India placing additional strain on the import market, geopolitical challenges are likely to increase in the future for import-dependent countries like the United States (Heiman and Solomon 2007).

Figure 7. U.S. Gasoline Expenditures and Price, 1978-2007



Note: Retail gasoline price data represent an average across all gasoline grades.
 Source: 1978-2006 data from EIA 2007d Table 5.24, EIA 2007e. 2007 data from BLS 2008

Figure 8. Total U.S. Petroleum Production and Net Petroleum Imports, 1970-2006



Note: Petroleum consumption and import data include all sectors.
 Source: Davis and Diegel 2007.

An Urgency for Action

The environmental, economic, and geopolitical consequences of oil consumption each provide strong rationale to curb passenger car and truck petroleum use. In the case of global warming, for example, a recent study by the Union of Concerned Scientists (UCS) concludes that the United States and other developed nations will need to reduce their heat-trapping emissions at least 80 percent below 2000 levels by 2050 in order to avoid irreversible and dangerous climate change impacts such as sea level rise and species extinction (Luers et al. 2007). Taken over time, the reduction is equivalent to approximately 4 percent per year beginning no later than 2010. Stalling action until 2020 would require accelerating emissions reductions to roughly 8 percent per year in order to meet the 2050 target. Clearly, time is of the essence.

And yet the automobile industry is hardly nimble. While the industry releases new products each year, product plans are made years in advance and assembly line requirements limit on-the-fly changes. Even after decisions are made to bring new technologies to showrooms, those technologies take years to fully work their way into the market. And given that today's cars have a lifetime of roughly 15 years, the decision to bring (or not bring) a technology to market will have lasting direct impacts on the environment for the following decade and a half.

These are not reasons to abandon hope for the automotive sector. On the contrary, they are further justification for setting aggressive mandates to improve the fuel economy of the vehicles we drive well beyond 2020. The auto industry has historically demonstrated profound resistance against improving the fuel economy and environmental performance of its vehicles unless required to do so by the government. It is therefore incumbent upon both legislators and regulators to propose meaningful policies that address the challenges posed by our oil addiction.

That said, such policies should be thoughtfully chosen. While the vehicles we drive have a direct impact on the local economy, national security, and global environment alike, policies seeking to remedy transportation-related concerns should not fall prey to playing one benefit off of another. Converting coal into liquid fuel, for example, is being viewed by some as a way to create a domestic fuel source. Yet over its life cycle, liquid coal releases nearly twice as much global warming pollution per gallon as regular gasoline, making it virtually impossible to meet the emissions reduction targets needed to avoid the most dangerous consequences of climate change (UCS 2007a).

Chapter 2. Vehicle Technologies: Yesterday, Today, and Tomorrow

An examination of classic and contemporary cars quickly illustrates the plethora of new technologies employed on vehicles over the past few decades. Cabin amenities that were once considered luxury add-ons—such as air conditioning, compact disc players, contoured seats, and power windows—have become standard items in today’s new vehicles. Safety features such as three-point seatbelts and airbags are also standard items now common in both the front and rear passenger areas as a result of improved safety regulations.

Under the hood, technology has improved as well.

Today’s cars and trucks do more with a gallon of gasoline than they did in the past, largely through engineering improvements to engines and transmissions. Yet, rather than using those improvements to save fuel while maintaining vehicle performance, the industry has done the opposite. Since the early 1980s, automakers have produced heavier, faster, and more powerful vehicles on average, while ignoring vehicle fuel economy (Figure 9). Compared with the average passenger vehicle from 20 years ago, today’s average vehicle is more than 900 pounds heavier and has 89 percent more horsepower (EPA 2007). In fact, today’s typical “family car” is faster and more powerful than the iconic “muscle cars” of the 1970s (see box).

The Invisible Muscle of Contemporary Cars

Have you ever found yourself sitting behind the wheel of a contemporary sedan longing for the good ol’ days of performance-oriented muscle cars? If so, you may want to adjust those rose-colored glasses. Many of today’s most popular sedans offer better performance than even the archetypal muscle cars of the late 1960s and early 1970s. Take the 1968 Pontiac GTO and 2007 Toyota Camry V6, for example. Despite the fact that the Camry’s engine is roughly half the size of the GTO’s, the Camry has faster acceleration and standing quarter-mile times (see table below).

Table 1. Yesterday's Muscle Car, Today's Family Car



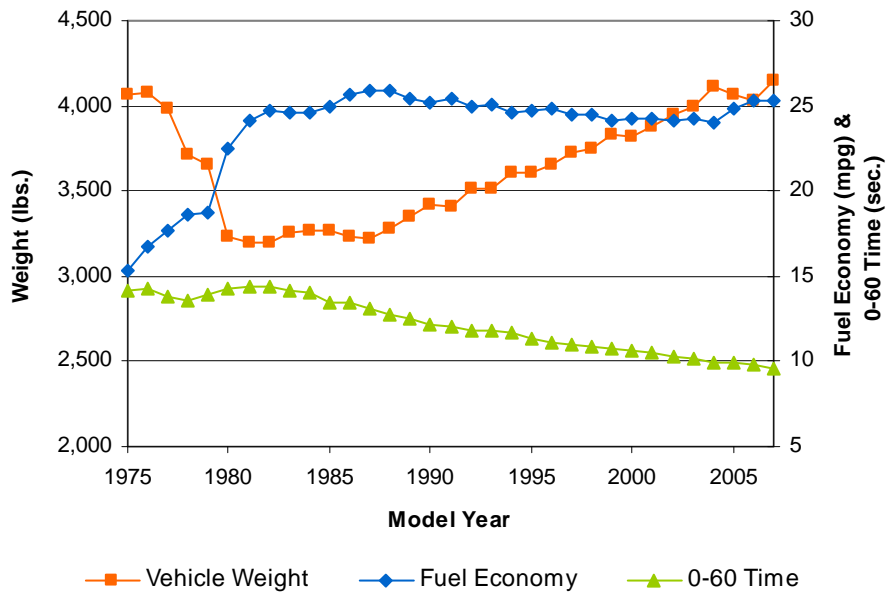
Performance feature	1968 Pontiac GTO	2007 Toyota Camry
Acceleration (0-60 mph)	7.3 sec.	6.0 sec.
Standing quarter-mile time	15.93 sec.	14.5 sec.
Engine Type	6.5-liter V8	3.5-liter V6
Transmission	3-speed automatic	6-speed automatic
Weight	3,506 lbs.	3,519 lbs.

Source: Motor Trend 2007; theautochannel.com 2007.

In one respect, this can be viewed as a testament to the technical prowess of today’s automotive engineers. Yet it is also an unfortunate commentary on decision making within the automotive industry over the past few decades. Rather than focusing engineering achievements on ways to improve overall vehicle fuel economy, the industry chose to turn their family cars into muscle cars, holding fuel economy constant (the 2007 Camry has the same combined city/highway mpg as the largest-engine-option Camry from 1985, but is heavier, faster and more powerful). These facts pan out across the car market. Compared with the average passenger car 20 years ago, today’s average car is 550 pounds heavier, has 78 percent more horsepower, and has 27 percent better acceleration (a 3.5-second shorter zero-to-sixty time, on average). Yet it offers no better fuel economy than its two-decades-old counterpart (EPA 2007).

To fully understand the fuel-saving potential of certain vehicle technologies, it is helpful to have a basic understanding of how energy is used in vehicles. Gasoline contains chemical energy that, when burned, is translated into thermal energy (heat) and mechanical energy (motion). In vehicles, the majority (more than 60 percent) of gasoline’s energy is translated to heat, which escapes from the exhaust pipe or the radiator. Much of the remaining energy is used to overcome various losses in the drivetrain such as friction, and to supply power to vehicle accessories such as air conditioners, lights, and radios. Additional energy is lost when idling, an event that occurs more frequently in city driving conditions.

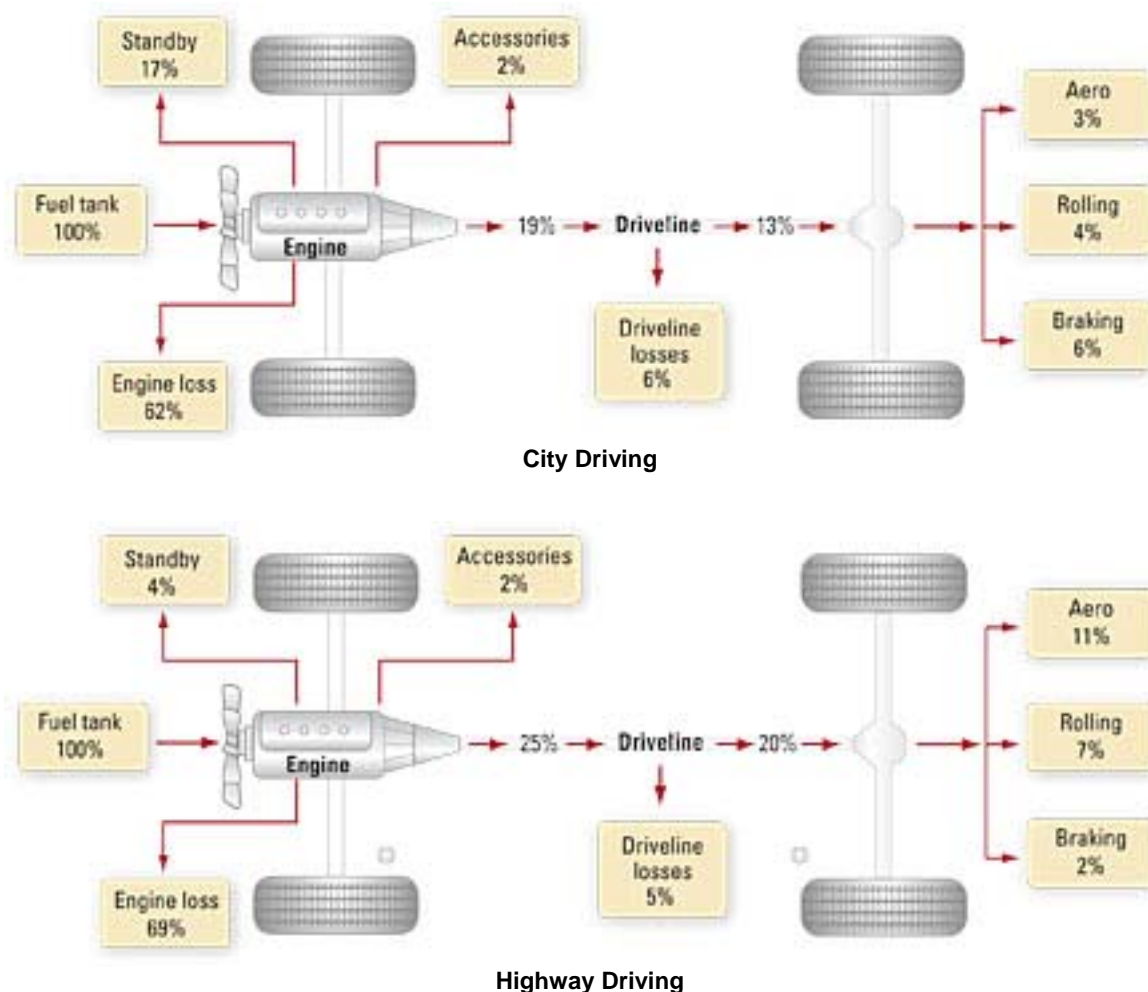
Figure 9. Average Vehicle Fuel Economy, Weight, and Performance, 1975-2007



Source: EPA 2007a.

The energy that remains (roughly 13 to 20 percent of the energy originally contained in the fuel, depending on driving conditions) actually works to push the vehicle down the road (Figure 10). A portion of this energy is used to accelerate the vehicle (and is then lost through friction each time the driver steps on the brakes), while the rest is used to overcome both wind resistance and rolling resistance.

Figure 10. Vehicle Energy Use in a Typical Passenger Car



Source: Transportation Research Board 2006.

Automotive engineers seeking to reduce a vehicle's energy losses and loads (and thereby boost its fuel economy) have a variety of strategies to pursue:

- Improve the efficiency of the engine and transmission components
- Reduce driving loads (wind resistance, weight, rolling resistance) and recapture energy normally lost in braking
- Reduce the losses associated with vehicle accessories and idling

There are a host of technologies available to help automotive engineers implement these strategies, such as variable valve control engines, continuously variable transmissions, high-strength lightweight materials, electric power steering, and low rolling resistance tires. These "off-the-shelf" technologies exist today and are already being employed on many vehicles (see Appendix A). While some of these designs offer relatively modest fuel economy gains on their own, they can offer a substantial hike in fuel economy when packaged together.

Even greater promise in fuel savings lies in advanced technologies such as hybrid gasoline-electric drivetrains, which could boost the passenger car and truck fleet average fuel economy up to 60 mpg when combined with conventional technologies (Friedman 2003). In a hybrid vehicle, an electric motor provides supplemental power to the vehicle, which, in turn, allows the vehicle to be fitted with a smaller engine that operates more efficiently. The electric motor also allows the engine to shut off at stoplights, rather than wasting fuel while idling. Hybrids also employ energy-saving “regenerative braking,” in which a portion of the energy normally lost during braking is recovered and fed back into the vehicle’s battery. These technologies work together to offer improved fuel economy while maintaining vehicle performance.

Fueling the Future

While the focus of this report is on improving the efficiency of conventionally fueled vehicles, it is important to consider the additional benefits that can be reaped from developing vehicles and infrastructure that accommodate non-petroleum fuels. While gasoline-powered vehicles won’t disappear from our driveways anytime soon, alternative fuels and vehicle technologies will play a critical role in making an eventual transition away from fossil fuels. Research is currently focused on three broad alternative fuel categories: biofuels, electricity, and hydrogen.

Interest in the use of plant-based **biofuels** (such as ethanol and biodiesel) has grown recently, and in many respects the enthusiasm is justified. While biofuels are not a silver bullet—there are near-term cost challenges and limits to how much petroleum biofuels can replace—they could offer the potential to reduce our dependence on oil. In many cases, biofuels also offer the potential for dramatic reductions in global warming pollution. That said, not all biofuels are created equal. Upstream emissions can be generated during the growing, harvesting, and processing of biomass, and the emissions vary greatly depending on the type of feedstock being used. And the use of certain feedstocks could actually lead to significantly increased global warming pollution due to deforestation or other land use changes associated with using that resource. Therefore, careful attention must be paid to development of the technology and policies that encourage its use (UCS 2007a).

Vehicles utilizing grid-based **electricity** as their primary (or exclusive) power source are also seeing a resurgence of popularity, in large part because of recent developments in battery technology. Pure electric vehicles that are affordable and offer all the amenities of today’s cars and trucks may be a number of years off, but plug-in hybrid-electric vehicles (PHEVs), which combine the benefits of conventional hybrids with the ability to use grid-based electricity over a given limited range, have shown promise. Continued research on battery cost, safety, and performance will be critical to the widespread adoption of this technology (Kliesch and Langer 2006). Because pure electric and PHEV models use grid-based electricity, it is critical to consider the upstream emissions associated with the power grid. The fuel mix of the generated electricity (i.e., whether it is produced from renewable energy sources or a carbon-intensive coal power plant) can significantly affect the emissions profile of the cars.

Over the past few years, **hydrogen** fuel cell vehicles (FCVs) have seen significant cost reductions and performance and durability improvements, though additional breakthroughs in these areas, as well as in hydrogen infrastructure, will be critical to developing an affordable commercial FCV. FCVs are still decades away from widespread adoption, yet the promise they offer warrants continued research in these areas. Acquiring non-petroleum, zero-carbon fuels for the transportation sector is a daunting challenge that cannot be solved overnight. Hydrogen produced using renewable energy remains a long-term option, but realizing that goal necessitates that we remain committed to its development in the near term as well.

All of these alternative fuels and vehicles build upon most, if not all, of the conventional fuel-saving technologies described earlier in this report. Combining biofuels with a more efficient engine, for example, will help compensate for the lower energy content (and consequently lower range) of ethanol. Plug-in hybrids that incorporate an efficient engine, weight reduction, aerodynamic streamlining, reduced rolling resistance, and accessory load reduction will be able to utilize smaller batteries while achieving comparable performance, thus reducing vehicle cost and improving vehicle marketability. Similarly, FCVs utilizing these efficient platform elements will require smaller, less expensive fuel cell stacks and a reduced demand for hydrogen production infrastructure. Quite simply, efficient conventional technologies are a key ingredient to nearly *all* future vehicle designs.

Chapter 3. Fuel-saving Technologies: Potential and Costs

As noted in Chapter 2, automakers seeking to boost a vehicle’s fuel economy have numerous options to achieve that goal. Technologies that improve a vehicle’s fuel economy are not free, however, and design decisions must be made that encompass cost, marketability, and manufacturability factors, among others. Policy makers or regulators must also consider a broad, though related, set of issues when determining the appropriate level to which standards should be set. Two of the most fundamental questions to consider are:

- How much of an improvement in fuel economy can vehicle technologies provide?
- How much will those technologies cost?

Over the past few years, a number of studies from the private, government, academic, and nonprofit sectors have examined these topics (see box); while the specific details and underlying assumptions of the studies vary, it is possible to draw general conclusions and comparisons between their findings.⁶ This chapter summarizes these findings and provides an objective, concise “lay of the land” about how far vehicle technology can go in improving fuel economy, and how much it would cost. In the following chapter, this information will be used in cost-benefit analyses to suggest appropriate fleet average fuel economy standards for regulators and policy makers to pursue.

The Potential of Fuel Economy Technology

According to the studies UCS analyzed, vehicle technologies have the potential to significantly increase passenger car and truck fuel economy. Figure 11 shows the estimated maximum fuel economy potential achievable for a typical midsize passenger car based on the studies’ findings, both in terms of conventional

Studies Assessed in Setting the Standard

Study title: *On the Road in 2020: A Life-Cycle Analysis of New Automobile Technologies*

Year released: 2000

Authors: M.A. Weiss et al., Massachusetts Institute of Technology (MIT)

Study title: *Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015*

Year released: 2001

Authors: J. DeCicco et al., American Council for an Energy-Efficient Economy

Study Title: Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards

Year released: 2002

Author: National Academy of Sciences (NAS)

Study Title: *Examining the Potential for Voluntary Fuel Economy Standards in the United States and Canada*

Year released: 2002

Authors: S. Plotkin et al., Argonne National Laboratory

Study Title: *A New Road: The Technology and Potential of Hybrid Vehicles*

Year released: 2003

Author: D. Friedman, Union of Concerned Scientists (UCS)

Study Title: *Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles*

Year released: 2004

Author: Northeast States Center for a Clean Air Future (NESCCAF)

Study Title: *Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet*

Year released: 2007

Authors: M.A. Kromer and J.B. Heywood, MIT Sloan Automotive Library

⁶ More information about the studies and their assumptions, as well as a detailed explanation of the methodology used to analyze them, is found in Appendix B.

technology and hybrid technology.⁷ Conventional technologies alone can boost the fuel economy of a typical midsize car to between 40 and 47 miles per gallon in the 2009 to 2020 timeframe; one recent study, from the Massachusetts Institute of Technology (MIT), examines fuel economy potential through a longer timeframe and predicts that conventional technologies will allow a midsize sedan to achieve approximately 54 mpg by 2030 (Kromer and Heywood 2007).

Hybrid vehicle technologies can lead to even greater gains in fuel economy. Excluding the most conservative and aggressive mid-term assessments of hybrid technology potential (Plotkin and Weiss, respectively), studies suggest that between 2009 and 2020, a midsize hybrid sedan could achieve 62 to 70 mpg,⁸ and by 2030, such a vehicle could achieve 87 mpg.

It is important to bear in mind that, like most technologies, fuel-saving equipment and vehicle designs are constantly evolving and improving. Many of the technologies we regard as advanced today will likely be commonplace—or outdated—within the next 10 to 20 years. For example, electronic fuel injectors were considered advanced technology in the mid 1980s, but had entirely replaced carburetors under the hoods of passenger cars and trucks in just 10 years; today, even more sophisticated approaches to blending air and fuel are being devised by automotive engineers. It is also important to note that such technological developments may not necessarily correspond to an increase in vehicle fuel economy, since automakers could instead use them to offset increased fuel use resulting from additional weight and horsepower. This underscores the need for strong policies that place an importance on reducing oil consumption and heat-trapping emissions.

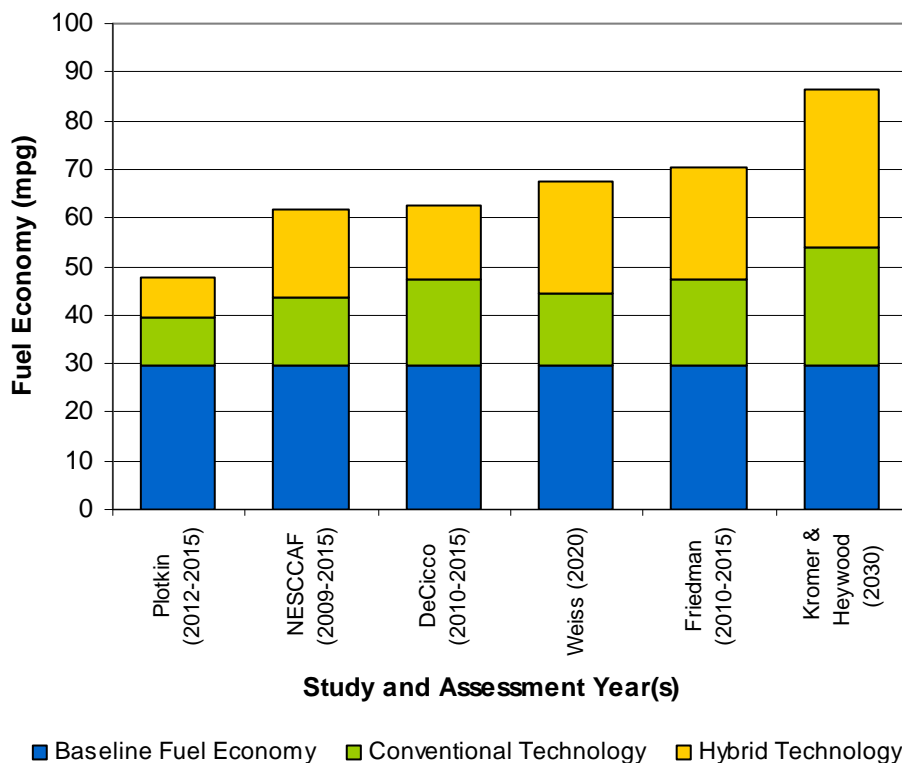
The Cost of Fuel Economy Technology

Vehicle technologies capable of providing dramatic boosts in fuel economy will not be marketed unless they are cost competitive. Five studies analyzed for this report examine both the fuel economy improvement potential of various vehicle technologies and their costs when deployed in a range of vehicle classes; UCS assessed these data to determine how technology deployment would translate into retail costs for consumers.

While these five studies all address technology potential and cost, their assumptions do vary. Some studies examine a broad spectrum of vehicle classes, while others examine only a few representative classes. Each study also examines a different set of vehicle technologies (some exclude certain conventional strategies such as use of high-strength lightweight materials, while one excludes hybrid technology completely). In addition, the baseline vehicle model year differs between the studies, ranging from 1999 to 2002.

⁷ The data analyzed in this report are for gasoline-fueled vehicles only. Data for diesel powertrains have been excluded from this analysis.

⁸ Variation in these assessments include different baseline fuel economies for modeled vehicles, different sets of technologies included in each assessment, and ascertained potential of those technologies.

Figure 11. Midsize Car Fuel Economy Potential by Study and Technology

Notes: UCS calculation based on studies listed in chart above, and EPA 2007a. Years listed denote the studies' respective assessment periods. Data shown have been downward-adjusted to account for technologies since applied to other amenities such as increased power (see Appendix B for details). Results are computed based on each technology's percentage improvement over the study's specified baseline mpg, then translated to fuel economy using the 2006 midsize car baseline of 29.6 mpg (EPA 2007a).

To provide a proper comparison of these five studies' findings, UCS applied adjustment factors to the findings to facilitate an apples-to-apples comparison.⁹ For example:

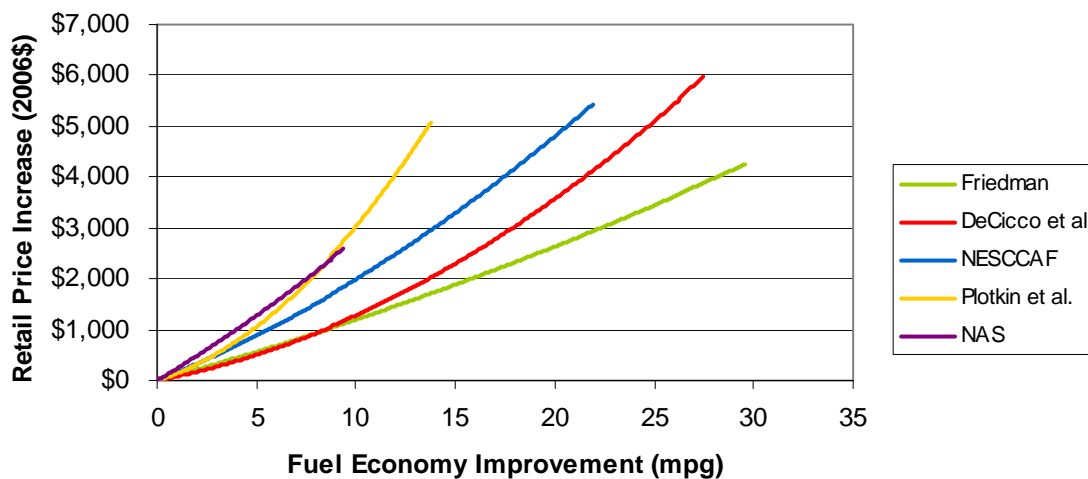
- All costs were translated into 2006 dollars to adjust for inflation, using data from the Consumer Price Index (BLS 2007).
- Data relating to diesel technologies (which are not covered in this report) and some of the less cost-effective technology packages¹⁰ from specific studies were excluded.

⁹ For more detailed information on this process, see Appendix B.

¹⁰ Certain technologies (such as the "moderate technology" hybrids from Friedman 2003) were excluded from this assessment, as it is unlikely that automakers would market technologies that have relatively high costs but comparably lower fuel economy improvement potential. See Appendix B for more detail.

- Fuel economy potential specified in each study was adjusted downward to account for technologies that have since been used to increase horsepower or to offset fuel economy losses incurred from increased weight. For example, overhead valve engines have become more common since 1999 as the technology has been used to increase horsepower, so potential fuel economy improvements from studies that relied on that technology were removed.
- The fuel economy potential of each vehicle class evaluated in the studies was aggregated into an estimate of the fleet mix fuel economy based on 2006 sales shares.

Figure 12. Vehicle Technology Assessments: Fuel Economy Potential vs. Retail Price Increase



Source: UCS calculation based on the studies listed in the chart above. Results based on model year 2006 fleet mix and vehicle performance.

Using these adjusted numbers, we examined the increase in retail cost associated with implementing fuel-efficient technology packages into the vehicle fleet (see Figure 12). These cost curves represent a sales-weighted fleet average of 2006 vehicles, as the fuel economy improvement potential and cost of technology deployed in large trucks, for example, will differ from those deployed in cars. As the figure illustrates, the suite of technologies analyzed by each of these studies greatly affects their findings about maximum technology potential (i.e., the “length” of each curve). For example, the 2002 National Academy of Sciences’ study shows very conservative fuel economy potential—a result, in large part, of the study’s exclusion of hybrid technology.

Chapter 4. Setting Fuel Economy Standards

To substantially reduce both our nation's contribution to global warming and dependence on oil, immediate policy shifts will be required. In addition to reducing vehicle miles traveled and shifting to lower carbon fuels (which are outside the scope of this report), policies that help support the production of fuel-efficient vehicles will be critical to reducing the environmental impact of the transportation sector.

For fuel economy, the overarching question is, how high can (and should) fuel economy standards be set? Since the 1970s, NHTSA has been tasked with regulating fuel economy standards for cars and trucks; NHTSA is legally required to set “the maximum feasible average fuel economy level that the Secretary [of Transportation] decides the manufacturers can achieve in that model year” (United States Code 1975). To determine “maximum feasible” fuel economy, “The Secretary of Transportation shall consider technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy.”

As demonstrated in Chapter 3, there is no question that with ample time to deploy technology in the marketplace, it is technologically feasible to substantially increase the fuel economy of the U.S. vehicle fleet well beyond the 35 mpg minimum standard recently enacted under the Energy Independence and Security Act of 2007. And, as detailed in Chapter 1, there is no question that the United States needs to conserve energy. Third, it is unlikely that most other motor vehicle standards will significantly affect fuel economy standards. Recent research has shown that there is no tradeoff required between safety and fuel economy (Gordon et al. 2007); upcoming safety standards would lead to only relatively small increases in vehicle weight. The majority of changes relating to Federal “Tier 2” tailpipe emissions standards, which are being phased in between 2004 and 2009, have already taken place; any remaining impact of them would be marginal. The only possible significant effect could come from California's Zero Emission Vehicle and global warming pollution standards, which are being widely adopted by other states. These standards will accelerate the development and sales of many technologies that simultaneously improve air quality, reduce global warming pollution, and, in many cases, also increase fuel economy, potentially making it even easier to reach higher fuel economy standards.

The remaining consideration, economic practicability, has been the greatest source of controversy. Historically, NHTSA has conducted cost-benefit analyses to inform the “maximum feasible” level of fuel economy that cars and trucks can achieve. However, the approach taken to date by the agency has been flawed, prompting criticism from states, consumer groups, science organizations, environmental advocates, and, in 2007, a federal appellate court. In response to a recent NHTSA rulemaking, the U.S. Ninth Circuit Court of Appeals determined in November 2007 that the cost-benefit analysis used by the agency did not properly account for certain benefits of increased fuel economy standards such as reduced global warming pollution (see box). Given the urgency of climate change, it is critical that NHTSA either switch to a methodology that does not fall prey to such accounting issues, or fully and accurately quantify these benefits so that fuel economy standards achieve meaningful gains.

Federal Court Finds NHTSA Analysis Flawed

Landmark legislation (the Energy Independence and Security Act of 2007) was passed in December 2007 calling for an increase in both passenger car and truck fuel economy standards—the first such increase in more than 30 years. The new standards require a combined fleet (car and truck) average of at least 35 mpg by 2020, a 40 percent increase over today's average of roughly 25 mpg. NHTSA will soon begin the process of setting rules for model year 2011–2015 vehicles as the first step toward this 35 mpg target. However, a court ruling one month prior to the energy bill's passage, which scrutinized the methodology NHTSA used when setting previous fuel economy rules for light trucks, will have an important effect on the interim-year fuel economy requirements soon to be set.

According to the Ninth Circuit Court of Appeals ruling, fuel economy standards established by NHTSA for model year 2008–2011 light trucks were found to be set using approaches that were “arbitrary and capricious and contrary to the EPCA [Energy Policy and Conservation Act of 1975]” (CBD v. NHTSA 2007). Observing numerous flaws in NHTSA's original approach, the court called for the agency to address the flaws and set new standards as soon as possible.¹ Many of these issues raised by the court will also influence the agency's upcoming 2011–2020 fuel economy standards. These issues are briefly summarized below.

Monetizing the Value of Carbon Emissions

In setting the 2008–2011 light truck standards, NHTSA used a marginal cost-marginal benefit (MCMB) assessment (see p. 26 for description) that assumed a zero-dollar value for carbon dioxide emissions reductions. While the Ninth Circuit Court of Appeals accepted the agency's use of a cost-benefit analysis in determining “maximum feasible” fuel economy standards, it fully rejected the notion of ignoring the economic benefits of reduced carbon dioxide emissions. As the court explained, “[NHTSA] cannot put a thumb on the scale by undervaluing the benefits and overvaluing the costs of more stringent standards” (CBD v. NHTSA 2007).

Setting a Fuel Economy “Backstop”

NHTSA structured the 2008–2011 light truck rule such that the required fuel economy level of each automaker is based upon that automaker's expected light truck sales. However, the rule excluded a minimum average fuel economy standard “backstop,” meaning that an interim shift in market sales toward greater production of light trucks could keep automakers from reaching their original fuel economy targets. The Ninth Circuit Court of Appeals ruled that NHTSA was “arbitrary and capricious” in failing to set a backstop, and that the agency failed to address petitioners' “well-founded concerns (given the historical trend) that a floating fleet-mix-based standard would continue to permit upsizing—which is not just a function of consumer demand, but also a function of manufacturers' own design and marketing decisions” (CBD v. NHTSA 2007).

Closing the SUV Loophole

The Energy Independence and Security Act of 2007 sets separate attribute-based target mpg levels for passenger and non-passenger vehicles, accommodating an industry interest in having non-passenger vehicles held to less stringent fuel economy standards than passenger vehicles of the same attribute (i.e., footprint size). These separate standards, which have been in effect in one form or another since the 1970s to accommodate performance-oriented, non-passenger work vehicles, created a long-standing loophole when NHTSA began equating light trucks with non-passenger vehicles. The association of these categories has allowed automakers to tweak passenger vehicle characteristics in order to have them classified as light trucks, and thereby held to lower fuel economy standards.

This “gaming” of the system is contrary to the original intent of the law and robs the nation of warranted energy savings. In the Ninth Circuit ruling, the court deemed that NHTSA's decision not to close the SUV loophole (by revising the definition of passenger and non-passenger automobiles) was arbitrary and capricious. The court ruled that, among other factors, NHTSA's decision “runs counter to the evidence showing that SUVs, vans, and pickup trucks are manufactured primarily for the purpose of transporting passengers and are generally not used for off-highway operation” (CBD v. NHTSA 2007).

Putting a Price Tag on Benefits

Today there is overwhelming scientific consensus and increased public recognition of not only the far-reaching impacts of global warming pollution, but also the fact that such pollution has real and quantifiable costs that are already being felt today. Recent rulings by the United States Supreme Court, United States District Court, and Ninth Circuit Court of Appeals have all acknowledged the importance of regulating and valuating global warming emissions; in fact, the

latter explicitly required in a 2007 ruling that NHTSA consider the costs of climate change in its setting of fuel economy standards. The prior notion that global warming emissions could be ignored in cost-benefit analyses has been unequivocally rebuked.

Of course, global warming is not the only cost associated with America's addiction to oil. Deploying technologies that improve vehicle fuel economy also provides both direct and indirect economic benefits. In this report, UCS valued three specific benefits:

Global Warming. Increasing fuel economy is one way to ensure that vehicles emit less global warming pollution, helping reduce the risk of dangerous climate impacts such as hotter temperatures and rising sea levels. These effects have economic consequences such as increased air conditioning costs and repair of coastal structures. Valuations of global warming emissions reductions vary widely; for this report, we use as an estimate the current market value for global warming pollution in 2012 under Europe's carbon-constrained market: approximately \$41 per ton of CO₂-equivalent (\$150 per ton of carbon-equivalent, or \$0.49 per gallon¹¹) (European Climate Exchange 2007). This represents a predicted marginal abatement cost (the cost of avoiding global warming pollution) and is likely a conservative estimate since the cost of avoiding climate change is lower than the cost of fixing the damage after it occurs.

Energy Security. Making cars and trucks more fuel-efficient can reduce our dependence on imported oil, which lowers not only global demand pressure, but also the financial risks of potential supply disruption and market price spikes, and the strategic costs of attempting to avoid them.¹² A recent study from Oak Ridge National Laboratory assesses these energy security benefits of reduced oil consumption at \$14.51 per barrel,¹³ or \$0.35 per gallon. This is a conservative assessment, as it excludes all military program costs, as well as the "difficult-to-quantify foreign policy impact of oil import reliance" (Leiby 2007).

Fuel Cost Savings. As noted earlier in this report, fuel prices have dramatically escalated in recent years; from 1997 to 2007, the average spot price of a barrel of crude oil rose from \$25.89 to \$70.34 (in 2006 dollars), while as of February 2008, oil was trading at more than \$100 a barrel (EIA 2007f). In spite of current trends, the Energy Information Administration (EIA) anticipates a *decline* in fuel prices due to increases in conventional oil production and greater use of unconventional fuel sources such as oil sands, ultra-heavy oils, liquefied natural gas, and liquid coal.¹⁴ The EIA estimates average crude prices declining to \$57 per barrel (2006 dollars) in 2016, and then increasing to a mere \$70 per barrel (2006 dollars) in 2030 (EIA 2007g). However, given current oil prices, the increased global demand for energy from countries such as China and India, and the increased use of market mechanisms (such as emissions trading) to limit carbon emissions, we find this rationale unfounded. A more plausible, yet still conservative, estimate of the retail price of fuel in future years would be a computed average of the past few

¹¹ Assuming full life cycle emissions of 24 pounds of CO₂-equivalent per gallon. Other recent allowance price estimates include \$28–\$51 in 2020 and \$46–\$83 in 2030, both in 2005 dollars per ton of CO₂-equivalent (EPA 2008).

¹² An extensive, non-monetized list of valued benefits resulting from reduced oil consumption can be found in S. 768, the Fuel Economy Reform Act.

¹³ When converted to 2006 dollars. Leiby estimates \$13.60 per barrel in 2004 dollars.

¹⁴ In addition to increased fuel costs, these unconventional fossil fuels would increase global warming pollution. For example, making gasoline from coal could more than double global warming pollution per gallon.

years' prices; for example, between 2005 and 2007 the average retail price of gasoline was \$2.61 per gallon. Excluding \$0.40 per gallon in gasoline taxes (the revenue from which is used to fix roads and highways and support increased public transit, and is therefore not considered a societal cost), this equates to a pre-tax gasoline price of \$2.21 per gallon.

Types of Cost-Benefit Analysis

There are a couple different ways in which the benefits associated with fuel-saving technology can be weighed against the cost of deploying the technology. The type of cost-benefit analysis conducted, as well as the assumptions used in the analysis, can yield profoundly different results about how high “maximum feasible” fuel economy standards can be set. UCS examines the differences between two major types of cost-benefit analyses, and, using the technology packages outlined in several studies, conducts our own analyses to determine the range of findings that can occur.

Total Cost-Total Benefit (TCTB) Analysis

Under a TCTB analysis, fuel economy can be increased to the point at which the total costs of deploying fuel-saving technologies in a vehicle are equal to the total benefits associated with fuel savings over the life of the vehicle. The question with a TCTB assessment is, in effect, “How high can we raise fuel economy standards so that Americans will be at least as well off economically as they are today?” TCTB analyses have multiple ways to account costs and benefits, depending on whether the goal is for consumers—or society as a whole—to be at least as well off as they are today.

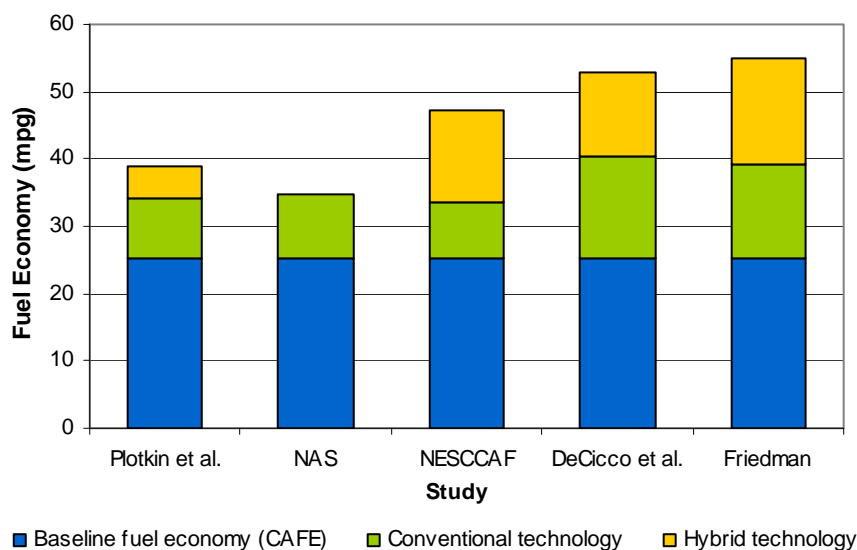
Using cost curve data from Figure 12 (p. 21), UCS conducted a TCTB analysis on the five studies' technology packages, assuming a retail gasoline price of \$2.61 per gallon. This TCTB analysis is focused exclusively on consumer fuel cost savings, so energy security and emissions reductions benefits that are shared by society as a whole are excluded. Therefore the maximum feasible fuel economy levels for each of the five studies are computed as the point at which the cost of the fuel economy technology package is completely offset by the pre-tax gasoline savings. In four of the five studies, however, the technology never even reached that level of expense. In other words, the maximum fuel economy achieved in these studies is limited by technology and not economic feasibility.

Figure 13 shows the corresponding “maximum feasible” fuel economy levels possible with conventional and hybrid technology under a TCTB analysis of each study, assuming a baseline fleet average fuel economy (2006 unadjusted CAFE value) of 25.3 mpg. The results of this analysis indicate that a maximum feasible fleet average fuel economy target is 39 mpg assuming a pessimistic assessment of technology costs and conservative technology deployment,¹⁵ and 55 mpg assuming more optimistic technology costs and aggressive technology deployment; a median fleet average fuel economy standard of 47 mpg (from the NESCCAF study) is eminently

¹⁵ The NAS study excludes hybrid technology in its analysis, and thus yields more conservative fuel economy estimates. The Plotkin study, which has similar findings to the NAS study in terms of conventional technology but does include hybrids, is assumed as a proxy for NAS findings with respect to maximum vehicle potential when including hybrid technology.

achievable. It is important to reinforce that the maximum feasible fuel economy for four of the five studies was restricted by the assumptions regarding application of conventional and hybrid technologies; a breakthrough in advanced technologies such as plug-in hybrid electric vehicles or fuel cell vehicles could substantially increase the maximum feasible fuel economy values.

Figure 13. Fleet Average Fuel Economy Potential (TCTB Analysis) by Study and Technology



Notes: Assumes a baseline "CAFE" fuel economy of 25.3 mpg (20.2 mpg in real-world operating conditions), 15,600 year-one base miles with a diminishing travel each year of 4.5%, discount rate of 7%, rebound effect of 10%, and a retail gasoline price of \$2.61 per gallon (2006 dollars) minus a combined federal and state gasoline tax of 40 cents per gallon. (Gasoline taxes are excluded from the analysis because they are considered a "transfer" from taxpayers to pay for road repairs and to support public transit.) Externalities such as reduced global warming pollution and increased energy security are excluded from this TCTB analysis.

Marginal Cost-Marginal Benefit Analysis

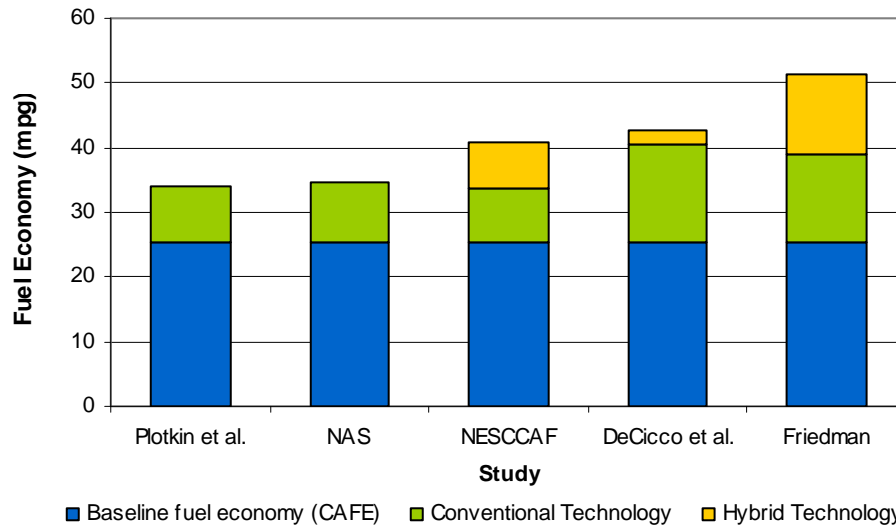
Under an MCMB analysis, fuel economy can be increased to the point at which the cost of deploying an additional fuel-saving technology is equal to the benefits associated with its incremental boost in fuel economy. Because an MCMB evaluates incremental, or marginal, costs and benefits, the results are much more sensitive to the input values than a TCTB analysis, which evaluates total costs and benefits.

Under an MCMB analysis, the proper identification and accurate valuation of "benefits" is very important. Accurately assessing *all* of the costs and *all* of the benefits in an effort to create optimal fuel economy standards may represent an ideal economic test, but the practicality of including and accurately valuing all factors calls this approach into question. An MCMB analysis that excludes or undervalues even some of the benefits—like lower CO₂ emissions, reduced energy dependence, or reduced gasoline consumption at high gas prices—is fundamentally flawed.

Figure 15 shows the results of an MCMB analysis on five studies that uses the average retail gasoline price for the last 3 years, \$2.61 per gallon, as well as \$0.35 per gallon for the benefit of

improved energy security through reduced oil consumption, and \$0.49 per gallon for the benefit of reduced global warming pollution. The results shown here are conservative, as we are likely underestimating the full set of benefits associated with fuel savings; more comprehensive accounting could lead to even higher results.

Figure 14. Fleet Average Fuel Economy Potential (MCMB Analysis with Externalities) by Study and Technology



Notes: Assumes a baseline "CAFE" fuel economy of 25.3 mpg (20.2 mpg in real-world operating conditions), 15,600 year-one base miles with a diminishing travel each year of 4.5%, discount rate of 7%, rebound effect of 10%, and a retail gasoline price of \$2.61 per gallon (2006 dollars) minus a combined federal and state gasoline tax of 40 cents per gallon. (Gasoline taxes are excluded from the analysis because they are considered a "transfer" from taxpayers to pay for road repairs and to support public transit.) Externalities include 84 cents per gallon for reduced heat-trapping emissions and improved oil security.

As shown in the figure, a 35 mpg standard (the minimum level set under the 2007 energy bill) is cost-effective with conventional technology even under the most conservative technology assumptions. The Friedman study, which assumes aggressive technology deployment, estimates that a 51 mpg fuel economy standard is cost-effective under an MCMB analysis, with 14 mpg coming from conventional technology and an additional 12 mpg coming from hybrid technology. A mid-range assessment such as NESCCAF indicates that a 41 mpg standard is eminently cost-effective under an MCMB test.

While the two cost-benefit analyses above assume a conservative gasoline price equal to the 2005–2007 retail average (with taxes excluded), it is likely that gasoline prices will continue to climb over the coming years. Appendix C presents the cost-benefit assessments in Figures 13 and 14 assuming a retail gasoline price of \$3.00 per gallon.

Chapter 5. Assessing the Benefits

While the technology assessments discussed in this report indicate that substantial, cost-effective increases in fuel economy are eminently achievable, it will take time to deploy these technologies in the vehicle market. Assuming a conservative estimate of five-year product cycles,¹⁶ it could take roughly two product cycles, or 10 years, for automakers to fully deploy conventional fuel-efficient technologies on vehicles.¹⁷ We assume another two product cycles to fully deploy hybrid technology. Thus, for this report, UCS estimates a full deployment of conventional technology by 2020, and hybrid technology by 2030; using this deployment timeframe and the results of the cost-benefit analyses in Chapter 4, sample fuel economy standards derived from the selected studies are shown in Table 2.

These should be regarded as conservative estimates, since this assumes that hybrid technology—which is gaining a steady market interest *today*—will not see significant deployment until after 2020. Since we are already seeing rapid adoption of hybrid technologies, higher fuel economy standards could certainly be achieved sooner. For example, if hybrids represented 25 percent of the new vehicle market in 2020, fuel economy could reach as high as 42 mpg from vehicle improvements alone.

Table 2. Cost-Effective Fuel Economy Potential by Study and Analysis Type

Policy/Study	Analysis Type	Fuel Econ Standard 2020 (mpg)	Fuel Econ Standard 2030 (mpg)
2007 Energy Bill	n/a	35 minimum	n/a
Plotkin/NAS	TCTB	35	39
NESCCAF	TCTB	35	47
Friedman	TCTB	39	55
Plotkin/NAS	MCMB	35	35
NESCCAF	MCMB	35	41
Friedman	MCMB	39	51

Notes: The Energy Independence and Security Act of 2007 requires a minimum fleet average fuel economy standard of 35 mpg by 2020; fuel economy standards are not specified post-2020. The Plotkin and NAS studies, which have similar modeling foundations and similar conventional technology findings, were combined to facilitate inclusion of hybrid technologies; hybrid vehicles were not assessed in the original NAS study.

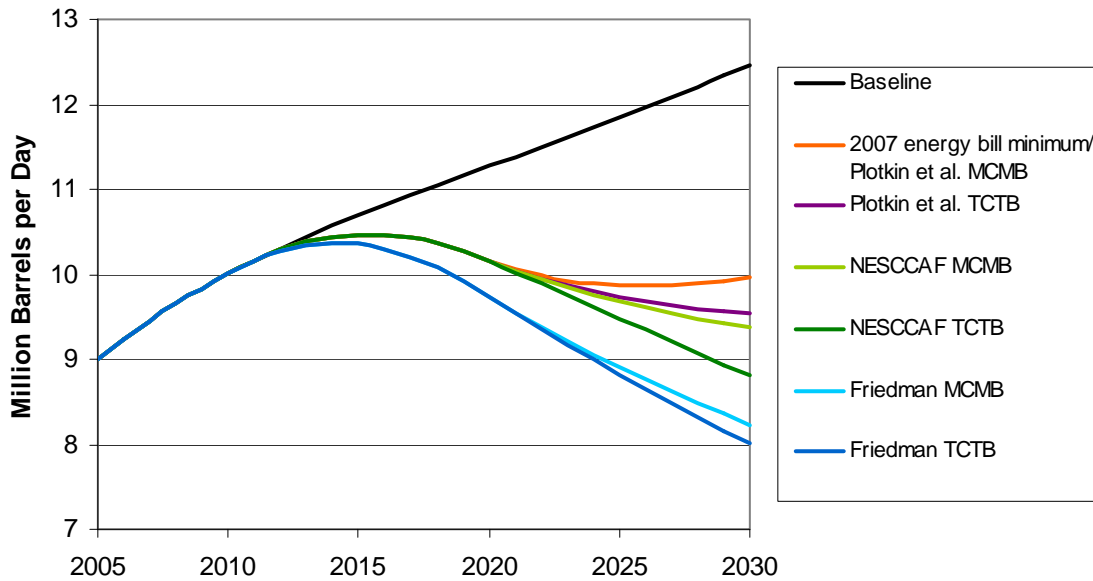
Under even the most conservative estimate (meeting the 2007 energy bill minimum requirement of 35 mpg by 2020), increasing fuel economy standards will lead to significant reductions in oil consumption compared with a baseline scenario that assumes no fuel economy progress other than laws that were on the books as of 2006 (see Figure 15). These reductions are impressive,

¹⁶ In early 2008, Ford Motor Company announced its intention to move from four-year to three-year product cycles (Zoia 2008).

¹⁷ This report assumes changes are made during normal product cycle retooling periods.

though it is worth noting that simply satisfying the 2007 energy bill minimum requirement will only stabilize oil demand for cars and trucks at 2010 projected levels. On the other hand, a more aggressive, yet still cost-effective, deployment of conventional and hybrid technology based on a TCTB analysis would, in 2030, reduce oil consumption about 12 to 20 percent below 2010 levels, or about 30 to 35 percent below projections for a flat fuel economy future.

Figure 15. The Impact of Increased Fuel Economy on Oil Consumption



Note: Baseline represents a scenario in which fuel economy policies in place as of 2006 remain in effect and fuel economy does not change significantly after 2011.

Source: UCS calculation using Long-range Energy Alternatives Planning (LEAP) computer model.

Taken over time, oil savings vary substantially depending on both the assessment study and the type of cost-benefit analysis conducted (see Table 3). The “middle-of-the-road” cost-effective fleet average fuel economy calculated in our report (47 mpg by 2030, using NESCCAF data in a TCTB analysis) will save an estimated 445 billion gallons of fuel through 2030, 78 billion gallons more than is provided by the 35 mpg minimum standard required by the 2007 energy bill. Under the most aggressive deployment and cost assumptions, oil savings could climb to as high as 572 billion gallons, or 205 billion gallons more than is saved by the energy bill.

Table 3. Cumulative Benefits from Increased Fuel Economy Standards

Policy/Study	Analysis Type	Oil Savings (billion gallons gasoline)		Avoided Global Warming Pollution (MMT CO ₂ -equiv)	
		Through 2020	Through 2030	Through 2020	Through 2030
2007 Energy Bill Minimum	n/a	61	367	681	4,071
Plotkin/NAS	TCTB	61	396	681	4,390
NESCCAF	TCTB	61	445	681	4,937
Friedman	TCTB	87	572	964	6,347
Plotkin/NAS	MCMB	61	367	681	4,071
NESCCAF	MCMB	61	407	681	4,513
Friedman	MCMB	87	556	964	6,174

Notes: UCS calculation based on the policy and studies referenced in the table above. Estimated benefits are based on full deployment of conventional technology by 2020 and full deployment of hybrid technology by 2030. (The 2020 assessment includes no hybrids and is thus a very conservative estimate.) Cumulative benefits are compared with a baseline scenario in which fuel economy policies in place as of 2006 remain in effect and fuel economy does not change significantly after 2011. The Plotkin and NAS studies, which have similar modeling foundations and similar conventional technology findings, were combined to facilitate inclusion of hybrid technologies; hybrid vehicles were not assessed in the original NAS study.

As Table 3 also shows, global warming emissions reductions from these policy options vary significantly. Increased fuel economy standards could reduce CO₂-equivalent emissions from nearly 4,100 to more than 6,300 million metric tons relative to a flat fuel economy future, depending on assessment study and cost-benefit analysis type. Relative to the 35 mpg minimum fuel economy specified in the 2007 energy bill, the CO₂ emissions reduction potential using a moderate technology cost curve such as that of the NESCCAF study is nearly cut in half when evaluated under an MCMB analysis rather than a TCTB analysis, again underscoring the importance of assumptions and analysis type when cost-benefit assessments are employed.

Chapter 6. Securing a Strong Fuel Economy Future

Over the past few decades, stagnant fuel economy standards, combined with steady travel growth and a market shift toward less efficient light trucks, have resulted in a vehicle fleet addicted to oil. Grave concerns about climate change, energy security, and the U.S. economy have prompted broad support for a more energy-efficient and environmentally benign transportation sector that will ultimately move the country off of oil and dramatically reduce our nation's contribution to global warming.

No single solution exists to free the United States from oil dependence, but steady and aggressive improvements to passenger car and light truck fuel economy will be a critical first step. Fortunately, numerous studies have shown that deploying existing technologies in vehicles to substantially boost fuel economy is not only possible, but cost-effective. Efficient engines and transmissions, reduced auxiliary loads, and reduced aerodynamic drag or rolling resistance—not to mention advanced technologies such as hybrid-electric systems—all offer ample opportunities to boost vehicle fuel economy, reduce emissions, and provide consumers extra savings at the pump.

The Energy Independence and Security Act of 2007 presents the first significant step in more than three decades to improve the fuel economy of our nation's cars and trucks. To develop the new fuel economy standards, regulatory agencies will be conducting analyses to determine how high these standards can be set while being cost-effective. However, the type of assessment, underlying assumptions, and monetary valuations chosen for those assessments can yield dramatic variation in results. It is therefore critical that regulators accurately identify and quantify these criteria.

As acknowledged by the Ninth Circuit Court of Appeals, one of the key benefits of increasing fuel economy standards is the reduction of heat-trapping gases responsible for global climate change. Cost-benefit assessments that ignore or under-represent the monetary value of carbon emissions reductions are fundamentally flawed. Given this, UCS recommends that NHTSA employ the following changes to its cost-benefits assessment process:

- NHTSA should switch from an MCMB analysis to a TCTB analysis that is less susceptible to inaccurate or partial valuation of benefits.
- Should NHTSA continue to use an MCMB analysis, the agency must include more realistic gasoline prices, as well as include at least conservative values for global warming pollution (\$0.49 per gallon in 2006 dollars) and oil dependence (\$0.35 per gallon in 2006 dollars) when conducting its analysis.

As this report has shown, a 47 mpg fleet average fuel economy standard in 2030 is eminently achievable under moderate cost-benefit analysis assumptions; under more favorable assumptions, advanced fuel-saving vehicle technologies could cost-effectively raise cars and trucks' combined average fuel economy up to 55 mpg by 2030. The 35 mpg fleet average fuel economy standard set for 2020 is an unequivocal *minimum* near-term goal for our nation's cars and trucks. Policy

makers can—and should—go beyond this minimum by pursuing sustained, aggressive fleet average fuel economy targets during the coming years to cost-effectively achieve maximum feasible fuel savings and global warming pollution reductions. Specifically, policy makers should:

- Regard the 35 mpg fleet average fuel economy level as a bona fide *minimum* standard for 2020.
- Include analysis of data from a broad number of studies when considering maximum feasible fleet average fuel economy targets for 2020. Multiple studies assessed in this report indicate an ability to cost-effectively achieve fleet average fuel economies of around 40 mpg *with conventional technology alone*. A combination of conventional and hybrid vehicle technology could achieve even higher fuel economy levels; if hybrids represented a modest 25 percent of the new vehicle market in 2020, fuel economy could cost-effectively reach up to 42 mpg.
- Target a fleet average fuel economy of *at least* 50 mpg in 2030, reflecting an achievable, cost-effective fuel economy level based on conventional and hybrid vehicles.

These recommendations serve as a critical first step in the process of seeking solutions to the environmental, economic, and national security challenges posed by our nation's oil dependence. While fully realizing U.S. transportation goals will require a concerted, long-term effort from policy makers, consumers, and industry alike, the severity of consequences associated with inaction underscores the critical need to initiate this effort today.

References

- An, F., and J. DeCicco. 2007. *Trends in technical efficiency trade-offs for the U.S. light vehicle fleet*. SAE Report 2007-01-1325. Warrendale, PA: Society of Automotive Engineers.
- Bernanke, B.S. 2007. Statement of Ben S. Bernanke, Chairman, Board of Governors of the Federal Reserve System before the U.S. House of Representatives Joint Economic Committee, U.S. Congress. November 8. Online at <http://www.house.gov/jec/hearings/testimony/110/11-08-07%20Bernanke%20JEC%20statement.pdf>.
- Bureau of Economic Analysis (BEA). 2007. Current-dollar and “real” gross domestic product. Washington, DC: U.S. Department of Commerce. Online at <http://www.bea.gov/national/index.htm#gdp>. GDP deflator online at <http://www.bea.gov/nea/dn/nipaweb/TableView.asp#Mid>.
- Bureau of Labor Statistics (BLS). 2007. Consumer price index, all urban consumers (CPI-U). Washington, DC: U.S. Department of Labor. Online at <ftp://ftp.bls.gov/pub/special.requests/cpi/cpiuai.txt>. Accessed November 15, 2007.
- Bureau of Labor Statistics (BLS). 2008. Average monthly gasoline price data: U.S. city average; gasoline, all types. Online at <http://www.bls.gov/cpi>.
- Center for Biological Diversity v. National Highway Traffic Administration (CBD v. NHTSA). No. 06-71891 (9th Cir. 2007).
- Davis, S.C., and S.W. Diegel. 2007. *Transportation energy data book*. Edition 26. ORNL-6978. Oak Ridge, TN: Oak Ridge National Laboratory.
- DeCicco, J., F. An, and M. Ross. 2001. *Technical options for improving the fuel economy of U.S. cars and light trucks by 2010-2015*. Washington, DC: American Council for an Energy-Efficient Economy. July.
- U.S. Department of Energy and U.S. Environmental Protection Agency (DOE/EPA). 2007. 2007 EPA fuel economy datafile. Online at www.fueleconomy.gov/feg/epadata/07data.zip.
- Energy Information Administration (EIA). 2007a. *Emissions of greenhouse gases in the United States 2006*. DOE/EIA-0573(2006). Washington, DC: U.S. Department of Energy. November.
- Energy Information Administration (EIA). 2007b. Retail gasoline historical prices (United States, all grades, all formulations). Online at http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.html.
- Energy Information Administration (EIA). 2007c. *Monthly energy review*. DOE/EIA-0035(2007/10). Washington, DC: U.S. Department of Energy. October.

Energy Information Administration (EIA). 2007d. *Annual energy review 2006*. DOE/EIA-0384(2006). Washington, DC: U.S. Department of Energy. June.

Energy Information Administration (EIA). 2007e. U.S. finished motor gasoline product supplied. Online at <http://tonto.eia.doe.gov/dnav/pet/hist/mgfupus1A.htm>.

Energy Information Administration (EIA). 2007f. Cushing, OK WTI Spot Price FOB (Dollars per Barrel). Online at <http://tonto.eia.doe.gov/dnav/pet/hist/rwtca.htm>.

Energy Information Administration (EIA). 2007g. *Annual energy outlook 2008 overview*. Washington, DC: U.S. Department of Energy. December. Online at <http://www.eia.doe.gov/oiaf/aeo/pdf/overview.pdf>.

Environmental Protection Agency (EPA). 2008. *EPA analysis of the Lieberman-Warner Climate Security Act of 2008, S. 2191 in 110th Congress*. March 14. Online at http://www.epa.gov/climatechange/downloads/s2191_EPA_Analysis.pdf.

Environmental Protection Agency (EPA). 2007a. *Light-duty automotive technology and fuel economy trends: 1975 through 2007*. EPA420-R-07-008. Washington, DC: U.S. Environmental Protection Agency, Office of Transportation and Air Quality. September.

Environmental Protection Agency (EPA). 2007b. 2007 Green Vehicle Guide. Online at http://www.epa.gov/greenvehicles/download/all_alpha_07.xls.

Environmental Protection Agency (EPA). 2006. *Greenhouse gas emissions from the U.S. transportation sector: 1990–2003*. EPA 420-R-06-003. March. Online at <http://www.epa.gov/otaq/climate/420r06003.pdf>.

European Climate Exchange. 2007. Market Data Snapshot: ECX EUA and CER Futures Contracts. Online at http://www.europeanclimateexchange.com/default_flash.asp?page=http%3A//www.europeanclimateexchange.com/content.asp%3Fid%3D4%26sid%3D391%26o%3D1. Accessed March 13, 2008.

Friedman, D. 2003. *A New Road: The technology and potential of hybrid vehicles*. Cambridge, MA: Union of Concerned Scientists. January.

Gordon, D., D.L. Greene, M.H. Ross, and T.P. Wenzel. 2007. *Sipping fuel and saving lives: Increasing fuel economy without sacrificing safety*. Prepared for the International Council on Clean Transportation. June. Online at http://www.theicct.org/documents/ICCT_SippingFuelFull_2007.pdf.

Greene, D.L., and S. Ahmad. 2005. *Costs of U.S. oil dependence: 2005 update*. ORNL/TM-2005/45. Oak Ridge, TN: Oak Ridge National Laboratory. February.

Heiman, M.K., and B.D. Solomon. 2007. Fueling U.S. transportation: The hydrogen economy and its alternatives. *Environment* 49(8). October.

Kliesch, J., and T. Langer. 2006. *Plug-in hybrids: An environmental and economic performance outlook*. Washington, DC: American Council for an Energy-Efficient Economy. September.

Kromer, M.A., and J.B. Heywood. 2007. *Electric powertrains: Opportunities and challenges in the U.S. light-duty vehicle fleet*. LFEE 2007-03 RP. Cambridge, MA: Sloan Automotive Laboratory, Laboratory for Energy and the Environment, Massachusetts Institute of Technology. May.

Leiby, P.N. 2007. *Estimating the energy security benefits of reduced U.S. oil imports*. ORNL/TM-2007/028. Oak Ridge, TN: Oak Ridge National Laboratory. Revised July 23.

Luers, A.L., M.D. Mastrandrea, K. Hayhoe, and P.C. Frumhoff. 2007. *How to avoid dangerous climate change: A target for U.S. emissions reductions*. Cambridge, MA: Union of Concerned Scientists. September.

Marland, G., T.A. Boden, and R.J. Andres. 2007. Global, regional, and national fossil fuel CO₂ emissions. In *Trends: A compendium of data on global change*. Oak Ridge, TN: Carbon Dioxide Information Analysis Center. Online at <http://cdiac.ornl.gov/trends/emis/top2004.tot>.

Motor Trend. 2007. 2007 Toyota Camry specs and pricing. Online at http://www.motortrend.com/womt/112_0701_2007_coty_2007_toyota_camry/specs_pricing.html

National Academy of Sciences (NAS). 2002. *Effectiveness and impact of corporate average fuel economy (CAFE) standards*. Washington, DC: National Academy Press.

National Highway Traffic Safety Administration (NHTSA). 2004. *Automotive fuel economy program annual update: Calendar year 2004*. DOT HS 809 512. Online at http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Vehicle%20Safety/CAFE/2004_Fuel_Economy_Program.pdf.

Northeast States Center for a Clean Air Future (NESCCAF). 2004. *Reducing greenhouse gas emissions from light-duty motor vehicles*. September.

Plotkin, S., D. Greene, and K.G. Duleep. 2002. *Examining the potential for voluntary fuel economy standards in the United States and Canada*. ANL/ESD/02-5. Argonne, IL: Center for Transportation Research, Energy Systems Division, Argonne National Laboratory. October.

Quong, S. 2007. *The UCS Vanguard: A vehicle to reduce global warming emissions using today's technologies and fuels*. Cambridge, MA: Union of Concerned Scientists. March.

Theautochannel.com. 2007. *1968 Pontiac GTO specifications*. Original source cite: Motor Trend. Online at <http://www.theautochannel.com/vehicles/muscle/gto/68GTO.frame>.

Transportation Research Board. 2006. Tires and Passenger Vehicle Fuel Economy. Committee for the National Tire Efficiency Study, Special Report 286. Washington, DC: National Academy of Sciences. Online at <http://onlinepubs.trb.org/onlinepubs/sr/sr286.pdf>.

Union of Concerned Scientists (UCS). 2007a. *Biofuels: An important part of a low-carbon diet*. Cambridge, MA: Union of Concerned Scientists. November.

Union of Concerned Scientists (UCS). 2007b. *A billion dollar a day habit*. Fact sheet. Online at <http://www.ucsusa.org>. November.

United States Code. 1975. Average fuel economy standards. 49 USC § 32902. Washington, DC. Online at <http://uscode.house.gov/search/criteria.shtml>.

Ward's Automotive Group. 2007. U.S. vehicles in operation by year. Online at <http://www.wardsauto.com>.

Weiss, M.A., J.B. Heywood, E.M. Drake, A. Schafer, and F.F. AuYeung. 2000. *On the road in 2020: A life-cycle analysis of new automobile technologies*. MIT EL 00-003. Cambridge, MA: Massachusetts Institute of Technology. October.

White House. 2006. State of the union address by the president. January 31. Online at <http://www.whitehouse.gov/stateoftheunion/2006>.

Zoia, D.E. 2008. Ford to cut cycle times to three years. Online at <http://www.wardsauto.com>. January 24.

Appendix A. Fuel-Efficient Technologies Currently on the Market

Numerous technologies capable of reducing a vehicle's fuel consumption are already on the road. Some of these designs offer comparably modest fuel economy gains on their own; packaged with other fuel-efficient technologies they can offer an even greater increase in fuel economy. Below is a non-comprehensive list of advanced engine, transmission, and electrical system technologies capable of improving vehicle fuel economy, and the model year 2007 vehicles outfitted with the respective technologies.¹⁸

Cylinder Deactivation

- Buick Rainier
- Chevrolet Avalanche, Impala, Monte Carlo, Silverado, Suburban, Tahoe, Trailblazer
- Chrysler 300, Aspen
- Dodge Charger, Durango, Magnum
- GMC Envoy, Sierra, Yukon
- Honda Odyssey, Pilot
- Jeep Commander
- Pontiac Grand Prix

Continuously Variable Transmission (CVT)

- Audi A4, A6
- Dodge Caliber
- Ford Escape Hybrid, Five Hundred, Freestyle
- Honda Civic Hybrid
- Jeep Compass, Patriot
- Lexus RX 400h
- Mercury Mariner Hybrid, Montego
- Mini Cooper Convertible
- Nissan Altima, Altima Hybrid, Maxima, Murano, Sentra, Versa
- Toyota Camry Hybrid, Highlander Hybrid, Prius

Automated Manual Transmission

- Acura MDX, RDX, RL, TL, TSX
- Aston Martin DB9, V8 Vantage
- Audi A3, A4, A4 Avant, A4 Cabriolet, A6, A6 Avant, A8, A8 L, Q7, S4, S4 Avant, S4 Cabriolet, S6, S8
- Bentley Arnage, Azure, Continental
- BMW 328, 335, 525, 530, 550, 650, 750, 760, Alpina B7, M5, M6, X3, X5, Z4

¹⁸ Sources—Quong 2007: cylinder deactivation, stoichiometric direct injection, variable valve lift and timing, electric power steering; EPA 2007b: continuously variable transmission, automated manual transmission, automatic six-speed transmission, automatic seven- or eight-speed transmissions; DOE/EPA 2007: turbocharging.

- Cadillac CTS, SRX, STS, XLR
- Chevrolet Corvette, Malibu, Malibu Maxx
- Honda Fit
- Infiniti FX35, FX45, G35, G35X, M35, M35X, M45
- Lamborghini Gallardo, Murcielago
- Land Rover LR3, Range Rover, Range Rover Sport
- Lexus ES 350, GS 350, GS 430, GS 450h, IS 250, IS 350, LS 460, LS 460 L, RX 350, SC 430
- Mazda 3, 5, 6, 6 Sport Wagon, CX-7, CX-9, MX-5, RX-8
- Mercedes-Benz CLK63 AMG Cabriolet, CLS63 AMG, E63 AMG, E63 AMG Wagon, ML63 AMG, R63 AMG, S65 AMG, SL55 AMG, SL65 AMG, SLK55 AMG, SLR
- Mini Cooper, Cooper S, Cooper S Convertible
- Mitsubishi Eclipse, Eclipse Spyder, Endeavor, Galant, Outlander
- Nissan 350Z
- Pontiac G6, Grand Prix
- Rolls-Royce Phantom
- Saab 9-3 series, 9-5 series
- Saturn Aura
- Subaru B9 Tribeca, Legacy, Legacy Wagon, Outback, Outback Wagon
- Suzuki XL7
- Toyota Avalon, Camry, Solara, Solara Convertible, Tundra
- Volkswagen Eos, GTI, Jetta, New Beetle, Passat, Passat Wagon, Rabbit, Touareg
- Volvo C70, S40, S60, S80, V50, V70, XC70, XC90

Six-Speed Automatic Transmission

- Aston Martin DB9, DB9 Volante, V8 Vantage
- Audi A3, A4, A4 Avant, A4 Cabriolet, A6, A6 Avant, A8, A8 L, Q7, S4, S4 Avant, S4 Cabriolet, S6, S8
- Bentley Arnage, Azure, Continental
- BMW 328, 335, 525, 530, 550, 650, 750, 760, Alpina B7, X3, X5, Z4
- Cadillac Escalade, SRX, STS, XLR
- Chevrolet Corvette
- Chrysler Pacifica, Sebring
- Ferrari 599 GTB, 612 Scaglietti, F430
- Ford Edge, Expedition, Explorer, Explorer Sport Trac, Five Hundred, Fusion
- GMC Acadia, Sierra, Yukon
- Hyundai Veracruz
- Jaguar S-Type, Super V8, VDP, XJ8, XJ8L, XJR, XK, XKR
- Lamborghini Gallardo, Murcielago
- Land Rover LR3, Range Rover, Range Rover Sport
- Lexus ES 350, GS 350, GS 430, GS 450h, IS 250, IS 350, SC 430
- Lincoln MKX, MKZ, Navigator
- Maserati Quattroporte, Quattroporte Sport GT,
- Mazda 6, 6 Sport Wagon, CX-7, CX-9, MX-5, RX-8

- Mercury Milan, Montego, Mountaineer
- Mini Cooper, Cooper S
- Mitsubishi Outlander
- Nissan 350Z, Altima, Frontier, Sentra, Versa, Xterra
- Pontiac G6
- Porsche Cayenne
- Rolls-Royce Phantom
- Saab 9-3 series
- Saturn Aura, Outlook
- Toyota Camry, Tundra
- Volkswagen Eos, GTI, Jetta, New Beetle, Passat, Passat Wagon, Rabbit, Touareg
- Volvo S60, S80, V70, XC90

Seven- or Eight-Speed Automatic Transmission

- BMW M5, M6
- Lexus LS 460, LS 460 L
- Mercedes-Benz C230, C280, C350, CL550, CLK350, CLK550, CLS63 AMG, E320 Bluetec, E350, E550, E63 AMG, E63 AMG Wagon, G500, GL320 CDI 4Matic, GL450 4Matic, ML320 CDI 4Matic, ML350 4Matic, ML500 4Matic, ML63 AMG, R320 CDI 4Matic, R350 4Matic, R500 4Matic, R63 AMG, S550, SL550, SLK280, SLK350, SLK55 AMG

Turbocharging

- Acura RDX
- Audi A3, A4
- Bentley Arnage, Azure, Continental
- BMW 335
- Chrysler PT Cruiser
- Mazda CX-7, 3, 6
- Maybach 57, 57S, 62, 62S
- Mercedes-Benz CL600, E320 Bluetec, GL320 CDI, ML320 CDI, R320 CDI, S600, S65 AMG, SL600, SL65 AMG
- Mini Cooper S
- Pontiac Solstice
- Porsche Cayenne, 911
- Saab 9-3 series, 9-5 series
- Saturn Sky
- Subaru Forester, Impreza, Legacy, Outback
- Volkswagen Eos, GTI, Jetta, Passat, Passat Wagon, Touareg
- Volvo C70, S40, S60, S60 R, V50, V70, V70 R, XC70, XC90

Stoichiometric Direct Injection

- Acura RDX
- Audi A3, A4, A6, A8, RS, S6, S8

- BMW 760Li
- Chevrolet Express, Silverado
- Dodge Ram
- Ford Econoline, F-series
- GMC Savana, Sierra
- Jeep Cherokee
- Lexus GS, DI, IS
- Mazda CX-7, Mazdaspeed
- Mercedes E320
- Pontiac Solstice
- Saturn Ion, Sky
- Volkswagen Eos, GTI, Jetta, Passat, Touareg

Variable Valve Lift and Timing

- Chrysler 300C
- Jeep Grand Cherokee
- Ford (many models)
- Infiniti G35
- GMC Yukon
- Lexus IS
- Honda (most vehicles)
- Toyota (most vehicles)

Electric Power Steering

- Acura NSX
- Fiat (most vehicles)

Appendix B. Studies and Assessment Methodology

The analyses UCS conducted for this report draw heavily upon seven recent research studies about vehicle technology potential and cost. Below is a brief description of each study’s basic assumptions, baseline vehicle characteristics, and computational approaches to help explain variation in their findings. This appendix also includes a description of the methodological process UCS used to adjust the findings of these studies to enable “apples-to-apples” comparisons.

Study title: *On the Road in 2020: A Life-Cycle Analysis of New Automobile Technologies*

Year released: 2000

Authors: M.A. Weiss et al., Massachusetts Institute of Technology

This study, conducted over two years, evaluates the costs and global warming emissions mitigation potential of vehicle technologies for new passenger cars developed and commercialized by 2020. Its applicability to our analysis is limited in that it evaluates only midsize passenger cars, but it does provide a valuable comparison for the midsize car findings drawn from the other studies used in our analysis. As shown in Figure 12 (p. 21), this study’s general findings regarding the potential of conventional vehicle technologies in a midsize car are consistent with the other studies’ findings. While findings about hybrid potential vary to greater degrees between studies, the findings of Weiss et al. again are generally consistent with others. This study uses an earlier baseline vehicle (model year 1996) than other studies, and thus adjustments made by UCS to the findings of this study (see methodology below) are greater than those made to more recent studies.

Study title: *Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015*

Year released: 2001

Authors: J. DeCicco et al., American Council for an Energy-Efficient Economy

This study analyzes the costs and fuel economy improvement potential of a number of vehicle technology packages that could be made available over the subsequent 10 to 15 years. Computer simulations of the following four technological improvement “packages” were examined and compared with baseline model year 2000 vehicles:

1. moderate conventional technology package
2. advanced conventional technology package
3. “mild hybrid” technology package
4. “full hybrid” technology package

Various fuel-saving technologies were modeled as a part of each package, including mass reduction and other load reductions, engine improvements, transmission improvements, and integrated starter-generators. Each package was evaluated for the following vehicle classes:

small car, midsize car, full-size pickup, minivan, standard SUV, and, in certain cases (though not included in the UCS analysis), performance SUV. Because certain fuel-saving technologies are more applicable to one vehicle type over another, each class of vehicles receives a set of technologies most suitable to that vehicle type. For example, the moderate conventional technology package included a 20 percent mass reduction for minivans, pickups, and SUVs; a 10 percent mass reduction for midsize cars; and zero net mass reduction for small cars. This study makes aggressive assumptions about the role of mass reduction, and is among the more optimistic scenarios we evaluate.

Study title: *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*

Year released: 2002

Author: National Academy of Sciences (NAS)

This study, conducted at the request of Congress, addresses the impact of modifying CAFE standards, and examines existing and emerging technologies that could cost-effectively be deployed within a 10- to 15-year timeframe (i.e., fully deployed between 2012 and 2017), without adversely affecting vehicle size, weight, or performance.

The technologies examined, assumptions, and input values utilized in this study were notably more conservative than those in other studies UCS evaluated. For example: hybrid gasoline-electric vehicles were grouped with hydrogen fuel cell vehicles as “emerging technologies” and excluded from the technical assessment; low gasoline prices (\$1.50 per gallon in 1999 dollars) were used in its assumptions; and high-strength lightweight materials were not included as a deployable conventional technology. As a result, the NAS study serves as a conservative assessment capable of providing only a near-term perspective of available technology today.

NAS cost curves calculated by UCS were developed using the endpoint values of each of the three product development “paths” detailed in Table 3-4 of the NAS report.

Study title: *Examining the Potential for Voluntary Fuel Economy Standards in the United States and Canada*

Year released: 2002

Authors: S. Plotkin et al., Argonne National Laboratory

While this study examines a broader range of topics (such as an examination of fuel economy initiatives in Japan and Europe) than is covered in this UCS analysis, it does include information on fuel economy potential and costs for vehicles sold in the United States, which we used to develop associated cost curves. This study analyzes the fuel economy potential of conventional, diesel, and hybrid technologies deployed in both passenger cars and light trucks over respective 2000 baseline vehicles. Assessments in this study are based on the Energy & Environmental Analysis (EEA) modeling work of K.G. Duleep.

Although this study addresses diesels, UCS excluded diesel technology data points when developing cost curves. Compared with the number of representative classes assessed in the

other studies, the limited number of classes assessed by Plotkin et al. (two; passenger cars and light trucks) will presumably curtail our precision in estimating a fleet average cost curve for this study.

Study title: *A New Road: The Technology and Potential of Hybrid Vehicles*

Year released: 2003

Author: D. Friedman, Union of Concerned Scientists

This report examined the fuel economy potential of a range of hybrid technology packages. Also included in the analysis for comparative purposes is an assessment of conventional vehicle technologies. The following technology packages were examined:

Conventional Gasoline Tech.	Moderate Hybrid Tech.	Advanced Hybrid Tech.
Moderate Technology	Mild Hybrid (15% peak power)	Mild Hybrid (15% peak power)
Advanced Technology (with idle-stop)	Full Hybrid (25% peak power)	Full Hybrid (25% peak power)
		Full Hybrid (40% peak power)

Like the DeCicco et al. analysis, the analysis of conventional technologies in *A New Road* is based on the vehicle technology computer modeling work of vehicles specialist Feng An, and as such has similar findings, especially with respect to lower-cost, lower-savings technologies (which were in part incorporating DeCicco et al.'s findings). Analysis for hybrid fuel economy values was based on modeling by Friedman using ADVISOR, a vehicle modeling tool from the National Renewable Energy Laboratory. As several charts in Chapters 3 and 4 show, this study is the most optimistic of the scenarios evaluated. Excluded from analysis of this study are the data points associated with moderate mild and full hybrid technologies that are unlikely to be pursued by automakers, as they offer poorer energy savings at comparable cost to other, more advanced technologies. Similarly, the 40 percent peak power full hybrid technology analyzed by Friedman was excluded from our assessment; we believe other technological developments not covered in the Friedman study, such as plug-in hybrids, will be deployed to achieve fuel economy gains of this or greater magnitude.

Study title: *Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles*

Year released: 2004

Author: Northeast States Center for a Clean Air Future (NESCCAF)

This study examined the heat-trapping emissions reduction potential of conventional and advanced vehicle technologies deployed between 2009 and 2015. NESCCAF employed AVL Powertrain Engineering Inc. to run its CRUISE modeling software to simulate heat-trapping emissions profiles of various technology packages for five vehicle classes: small car, large car, minivan, small truck, and large truck. Cost estimates for the technology packages used in the simulations were acquired from Martec Group, Inc., who worked in concert with AVL to ensure that the cost estimates correlated with the functional specifications of the technologies.

An important note regarding the modeling approach in this study is that NESCCAF used actual certification test data in its assessment of hybrid vehicle technologies. The result of this, as stated in the study, is a conservative assessment of hybrid potential between 2009 and 2015 since it assumes no additional improvements made to hybrid technology after the 2004 model year.

Additionally, the study assesses the potential for reduced emissions of other heat-trapping gases including hydrofluorocarbons (used in air conditioning systems), nitrous oxide, and methane. These are grouped with CO₂ in the study's overall emissions reduction estimates. Time limitations prevented the extraction of non-CO₂ emissions data from the in-use CO₂ emissions estimates, though we expect the discrepancy in projected fuel economy to be relatively small.

Finally, while the NESCCAF study does include assessment of diesel technologies, these were removed from the data set for the purpose of this UCS analysis.

Study title: *Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet*

Year released: 2007

Authors: M.A. Kromer and J.B. Heywood, MIT Sloan Automotive Library

This 2007 study from the MIT Sloan Automotive Laboratory examines the potential of electric powertrain vehicles to reduce oil consumption and global warming pollution in the light-duty fleet over a 30-year period. The study addresses pure electric, hybrid, plug-in hybrid, and fuel cell vehicles, in addition to future gasoline and diesel-powered vehicles.

As the authors note in their study, the hybrid-electric vehicle is viewed favorably over the coming decades “based on its position as an established technology, a projection that shows continued improvement and narrowing cost relative to conventional technologies, and similar GHG reduction benefits to other technologies as long as they rely on traditional fuel pathways.”

Like with the Weiss et al. study, detailed fuel consumption and cost assessments of different technologies are evaluated on a midsize car only (in particular, a 2.5-liter Toyota Camry); a resulting cost curve slope is slightly lower than that of the fleet average curve of Friedman (2003) in Figure 12 (p. 21). That said, Kromer and Heywood's assessment is a projection out to 2030, whereas the other studies project to 2015 or 2020; one would expect there to be cost reductions and further technical improvements over the longer time horizon assessed in this study. As such, one would also expect findings from the studies mentioned above to become, over a longer period of time, more in line with Kromer and Heywood's findings.

The lack of detailed results for multiple vehicle classes prevents use of Kromer and Heywood's data on a broader level in this report. Nonetheless, their assumptions about the technical potential of hybrids are included in Figure 12 of this report to provide a perspective on the longer-term potential of this technology in midsize cars, a popular vehicle class.

Methodology for Fuel Economy Potential and Cost Estimations

Figure 13 (p. 26) specifies fleet average cost curves for five of the aforementioned studies. However, it is important to note that these curves do not represent the raw data from the studies. In order to provide an “apples-to-apples” comparison of the studies’ findings, UCS made numerous adjustments to the results of each study. Below is an explanation of that process.

First, for each study’s set of vehicle class-specific technology packages, we extracted estimates for incremental fuel economy potential and associated incremental retail price equivalent (relative to the conventional vehicle baseline specified in each study). Using the consumer price index (CPI-U), we adjusted the monetary data for inflation and converted them into 2006 dollars.

Second, we acknowledged that a portion of large trucks (i.e., large pickups, large SUVs, and large vans) geared toward greater performance and towing capacity will not utilize technology represented by the “maximum available technology” data point. To account for this, we compute for these classes a maximum available technology data point based on a 50/50 split of full hybrid and mild hybrid technology, using a simple sales-weighted average (based on the sales mapping of each study’s classes; see Table B-1) of mild and full hybrid cost data, and a sales-weighted harmonic average of fuel economy potential.

Third, in the time since each study’s assessment, technologies presumed applicable to fuel economy were largely applied to other amenities such as increased power, thereby affecting the fuel economy potential estimated in the original analyses. To account for this, an adjustment is required that lowers the upper bound of technical feasibility for a given technology, and lowers the cost associated with the “loss” of the technology. Methodologically, this is a four-step process.

- A) For each vehicle class, a second-order polynomial cost curve is fit to the data for fuel economy improvement and associated cost.
- B) Using estimates of the “exclusive” gain in fuel economy associated with maintaining performance and size of cars and trucks (An and DeCicco 2007), we assessed the total fuel economy improvement lost between each study’s baseline vehicle model year and a model year 2006 car or truck (depending on the vehicle class being analyzed). The cost reduction associated with the loss of this technology is then determined using the mathematical function of the cost curve specified for that class (see step A). For example, the small car cost curve of DeCicco et al. (2001) fits¹⁹ the second-order polynomial equation:

$$y = (4.2142x^2 + 21.172x)$$

The fuel economy improvement lost between a model year 2000 and model year 2006 passenger car, as specified in An and DeCicco (2007), is 3.96 mpg. Entering this value

¹⁹ R² = 0.983

into the polynomial, the corresponding reduced cost is \$149.93.²⁰ The original data points are then shifted to account for both the lower fuel economy potential and associated cost, and a new second-order polynomial is determined for each vehicle class.

- C) After the new, class-based cost curves are assessed, we then determine the fleet average fuel economy improvement and associated cost for each study. These values are determined based on a percentage improvement over the class-specific baseline fuel economy specified in each study, incorporating the fact that different vehicle classes offer varying levels of maximum fuel economy potential (i.e., that the maximum potential of hybrid technology in a midsize car differs from the maximum potential of hybrid technology in a midsize SUV). Vehicle classes analyzed in each study are weighted according to 2006 vehicle sales specified by the Environmental Protection Agency (EPA 2007a). All of the five studies evaluate fewer classes than the EPA, so some sales percentages are consolidated. For example, in computing a fleet average for the DeCicco et al. study, we assumed that small car fuel economy and cost data would be weighted by the combined sales fractions of the EPA's Small Car and Small Wagon categories. (See Table B1 for a study-by-study mapping of vehicle classes to sales fractions.)
- D) Fleet average fuel economy estimates are then compared with the sales-weighted baseline fuel economy to determine incremental fuel economy improvements. Using incremental mpg and associated cost data, a second-order polynomial curve is fit, with the upper bound corresponding to the sales-weighted fleet average maximum value. This final curve is shown in Figure 13.

²⁰ In general, the cost reduction of this adjustment is small, as it is presumed automakers are improving power and other vehicle amenities using the least expensive technologies available to them.

Table B-1. Vehicle Class Mappings

DeCicco et al. (2001)

EPA Category	Study Category					
	Fullsize Pickup	Midsize Car	Midsize SUV	Minivan	Small Car	Total
Large Car		10.30%				10.30%
Large Pickup	12.20%					12.20%
Large SUV			9.60%			9.60%
Large Van				0.40%		0.40%
Large Wagon		0.70%				0.70%
Midsize Car		16.10%				16.10%
Midsize Pickup	1.90%					1.90%
Midsize SUV			14.00%			14.00%
Midsize Van				7.30%		7.30%
Midsize Wagon		2.00%				2.00%
Small Car					21.60%	21.60%
Small Pickup	0.00%					0.00%
Small SUV			0.80%			0.80%
Small Van				0.00%		0.00%
Small Wagon					3.20%	3.20%
Total	14.10%	29.10%	24.40%	7.60%	24.80%	100.00%

National Academy of Sciences (2002)

EPA Category	Study Category										
	Compact Car	Large Car	Large Pickup	Large SUV	Midsize Car	Midsize SUV	Minivan	Small Pickup	Small SUV	Sub-compact Car	Total
Large Car		10.30%									10.30%
Large Pickup			12.20%								12.20%
Large SUV				9.60%							9.60%
Large Van							0.40%				0.40%
Large Wagon		0.70%									0.70%
Midsize Car					16.10%						16.10%
Midsize Pickup								1.90%			1.90%
Midsize SUV						14.00%					14.00%
Midsize Van							7.30%				7.30%
Midsize Wagon					2.00%						2.00%
Small Car	13.00%									8.50%	21.60%
Small Pickup								0.00%			0.00%
Small SUV									0.80%		0.80%
Small Van							0.00%				0.00%
Small Wagon	3.20%										3.20%
Total	16.30%	10.90%	12.20%	9.60%	18.20%	14.00%	7.60%	1.90%	0.80%	8.50%	100.00%

Table B-1. Vehicle Class Mappings (continued)

Plotkin et al. (2002)

EPA Category	Study Category		
	Light Truck	Passenger Car	Total
Large Car		10.30%	10.30%
Large Pickup	12.20%		12.20%
Large SUV	9.60%		9.60%
Large Van	0.40%		0.40%
Large Wagon		0.70%	0.70%
Midsize Car		16.10%	16.10%
Midsize Pickup	1.90%		1.90%
Midsize SUV	14.00%		14.00%
Midsize Van	7.30%		7.30%
Midsize Wagon		2.00%	2.00%
Small Car		21.60%	21.60%
Small Pickup	0.00%		0.00%
Small SUV	0.80%		0.80%
Small Van	0.00%		0.00%
Small Wagon		3.20%	3.20%
Total	46.10%	53.90%	100.00%

Friedman (2003)

EPA Category	Study Category					Total
	Fullsize Pickup	Midsize Car	Midsize SUV	Minivan	Small Car	
Large Car		10.30%				10.30%
Large Pickup	12.20%					12.20%
Large SUV			9.60%			9.60%
Large Van				0.40%		0.40%
Large Wagon		0.70%				0.70%
Midsize Car		16.10%				16.10%
Midsize Pickup	1.90%					1.90%
Midsize SUV			14.00%			14.00%
Midsize Van				7.30%		7.30%
Midsize Wagon		2.00%				2.00%
Small Car					21.60%	21.60%
Small Pickup	0.00%					0.00%
Small SUV			0.80%			0.80%
Small Van				0.00%		0.00%
Small Wagon					3.20%	3.20%
Total	14.10%	29.10%	24.40%	7.60%	24.80%	100.00%

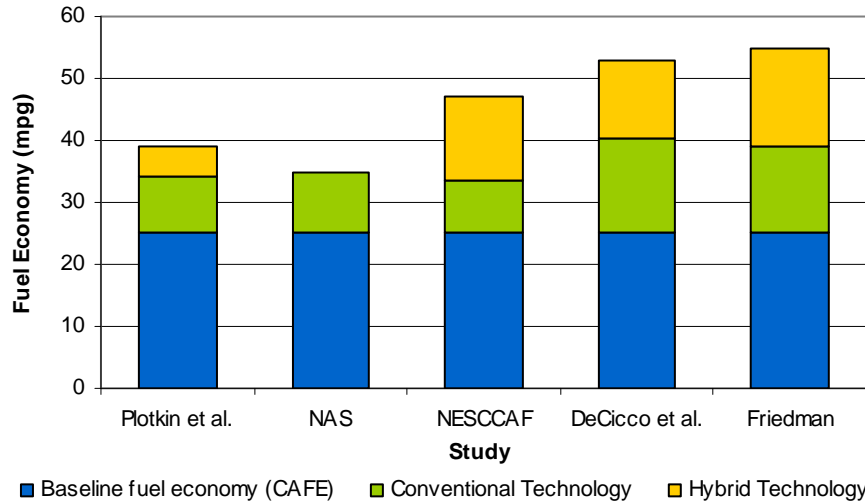
Table B-1. Vehicle Class Mappings (continued)

NESCCAF (2004)

EPA Category	Study Category					Total
	Large Car	Large Truck	Minivan	Small Car	Small Truck	
Large Car	10.30%					10.30%
Large Pickup		12.20%				12.20%
Large SUV		9.60%				9.60%
Large Van		0.40%				0.40%
Large Wagon	0.70%					0.70%
Midsized Car	16.10%					16.10%
Midsized Pickup					1.90%	1.90%
Midsized SUV					14.00%	14.00%
Midsized Van			7.30%			7.30%
Midsized Wagon	2.00%					2.00%
Small Car				21.60%		21.60%
Small Pickup					0.00%	0.00%
Small SUV					0.80%	0.80%
Small Van			0.00%			0.00%
Small Wagon				3.20%		3.20%
Total	29.10%	22.10%	7.30%	24.80%	16.70%	100.00%

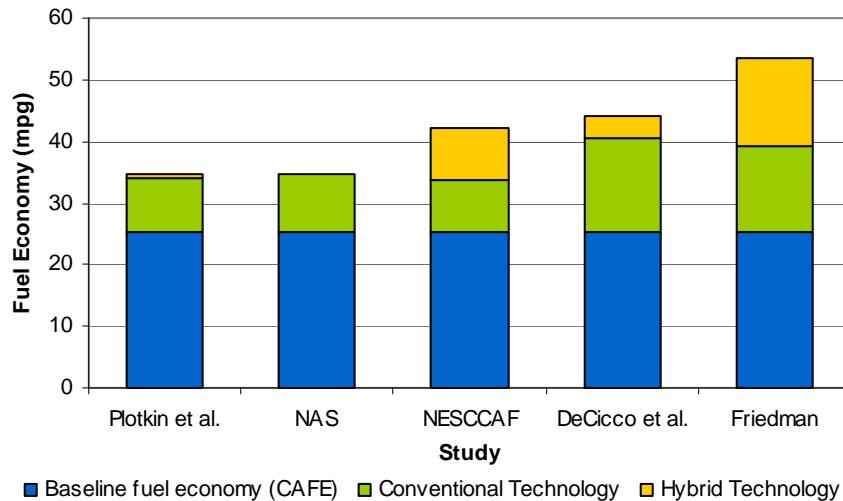
Appendix C. Cost-Benefit Assessment Assuming \$3.00/gallon Gasoline

Figure C-1. Fleet Average Fuel Economy Potential (TCTB Analysis, \$3.00/gal Gasoline) by Study and Technology



Notes: Assumes a baseline "CAFE" fuel economy of 25.3 mpg (20.2 mpg in real-world operating conditions), 15,600 year-one base miles with a diminishing travel each year of 4.5%, discount rate of 7%, rebound effect of 10%, and a retail gasoline price of \$3.00 per gallon (2006 dollars) minus a combined federal and state gasoline tax of 40 cents per gallon. (Gasoline taxes are excluded from the analysis because they are considered a "transfer" from taxpayers to pay for road repairs and to support public transit.) Externalities such as reduced global warming pollution and increased energy security are excluded from this TCTB analysis.

Figure C-2. Fleet Average Fuel Economy Potential (MCMB Analysis, \$3.00/gal. Gasoline, with Externalities) by Study and Technology



Notes: Assumes a baseline "CAFE" fuel economy of 25.3 mpg (20.2 mpg in real-world operating conditions), 15,600 year-one base miles with a diminishing travel each year of 4.5%, discount rate of 7%, rebound effect of 10%, and a retail gasoline price of \$3.00 per gallon (2006 dollars) minus a combined federal and state gasoline tax of 40 cents per gallon. (Gasoline taxes are excluded from the analysis because they are considered a "transfer" from taxpayers to pay for road repairs and to support public transit.) Externalities include 84 cents per gallon for reduced heat-trapping emissions and improved oil security.