DRILLING IN DETROIT

Tapping Automaker Ingenuity to Build Safe and Efficient Automobiles

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The Union of Concerned Scientists is a nonprofit partnership of scientists and citizens combining rigorous scientific analysis, innovative policy development and effective citizen advocacy to achieve practical environmental solutions.

The UCS Clean Vehicles program focuses on changing current transporation policies, which favor single-occupancy driving and fossil fuels. The program develops and promotes innovative strategies to make transportation less polluting and more energy efficient and provides information to policymakers, the media, and the public about transportation's impact on public health, the environment, and the economy.

More information about UCS and the Clean Vehicles program is available on the UCS website at *www.ucsusa.org/vehicles.*

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Executive Summary

The fuel economy of today's cars and light trucks is at its lowest point in 20 years. A combination of federal inaction on fuel economy policy and the increased marketing of sport utility vehicles (SUVs) and minivans as substitutes for passenger cars have led to this point. Our nation now faces a number of significant and growing problems that could be addressed through a reasonable but aggressive approach to fuel economy improvements. These problems include increased consumer fuel costs; a growing dependence on imported oil; rising emissions of greenhouse gases, toxics, and smog-forming pollutants; and a fleet that is less safe than it would have been without the massive infusion of today's light trucks.

This report represents a comprehensive assessment of both the technical and economic potential of achieving a safe and fuel-efficient fleet. The analysis is based on existing technologies, many of which are on the road today. The research combined conservative economic assessments with sound computer models to investigate the impacts of significant fuel economy improvements through the year 2020. The study shows that increasing the fuel economy of the nation's fleet of new cars and light trucks to 40 miles per gallon (mpg) by 2012 and then to 55 mpg by 2020 can yield significant benefits to consumers, the economy, and the environment without sacrificing passenger safety during a collision. These findings indicate that, instead of looking for oil in environmentally sensitive areas, the nation can tap the ingenuity of Detroit's automobile industry to produce a fleet of safe and fuel-efficient vehicles. For these benefits to be realized, the federal government needs to act now to provide meaningful and continuous increases in fuel economy standards.

Conclusions

This assessment of the impact of fuel-efficient technologies indicates the following:

A fleet that relies on continuously evolving conventional technologies could reach an average of more than 40 miles per gallon, nearly a 75 percent increase compared with today's fleet. Many of these gains could be made with technologies that are already in consumers' hands. These improvements would lead to fuel cost savings of $3,000 to more than $5,000 over the lifetime of a vehicle. These savings would more than make up for the cost of the fuel economy improvements. Under such a scenario, the typical family car could reach over 45 mpg, while the cost of filling up an SUV could be cut in half with a fuel economy of 40 mpg.

Relying on hybrid electric vehicle technologies could bring the fleet to at least 55 miles per gallon. Such a fleet would more than double current fuel economy levels and could save consumers between $3,500 and over $6,500 in fuel costs. Hybrid electric vehicle technologies could enable a family car to reach nearly 60 mpg, while an SUV could cross the 50 mpg mark. A simultaneous move to fuel cell vehicles could lead to a tripling of the fuel economy of family cars and could significantly reduce fuel costs for all drivers.

Improvements in fuel economy can be made while maintaining or improving current crash safety expectations. The majority of the improvements in fuel economy can be achieved through use of more-efficient powertrains, which will have no impact on vehicle safety. Additional gains can be achieved through reducing the weight of today's light trucks and altering their design to make them less dangerous to the other vehicles on the road. This strategy can have the dual effect of reducing the fatalities caused by these new vehicles and improving their fuel economy.

Automobile companies can further improve their customers' safety by implementing improved safety technologies that have yet to be incorporated in vehicles, regardless of what path the companies choose to pursue on fuel economy. Automakers have a multitude of options for producing a safe and fuel-efficient fleet of cars and light trucks to satisfy our driving needs. It is important that the industry commits to making the safety of their consumers a key priority in vehicle design.

There is no need to sacrifice air quality or human health to achieve fuel economy improvements. The technologies relied upon in this report can easily meet future emissions regulations and do not have significant tailpipe toxic emissions associated with their use. Alternatives that produce increased levels of toxic, particulate, and nitrogen oxide emissions, such as diesel engines, can be avoided while substantial fuel economy gains are achieved.

If the fleet reaches a fuel economy of 40 mpg by 2012, and then 55 mpg by 2020, our nation could significantly reduce its oil use. Instead of allowing US passenger car and light-truck oil use to grow unchecked, we can turn it back to today's levels by 2015 and then keep it going down. This strategy would save nearly 5 million barrels of oil a day after 18 years (2020) and 1.5 million barrels per day after only eight years (2010).

Significant fuel economy improvements would dwarf supplies obtained from proposed expansion into environmentally sensitive areas such as the Arctic National Wildlife Refuge. In 18 years the United States will have saved more than four times the oil available in the Arctic Refuge at today's oil prices. In that same year, we would save more than 10 times what the Arctic would be producing each day if development were begun there today.

Fuel savings would be accompanied by billions of dollars in savings each year through reduced fuel costs, along with the creation of a significant number of new jobs. By 2010, consumers could be saving $9.8 billion per year. This figure would rise to over $28 billion by 2020. These savings, along with the investments automobile manufacturers would make to improve fuel economy, could be returned to the nation's economy, with a resulting increase of over 40,000 jobs in the automobile industry by 2010, ultimately reaching over 100,000 new automobile industry jobs by 2020.

The environmental impact of our driving habits can be significantly reduced by increasing new-passenger-vehicle fuel economy to 40 mpg by 2012 and to 55 mpg by 2020. By 2010, the greenhouse-gas emissions from cars and light trucks could be reduced by 273 million tons. In the same time frame, producing less gasoline would mean that nearly 150 million pounds of toxic emissions and 320 million pounds of smog-forming pollutants would never reach our lungs. By 2020, vehicle pollution could be reduced by 888 million tons of greenhouse-gas emissions, 481 million pounds of toxic emissions, and 1,039 million pounds of smog-forming pollutants.

Recommendations: Reinvesting in Fuel Economy

In the early 1970s, the United States experienced an energy crisis that drove up gasoline prices and forced consumers to wait in long lines to fill their tanks and empty their pockets. The government responded by investing in fuel economy improvements and creating the Corporate Average Fuel Economy (CAFE) standards that doubled the passenger vehicle fuel economy over a period of 10 years but provided for no increases after 1985.

After 15 years of stagnant fuel economy standards, significant pressure from many stakeholders has prompted the US government to investigate a reinvestment in fuel economy policy. Based on the findings of this study, UCS recommends that the US government and the automobile industry responsible for supplying our passenger vehicles take the following steps:

1. Raise the CAFE standards for light-duty trucks to that of passenger cars in the near term. Closing the "light-truck loophole" is a key first step in improving fuel economy.

2. By 2012, raise the CAFE standards for the combined fleet of cars and light trucks to 40 mpg. Eliminating the separation between cars and light trucks will give automakers the flexibility to meet the standards in the manner that suits them best.

3. By 2020, raise the CAFE standards to 55 mpg. Several years earlier, studies should be commissioned on the potential for increased reliance on hybrid electric vehicles and fuel cell vehicles to achieve even higher fuel economy levels by 2030 and beyond.

4. In all years, through government standards or automaker initiative, place a greater emphasis on bringing improved safety technologies to the new-vehicle market. With today's engineering practices and technologies, there is no reason that consumers should have to sacrifice safety to gain improved fuel economy; the potential even exists to provide simultaneous improvements in both.

5. The US government can lend additional support to ensure that fuel-efficient vehicles come to market by funding research and development of advanced technologies and by creating incentives tied to fuel economy improvements.

CHAPTER 1

INTRODUCTION

Twenty-five years have passed since Congress acted to increase the fuel economy of cars and light trucks—the vehicles that so many of us depend on for our daily activities. This decision came in the wake of America's first major oil crisis, an event that shocked the nation with soaring prices and supply shortages. Memories of lines at gas stations may have faded, but new concerns over the economic and environmental risks of driving have put the fuel economy debate firmly back on the table.

Our nation's past investments in fuel economy have paid off tremendously, both for the economy and the environment. Despite the fact that vehicle travel has nearly doubled over the past quarter-century, the growth in fuel use has been held to 30 percent, thanks to establishment by the US Congress of the Corporate Fuel Economy Standards (Davis 2000). But continued growth in travel and the shift to bigger, heavier vehicles have made it imperative that our nation reinvest in technologies that will improve the efficiency with which we use our natural resources.

Vehicle travel over the coming decades is projected to continue rising at nearly historic rates (EIA 2000a). Unfortunately, fuel economy is not rising to compensate for this trend. The fuel economy of the average new vehicle sold in the United States has actually been declining since 1987 and is now at a two-decade low (Heavenrich and Hellman 2000).

In the absence of aggressive policies to boost vehicle fuel economy, fuel use will grow at unprecedented rates, and oil shocks will no longer remain a distant memory. With aggressive fuel economy standards, however, as well as strong government support and reasonable assistance, we can turn around our passenger vehicle oil use within the next 15 years and insulate the nation from oil concerns like those of the 1970s.

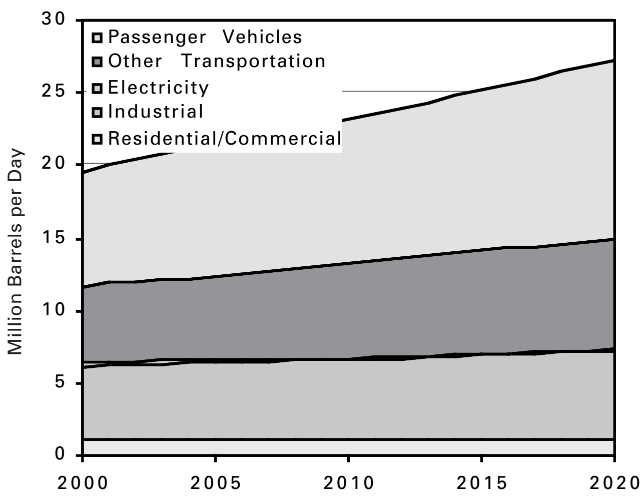
Why Fuel Economy Matters

The fuel economy of the cars and light trucks we drive each day is directly linked to the alarming economic and environmental cost of US passenger vehicle travel. The lower the fuel economy of our passenger vehicle fleet, the more fuel we burn and the greater the economic and environmental consequences. The impact is felt in the prices drivers pay at the pump, the economic and military risks of our nation's reliance on foreign oil, the unhealthy air many of us breathe, and changes to the climate that we depend upon for life.

Economic Impacts

US drivers consumed 121 billion gallons of gasoline in 2000 at a total cost of $186 billion.[1] The costs do not end here, however; the economic impacts of our gasoline use extend into the health of our nation's economy, as passenger vehicles account for 40 percent of the oil products that the nation consumes. This number places these vehicles at the heart of the growing debate over oil supplies (figure 1).

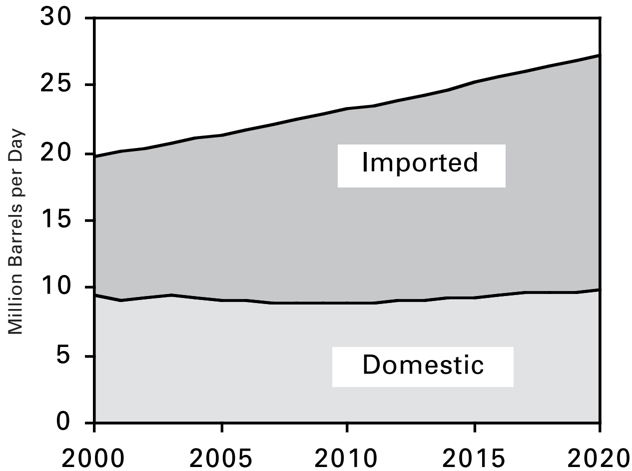
Figure 1. US Oil Product Demand



Notes:
1. The UCS estimate is based on EIA 2000a projections, which were based on an assumption of stagnant fuel economy.
2. Petroleum products include crude oil, natural gas plant liquids, imported refined products, imported unfinished oil, alcohols, ethers, petroleum product stock withdrawals, domestic sources of blending components, and other hydrocarbons.

[1] See table 1 for assumptions.

Figure 2. US Oil Product Supply



Notes:
1. The UCS estimate is based on EIA 2000a projections and an assumption of stagnant fuel economy. The relative shares of imported and domestic oil products are assumed to be the same as the EIA baseline because of increased demand's impact on oil prices, making domestic supplies more economically viable.
2. Petroleum products include crude oil, natural gas plant liquids, imported refined products, imported unfinished oil, alcohols, ethers, petroleum product stock withdrawals, domestic sources of blending components, and other hydrocarbons.

Today, over half of US oil products are imported, and as demand increases this portion will rise (figure 2). The cost of imported oil exacts a toll on our international balance of trade, as the United States currently sends about $200,000 overseas each minute to buy oil products.[2]

In recent years, the Organization of Petroleum Exporting Countries (OPEC) has regained its ability to substantially influence the price of oil throughout the world.[3] OPEC's market power can be expected to grow as its production approaches half of all world oil output in the next two decades (EIA 2000a).

A related issue is the fact that the OPEC members in the politically unstable Middle East continue to be a primary source for US oil, accounting for 25 percent of our imports.[4] Recent estimates suggest that the military expenditures associated with defending those oil supplies are on the order of $20 billion to $40 billion per year (Delucchi and Murphy 1996).

[2] This UCS estimate is based on the EIA 2000a import cost figure of $106 billion in 2000.

[3] OPEC is composed of the following countries: Algeria, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

[4] This is a UCS estimate based on EIA 2000a import values.

Table 1. Annual Passenger Vehicle Fuel Use and Fuel-Related Pollution[a]

Gasoline	
Fuel[b]	121 billion gallons
Fuel Costs[c]	$186 billion
Global Warming Pollution	
Greenhouse Gases[d]	1,450 million tons CO_2-equiv.
Upstream Air Pollution	
Smog-Forming Pollutants[e]	848,000 tons HC+NO_x
Toxics[f]	392,000 tons benzene-equiv.

a. Estimates for 2000. Fuel-related pollution is emissions tied directly to fuel consumption. This excludes tailpipe emissions of air pollutants but includes tailpipe emissions of carbon dioxide.

b. Source: EIA 2000a.

c. Based on $1.54/gallon, the average gasoline price in 2000 (EIA 2000a).

d. UCS estimate based on full fuel cycle model, GREET 1.5a, for federal reformulated gasoline (Wang 1999). All greenhouse gases are expressed as CO_2-equivalent emissions based on their relative radiative forcing. Emissions rate is 10,900 g/gal (24.0 lb/gal).

e. UCS estimate of the sum of upstream hydrocarbon (HC) and nitrogen oxide (NO_x) emissions for federal reformulated gasoline (Wang 1999). Emission rate is 6.4 g/gal.

f. Benzene, formaldehyde, acetaldehyde, butadiene, and diesel particulate emissions associated with federal reformulated gasoline production and distribution (Winebrake et al. 2000; Wang 1999). All toxics are expressed as benzene-equivalent emissions based on their relative cancer unit risk factors (EPA 2000; EPA 1993). Winebrake et al. 2000 do not estimate diesel particulate toxicity. To include these emissions, UCS estimated upstream emissions based on Wang 1999 and assigned the unit risk factor for diesel particulate matter from its recent listing as a toxic air contaminant (CARB 1998). Emission rate is 2.9 g/gal with diesel PM, 0.12 g/gal without.

Environmental Impacts

Transportation is the source of roughly one-third of all the heat-trapping gases (greenhouse gases) linked to global warming that are released in the United States every year (EIA 2000a). Greenhouse-gas emissions from the US transportation sector amount to more than most countries release from all sources combined.[5] The production, transportation, and use of gasoline for cars and light trucks resulted in the emission of 1,450 tons of greenhouse gases by the United States in 2000—over one-fifth of US global warming emissions that year.[6]

[5] Only China, Russia, and Japan have higher total emissions (based on Marland et al. 1996).

[6] This UCS estimate is based on EIA 2000a. Each gallon of gasoline burned emits nearly 19 pounds of carbon dioxide, the primary pollutant responsible

Cars and trucks are also the largest single source of air pollution in most urban areas. Emissions from a vehicle's tailpipe are by far the largest source of pollution from cars today; emissions from fuel production and delivery—so called upstream emissions—are becoming just as significant, however, as tailpipe emissions standards are tightened to protect public health. As environmental regulations require vehicles to emit fewer and fewer pollutants from the tailpipe, these upstream emissions will become one of the dominant sources of toxic emissions and smog-forming pollutants. Unlike tailpipe emissions, upstream pollution can be directly linked to vehicle fuel economy. Reducing gasoline use by half can cut upstream emissions by the same amount, since reduced fuel use means a reduction in all of the activities associated with bringing more fuel to market.

Assuming current fuel use, the production and distribution of gasoline alone result in the emission of 848,000 tons of smog-forming pollution and 392,000 tons of benzene-equivalent toxic emissions in the United States each year.[7] Reducing these numbers significantly through improvements in fuel economy can mean great strides in protecting human health.

for global warming. The production and delivery of gasoline are responsible for another five pounds per gallon of global warming pollutants (Wang 1999).

7 The production, refining, and delivery of each gallon of gasoline in the United States emit an estimated 6.4 grams (0.014 pounds) of smog-forming pollution (Wang 1999). Upstream activities also release harmful toxic pollution into the air that poses a major health hazard near refineries, along distribution routes, and at gasoline stations. For every gallon of gasoline delivered, 2.9 grams (0.0065 pounds) of benzene-equivalent toxic emissions are produced (Winebrake, He, and Wang et al. 2000; Wang 1999).

CHAPTER 2

THE ROAD TRAVELED SO FAR

Many factors account for current levels of US oil use. During the energy crisis of the 1970s, our policies were on the right track. But as the crisis faded, Americans returned to old habits. These habits are catching up to us again, and we would do well to heed the lessons of the past if we are to shape a sustainable and secure energy future.

Auspicious Beginnings

The Energy Policy and Conservation Act of 1975 established fuel economy standards for automakers, the so-called Corporate Average Fuel Economy (CAFE) standards. CAFE proved to be an effective means for doubling the fuel economy of the US passenger-car fleet over a period of 10 years. Under CAFE, the average vehicle sold by each automaker must meet a specified fuel economy level, measured in miles per gallon (mpg).[8] Standards for light-duty trucks—the category that collectively includes pickups, minivans, and SUVs—are different from those for cars, and vehicles produced domestically are averaged separately from those made overseas. Today, the average car must achieve 27.5 mpg, while the average light truck must meet a standard of 20.7 mpg. These values are approximately the same as those set by Congress to be achieved by 1985.

Automakers falling short of the CAFE standard are fined based on how far below the standard they are and how many vehicles they sell.[9] For much of the 1990s, one or more of the Big 3 (Ford, General Motors, and DaimlerChrysler) has fallen short of the CAFE standard for light trucks, although none has yet paid a fine. This situation is possible because automakers are allowed to use

[8] To comply, each major vehicle model is tested by the Environmental Protection Agency over a simulated city- and highway-driving cycle. The resulting CAFE test values are then averaged based on the sales of each model.

[9] Automakers are fined $5.50 per vehicle sold per 0.1 mpg that their fleet falls below the standard.

credits—either past credits generated by beating the standard in any of the previous three years or borrowed credits for up to three future years—in order to comply. While the Big 3 routinely work around the CAFE requirement, smaller manufacturers of luxury or sports cars, such as Rolls Royce and Porsche, routinely pay fines, which totaled some $15 million to $60 million in recent years (Davis 2000).

Benefits of Existing Standards

Although no significant increases in the fuel economy standards have occurred in the past 15 years, CAFE continues to reap benefits for US consumers and the environment. When CAFE standards were enacted in 1975, the average fuel economy of passenger vehicles on the road was 13.1 mpg (Greene 1998). Today, it is approximately 20.6 mpg (EIA 2000a). This higher efficiency has cut US gasoline consumption by one-third, saving consumers money at the pump, reducing harmful smog-forming and toxic pollution associated with gasoline refining and delivery, and reducing emissions of heat-trapping gases that cause global warming (table 2). In fact, in just the last two to five years, the 1975 CAFE law has resulted in more gasoline saved than could be economically recovered from the Arctic National Wildlife Refuge over its 30–50 year lifetime.[10] Overall, CAFE has kept the increase in gasoline use since 1975 to only 30 percent.

Backslide

The original CAFE law established a schedule for increasing fuel economy levels by the mid-1980s but did not prescribe further goals. Future changes in the passenger car standards were to be the responsibility of Congress, while the Department of Transportation was to set future standards for light trucks. With fuel economy doubled by 1985, however, many assumed it was time to rest easy and think about other issues. Today, the standards are virtually unchanged from the levels envisioned 25 years ago (figure 3).

The Impact of a Changing Market

In 1975, most light-duty vehicles were pickup trucks and vans used for commercial or farm applications. There was concern that

[10] This estimate is based on a projected 3.2 billion barrels of economically recoverable oil from ANWR at a market price of $20 per barrel and 6.3 billion barrels at $30 per barrel (USGS 1998).

Table 2. Annual Savings from Fuel Economy Standards[a]

Gasoline	
Fuel[b]	60 billion gallons
Fuel Costs[c]	$92 billion
Global Warming Pollution	
Greenhouse Gases[d]	720 million tons CO_2-equiv.
Upstream Air Pollution	
Smog-Forming Pollutants[e]	420,000 tons HC+NO_x
Toxics[f]	195,000 tons benzene-equiv.

a. Estimated savings in 2000.

b. Assuming on-road fuel economy is 13.1 mpg in the absence of CAFE (Greene 1998) versus 20.6 mpg today (EIA 2000a). Annual vehicle travel in 2000 is 2.41 trillion miles (EIA 2000a). Fuel savings estimate assumes vehicle-miles traveled has a rebound effect of 0.10 due to lower travel costs, so that travel would be lower in the no-CAFE case.

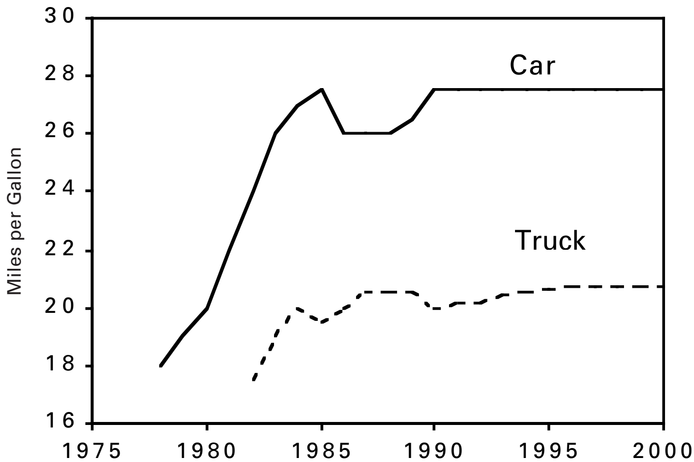
c. Based on $1.54/gallon, the average 2000 gasoline price (EIA 2000a).

d. Based on greenhouse-gas emissions from reformulated gasoline production and distribution plus tailpipe carbon dioxide emissions (Wang 1999). All greenhouse gases are expressed as CO_2-equivalent emissions based on their relative radiative forcing.

e. Hydrocarbon (HC) and nitrogen oxide (NO_x) emissions associated with gasoline production and distribution (Wang 1999).

f. Benzene, formaldehyde, acetaldehyde, butadiene, and diesel particulate emissions associated with gasoline production and distribution (Winebrake et al. 2000; Wang 1999). All toxics are expressed as benzene-equivalent emissions based on their relative cancer unit risk factors (EPA 2000; EPA 1993). The unit risk factor for diesel particulate matter is from its recent listing as a toxic air contaminant (CARB 1998).

Figure 3. Fuel Economy Standards



Source: NHTSA 1999

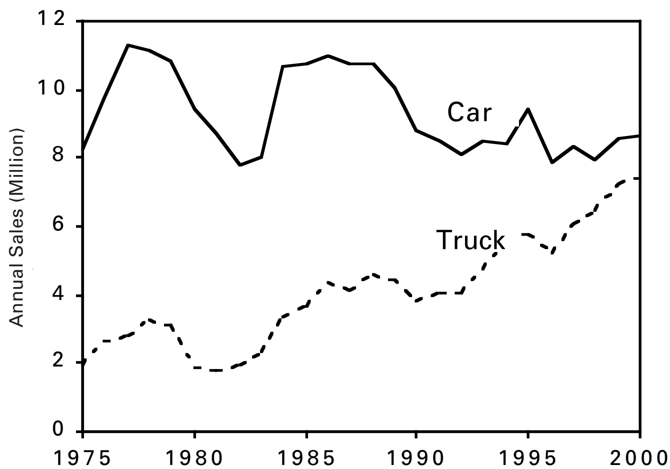
the functionality of these vehicles would be restricted if they were required to meet the same standards as cars. Thus, since its inception, the CAFE law has permitted light trucks to meet a standard that is less stringent than that of automobiles. Ironically, this loophole caused increased fuel costs for these farmers and businesses, costs that could have been avoided if stricter standards had been established. Adding insult to injury, these increased expenses have now filtered into much of the fleet, as light trucks account for nearly one in two vehicles sold. The small exception has become a gaping loophole.

The Shift in the Car Market

Although CAFE standards have not changed for 15 years, the vehicle market—which consisted mainly of cars in 1975—has gone through a dramatic transformation. What used to be considered the "car market" is now more appropriately the car and light-truck market. Nearly all of the growth in vehicle sales over the past 25 years has come in light trucks (figure 4). This trend is exacting a tremendous toll on our environment and our economy, since the result is more and more inefficient, dirty vehicles on the road.

Not only are light trucks held to a fuel economy standard lower than that for cars, but they have also traditionally been permitted to emit more pollution from the tailpipe under federal environmental rules. The result is that today the average light truck on the

Figure 4. Historic Vehicle Sales



Notes:
1. Source: Heavenrich and Hellman 2000.
2. Trucks include vehicles under 8,500 pounds gross vehicle weight (GVW) that are not classified as passenger cars.

road emits 47 percent more smog-forming pollution and 43 percent more global warming pollution than the average car (Mark 1999).

Booming SUV Sales

The largest gains in the vehicle market have been in the SUV segment, where sales increased more than 17-fold during the period from 1975 to 2000. Vans and pickups also saw important growth, while the car market shifted to more midsize vehicles, with reductions in both small- and large-car sales (table 3).

Table 3. Vehicle Sales (Million), 2000 vs. 1975

Year	Small Car	Midsize Car	Large Car	Pickup	Van	SUV	Total
1975	4.56	1.92	1.75	1.34	0.46	0.19	10.20
2000	3.98	3.00	1.65	2.69	1.47	3.22	16.00
Growth Factor	0.87	1.57	0.94	2.00	3.21	17.20	1.57

Source: Heavenrich and Hellman 2000

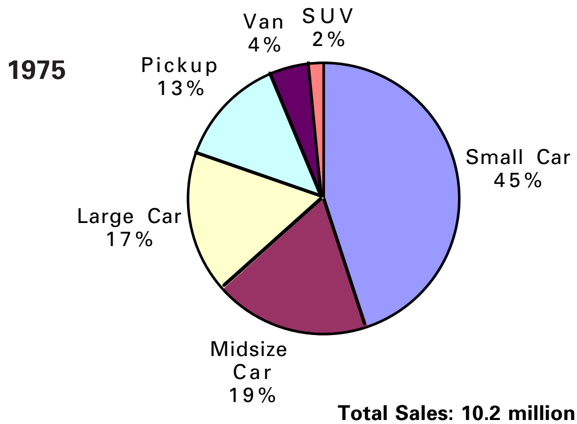
Quite simply, SUVs became the family car of the 1990s. They edged out midsize cars in sales and now account for one of every five vehicles sold each year; light trucks as a whole account for nearly one of every two vehicles sold (figure 5). As such, they have rightfully become the symbol of the changing vehicle market. And yet these vehicles are typically the least-efficient, dirtiest models on the road (Mark 1999).

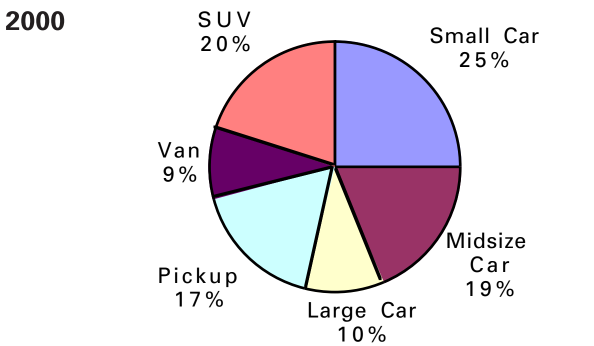
Fuel Economy Fallout

With standards stagnant for over a decade, the fuel economies of the average car and the average truck have stayed relatively fixed. But the rising sales of inefficient light trucks have actually caused the fuel economy of the average new passenger vehicle to drop from its high of 25.9 in 1987 to its current 24 mpg, sliding back to the same fuel economy of passenger vehicles 10 years ago (figure 6).

In the absence of higher standards or large increases in the price of motor fuel, it is difficult to imagine that the future outlook for vehicle fuel economy will be substantially different from what it is today. Current baseline projections of fuel prices over the coming decades forecast gasoline costs that are lower than

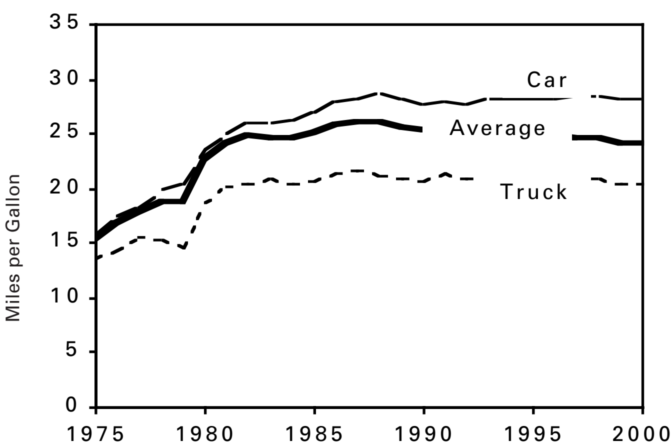
Figure 5. Vehicle Sales Mix: 1975 vs. 2000





Source: Heavenrich and Hellman 2000

Figure 6. New-Vehicle Fuel Economy



Source: Heavenrich and Hellman 2000

today's levels (EIA 2000a). Thus, the fuel economy of America's new vehicles appears likely to hover around today's 24 mpg unless there is a major change in vehicle policy.[11]

Key Energy Trends

With CAFE policy stalled and the market for inefficient SUVs and other light trucks growing, it is no wonder that transportation energy use is on the rise. Light-truck sales increases are showing some potential for slowing, but even if they stop at 50 percent of the market, the gasoline and oil situation is expected to worsen if current trends continue. Over the next 20 years, US gasoline use could increase by more than 50 percent, nearly double the growth seen in the last 25 years.

Vehicle Use on the Rise

The past three decades have seen tremendous growth in vehicle ownership and travel. There are now three vehicles for every four people in the United States and 10 percent more cars and light trucks than people licensed to drive (Davis 2000). In the past decade, the vehicle-to-person ratio has begun to level off, suggesting that the market is becoming saturated. The total vehicle population is still expected to rise, however, because of our nation's growing population.

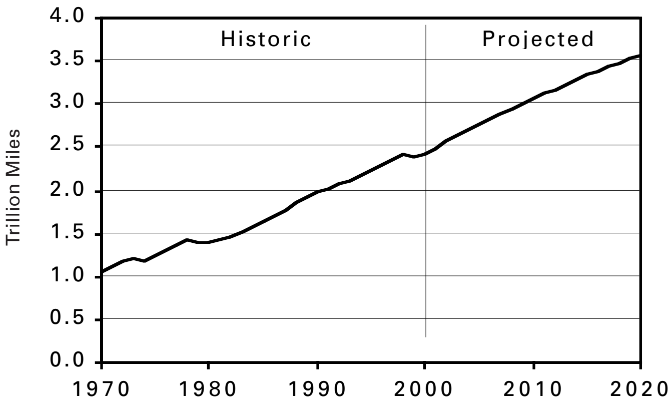
Far more significant has been the rise in vehicle travel over the past decades. Since 1970, the total number of miles traveled by cars and trucks has more than doubled, driven by population increases, rising vehicle ownership, and increasing travel demand. Projections for the future indicate that vehicle miles will continue to grow at near historic rates, so that travel will rise by an additional 50 percent by 2020 (figure 7).

Fuel Use on the Rise

Rising vehicle travel has driven up fuel use from US passenger vehicles over the past 25 years. Today, American drivers buy over 120 billion gallons of gasoline annually, compared with about 93 billion gallons in 1975 (figure 8). The rise in fuel use would have been far higher, however, without the 50 percent increase in

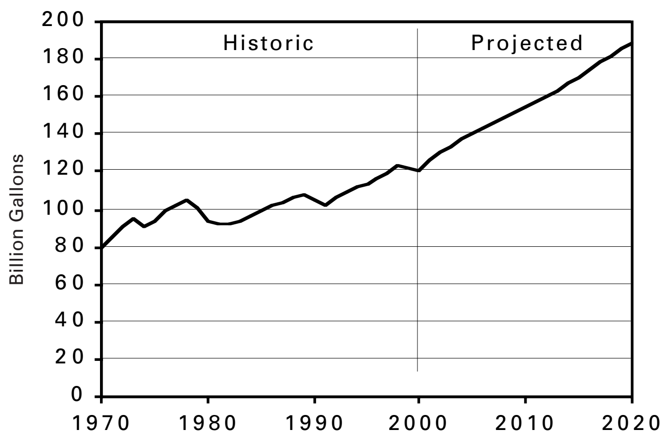
[11] UCS estimates that recent announcements by Ford, GM, and DaimlerChrysler would lead to only a 3 to 4 percent increase in new-car and light-truck combined average fuel economy, based on 1999 sales volumes and fuel economy levels from Ward's 2000. The result, at most, would be an increase in new-vehicle fleet fuel economy to 25 mpg.

Figure 7. Vehicle Travel



Note: Includes autos plus two-axle, four-tire trucks through 1998 (ORNL 2000), AEO01 projections for vehicles under 8,500 pounds gross vehicle weight (GVW) thereafter (EIA 2000a).

Figure 8. Vehicle Fuel Use



Notes:
1. Autos plus two-axle, four-tire trucks through 1998 (Davis 2000).
2. Projected values are based on UCS model calibrated to AEO01 baseline projections for vehicles under 8,500 pounds gross vehicle weight (GVW) (EIA 2000a). UCS estimates assume no future increase in new-vehicle fuel economy in the absence of major gasoline price increases or policy intervention.

vehicle fuel economy that has occurred since the implementation of the CAFE standards. The fact that fuel use has been held to a 30 percent increase since 1975—despite a near doubling of vehicle travel—is a testament to the benefits of CAFE.

With continued stagnant new-vehicle fuel economy but sustained travel increases, fuel use over the coming decades is estimated to grow 56 percent, to 189 billion gallons per year, by 2020. The rate of this increase would be unprecedented in recent history: during the period of 1975 to 2000, fuel use rose at an annual average rate of 1.0 percent, whereas future fuel use could rise at a rate of 2.2 percent per year through 2020.

Key Economic and Environmental Trends

Rising gasoline consumption will exacerbate the economic and environmental impacts of driving. If fuel economy standards are not strengthened, the national motor fuel bill will continue to increase, reaching $260 billion per year by 2020.

US oil consumption will also continue to rise as our vehicles burn ever more gasoline. Passenger vehicles will be responsible for 45 percent of our consumption of oil and other petroleum products by 2020. At current projections of domestic production rates, nearly all of this increased demand will be met through imports, and our reliance on foreign oil will grow to nearly two-thirds of our consumption by 2020.

Emissions of all major pollutants associated with fuel use will also rise, including the greenhouse-gas emissions that cause global warming, smog-forming pollution, and emissions of toxic substances (table 4).

Table 4. Energy, Economic, and Environmental Indicators of US Passenger Vehicle Travel[a]

	2000	2020
Gasoline		
Fuel Use (billion gallons)	121	189
Fuel Costs (billion dollars)[b]	186	260
Oil and Other Petroleum Products[c]		
Total Demand (billion barrels per year)	7.2	9.9
Total Imports (% of demand)	52%	64%
Passenger Vehicle Share of Use (%)	40%	45%
Global Warming Pollution[d]		
Greenhouse Gases (million tons CO_2-eq.)	1,450	2,260
Upstream Air Pollution[e]		
Smog-Forming Pollution (tons HC+NO_x)	848,000	1,320,000
Toxics (tons benzene-eq.)[f]	392,000	612,000

a. UCS estimates based on internal model calibrated to the Annual Energy Outlook (EIA 2000a), with adjustments per discussion in the text.

b. Constant 2000 dollars.

c. Includes all petroleum products, including crude oil, natural gas plant liquids, imported refined products, imported unfinished oil, alcohols, ethers, petroleum product stock withdrawals, domestic sources of blending components, and other hydrocarbons.

d. All greenhouse gases are expressed as CO_2-equivalent emissions based on their relative radiative forcing.

e. Emissions associated with gasoline production and delivery.

f. Benzene, formaldehyde, acetaldehyde, butadiene, and diesel particulate emissions expressed as benzene-equivalent emissions based on their relative cancer unit risk factors.

CHAPTER 3

TECHNOLOGIES FOR FUEL ECONOMY IMPROVEMENT

While the current and future state of affairs for fuel economy and fuel use look grim, our nation need not be locked into following this path. Cost-effective technologies for near-term and longer-term improvements in vehicle efficiency exist today. If these technologies are used to increase fuel economy over the next 20 years, our passenger vehicle oil use could be turned around, the amount of money consumers spend on gasoline could be substantially reduced, and the impact our driving has on the environment could be cut in half.

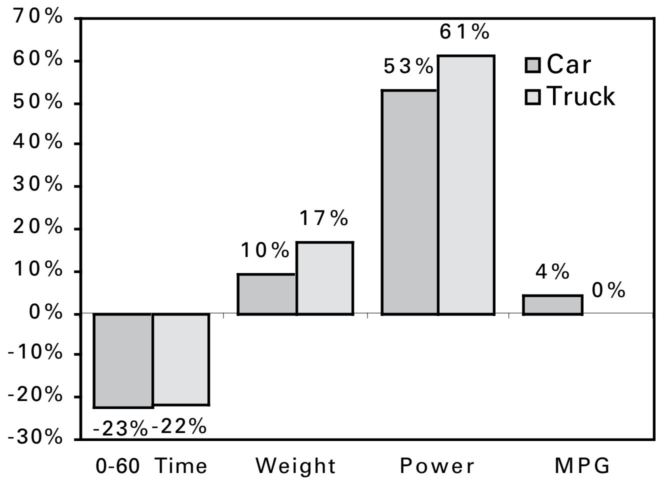
Technology Trends

Achieving the required doubling of passenger car fuel economy between 1975 and 1985 was a testament to the ingenuity of automakers selling vehicles in the United States at the time. The impressive developments from the auto industry did not stop when fuel economy standards were effectively frozen around 1985. Instead, vehicle technology has continued to evolve, providing engines with improved fuel efficiency. In the absence of higher fuel economy requirements, however, increased weight, performance, and power have canceled out these ongoing technical improvements.

These effects can be seen in the performance and mass of today's vehicles. In the 15 years that the CAFE standards have been constant, the average light truck has become 22 percent faster and 17 percent heavier, with an engine that is 61 percent more powerful. All the while, light trucks have maintained the same fuel economy they achieved in 1985. Car technology has followed a similar trend, as indicated in figure 9. Many of the technologies used to achieve these performance improvements, such as four valves per cylinder and four-speed automatic transmissions, could have been used to improve vehicle fuel economy, yet this potential was turned only toward increasing the power of the engines and the performance of the vehicles.[12]

If we are to move toward improving the fuel economy of our cars and light trucks, automakers will have to reinvest their technological advances in this direction without sacrificing current performance expectations. The good news is that a wide variety of technologies can still be used very successfully to achieve higher fuel economy.

Figure 9. Average Vehicle Attributes, 2000 vs. 1985



Notes:
1. Source: Heavenrich and Hellman 2000.
2. "0–60 Time" corresponds to the time (measured in seconds) that it takes to accelerate from a stop to 60 miles per hour.
3. "Power" is measured as engine horsepower.

Evolutionary Technology Options

Evolutionary technologies are those that are either on the road today in smaller volumes or that can be reasonably expected to enter the market within the next decade. These technology options, summarized in table 5, are based on evolutions of the current automobile design that uses an internal combustion engine as the sole method of moving a vehicle down the road.

Each of these technology options has a key role to play in meeting higher fuel economy goals. Vehicle load reductions use

[12] A 1992 report by the National Academy of Sciences' National Research Council (NRC 1992) showed the potential for these technologies, applied separately, to achieve fuel economy improvements of 5 percent each. But these improvements have been taken out of play for increases in fuel economy and have instead been used for increased power and performance.

streamlining and advanced tires to reduce aerodynamic drag and rolling resistance. In addition, mass and accessory load reductions reduce the power requirements from the engine, which translates into lower fuel use. Efficient engine technologies capitalize on the load reductions by using less fuel under all operating conditions through more-efficient fuel delivery and more precise control. Each of the efficient engine technologies used in this report has shown the ability to meet both current and future, more stringent, air quality standards. Integrated starter-generators allow for the elimination of idling and the use of more-efficient electric accessories to replace traditional belt-driven pumps and compressors. Finally, advanced transmission technologies use additional gearing and advanced control systems to ensure that as much of the engine power reaches the wheels as possible. Further details on each of these technologies appear in appendix B.

Table 5. Evolutionary Technology Options for Fuel Economy Improvement

Vehicle Load Reduction • Aerodynamic Improvements • Rolling Resistance Improvements • Mass Reduction • Accessory Load Reduction	**Improved Transmissions** • Five- and Six-Speed Automatic Transmissions • Five-Speed Motorized Gear Shift Transmissions • Optimized Shift Schedules • Continuously Variable Transmissions
Efficient Engines • Variable Valve Control Engines • Stoichiometric Burn Gasoline Direct-Injection Engines	**Integrated Starter-Generators**

Advanced Technology Options

Advanced technologies are those that are expected to be cost effective within the next 10 to 15 years. They represent significant steps in automotive development, rather than the smaller evolutions of the near-term technologies. All of these technologies are either entering the market in small volumes today or are well into the prototype cycle. These technologies may also incorporate many of the advancements from the evolutionary technology options. The two most promising advanced options are hybrid electric and fuel cell vehicles.

Hybrid electric vehicles (HEVs) combine the electric motor and energy-storage system of an electric vehicle with the engine of a conventional internal combustion engine vehicle. Toyota and Honda have already successfully introduced hybrid electric vehicles into the American car market, and every major automaker is expected to introduce a hybrid electric vehicle within the next few years, including SUVs and pickups. More details on hybrid electric vehicles are included in Appendix B.

Of the various automotive technologies currently under development, the fuel cell vehicle has the greatest promise for increasing fuel economy, reducing harmful emissions, and minimizing or eliminating the oil we use for passenger transportation. The fuel cells under consideration for automotive applications combine hydrogen and oxygen to produce electricity, which then runs an electric motor, completely replacing the internal combustion engine. Current expectations are that a family-sized fuel cell vehicle could have a fuel economy of 80 mpg—triple that of a conventional vehicle. All of the world's major automakers are investing billions of dollars in a race to be the first to introduce a commercially viable fuel cell vehicle during this decade. More details on these vehicles and their characteristics are included in appendix B.

The Trouble with Diesel

One technology not incorporated into this report is the diesel engine. This engine technology is similar to that of direct-injection gasoline engines, but typically has somewhat higher efficiencies. This higher efficiency comes with a trade-off: diesel engines pose a considerable risk to human health through the release of toxics, particulate emissions, and significant quantities of smog-forming pollutants.

Diesel exhaust contains 41 chemicals that the State of California has identified as toxic air contaminants. The health impacts of air toxics vary from pollutant to pollutant, but they are all very serious, including cancer risk, immune system disorders, and reproductive problems. The State of California estimates that diesel exhaust from all sources causes 70 percent of all airborne cancer risk. In addition to the toxic emissions, the particulate matter, or soot, emitted by diesel engines is small enough to evade the body's natural defenses and lodge deep in the lungs. Numerous health studies have linked diesel soot to asthma hospitalizations, chronic bronchitis, pneumonia, heart disease, and even premature death.

Finally, because they operate using excess air (lean operation), diesel engines produce significant nitrogen oxide emissions, adding to smog formation that leads to respiratory problems including coughing, choking and reduced lung capacity—and creating significant problems for sensitive members of the population, including children, asthmatics, and the elderly.

Some technologies are under development to reduce nitrogen oxide emissions, and others are showing some potential to control particulate emissions from diesel engines. Even with these technologies, however, the available data do not indicate that diesel engines can match the lower emissions performance of today's cleanest gasoline cars. Furthermore, these new clean-up technologies are still in early development stages for car and light-duty truck applications and have not been tested in real-world driving conditions over a vehicle's lifetime. Finally, no regulations exist today to address diesel's more significant public health questions, including toxic releases and emissions of very small particles. As a result, there will be few guarantees that diesel cars meeting lower tailpipe standards will solve diesel's public health problems.

Given the human health concerns associated with diesel exhaust, the lack of broadly effective emissions-control technologies, and the availability of other technologies that can achieve significant fuel economy gains while reducing air emissions, pursuing diesel technology does not seem a prudent course for fuel economy improvements. If such a path were pursued, waivers in emissions rules would likely be required to accommodate diesel cars—and some automakers have already asked for such waivers. This type of trade-off between fuel economy and air quality is both unwise and unnecessary.

CHAPTER 4

CREATING CONSUMER CHOICE

New cars and trucks come in a wide variety of shapes, sizes, and colors. Some have sunroofs; some have moon roofs; most probably have at least two cup holders. But one would be hard-pressed to find a new car whose fuel economy is much over 30 mpg. It would be even more difficult to find a truck, SUV, or van that reaches over the mid-20s in fuel economy.

These low fuel economy levels are costing Americans nearly $190 billion each year.[13] The average new car in 2000 was rated at 28.1 mpg. Over its lifetime, this vehicle can be expected to use nearly 7,000 gallons of gasoline, which will cost nearly $8,000.[14] The average year-2000 light truck was rated at 20.5 mpg and can be expected to use over 10,000 gallons of gasoline over its lifetime, at a cost of about $10,700 if one had to pay for it all ahead of time. Considering that the average cost of a new car in 1999 was about $21,000 (Ward's 2000), these fuel costs represent the equivalent of purchasing one new car for every two cars sold. In addition to the financial costs, these vehicles have significant impacts on public health and on our environment through the production of tons of greenhouse gases and over a hundred pounds of smog-forming and toxic emissions per vehicle over its lifetime (table 6).

These large expenditures and significant environmental impacts do not have to be the status quo. Given the slate of technologies that could be used for fuel economy improvements, automobile manufacturers could be offering a much wider variety of choices in fuel-efficient cars and light trucks. If the auto industry can be encouraged to move in that direction, what might a new car look like?

[13] This estimate assumes the average gasoline price in 2000 to be $1.54 per gallon (EIA 2000a).

[14] The gasoline cost represents the discounted net present value of the lifetime fuel costs. The price of gasoline over this time is around $1.40 in constant 2000 dollars per EIA 2000a. A 5 percent discount rate was used to calculate net present values.

Table 6. Lifetime Consumer and Environmental Impacts of the Average New Car and New Light Truck Sold in 2000[a]

Average Car	28.1 mpg CAFE rating 22.5 mpg real world
Gasoline	
Fuel	6,899 gallons
Fuel Costs[b]	$7,822
Global Warming Pollution	
Greenhouse Gases[c]	91 tons CO_2-equiv.
Upstream Air Pollution	
Smog-Forming Pollutants[d]	106 pounds $HC+NO_x$
Toxics[e]	49 pounds benzene-equiv.
Average Light Truck	20.5 mpg CAFE rating 16.4 mpg real world
Gasoline	
Fuel	10,366 gallons
Fuel Costs[b]	$10,722
Global Warming Pollution	
Greenhouse Gases[c]	124 tons CO_2-equiv.
Upstream Air Pollution	
Smog-Forming Pollutants[d]	145 pounds $HC+NO_x$
Toxics[e]	67 pounds benzene-equiv.

a. Estimates for 2000. Fuel-related pollution is emissions tied directly to fuel consumption. This excludes tailpipe emissions of air pollutants but includes tailpipe emissions of carbon dioxide.

b. Based on $1.54/gallon, the average gasoline price in 2000 (EIA 2000a).

c. UCS estimate based on full fuel cycle model, GREET 1.5a, for federal reformulated gasoline (Wang 1999). All greenhouse gases are expressed as CO_2-equivalent emissions based on their relative radiative forcing. Emissions rate is 10,900 g/gal (24.0 lb/gal).

d. UCS estimate of the sum of upstream hydrocarbon (HC) and nitrogen oxide (NO_x) emissions for federal reformulated gasoline (Wang 1999). Emission rate is 6.4 g/gal.

e. Benzene, formaldehyde, acetaldehyde, butadiene, and diesel particulate emissions associated with federal reformulated gasoline production and distribution (Winebrake et al. 2000; Wang 1999). All toxics are expressed as benzene-equivalent emissions based on their relative cancer unit risk factors (EPA 2000; EPA 1993). Winebrake et al. 2000 do not estimate diesel particulate toxicity. To include these emissions, we estimate upstream emissions based on Wang 1999 and assign the unit risk factor for diesel particulate matter from its recent listing as a toxic air contaminant (CARB 1998). Emission rate is 2.9 g/gal with diesel PM, 0.12 g/gal without.

REAL-WORLD FUEL ECONOMY

The fuel economy reported for CAFE certification is measured in a laboratory on two predetermined driving schedules, the city cycle and the highway cycle. A harmonic average is then calculated assuming city driving accounts for 55 percent of all miles traveled (DOE/EPA 2001). These test values are consistently higher than those found in real-world experiences, both because increasing amounts of driving take place in congested cities and because very slow speeds and accelerations are required over the test cycles. The result is that consumers end up paying more at the pump and use more oil than would be expected from the CAFE calculations. Data on fuel use and vehicle-miles traveled suggest that the on-road fuel economy is around 17 percent lower than the CAFE-rated value today and may climb to 20 percent lower in the future (EIA 2000a). Currently the Environmental Protection Agency adjusts highway fuel economy by 22 percent and city fuel economy by 10 percent; these are the values seen on new-car window stickers.

The Next Family Car

The three best-selling cars in the United States are the Toyota Camry, the Honda Accord, and the Ford Taurus. These cars and others like them have become the standard in the "family car" market. They seat five people comfortably, have spacious trunks, and usually come with a wide variety of accessory features to make them both comfortable and enjoyable to drive. The fuel economy of these classic "family cars" is around 26 mpg, depending on the model—around two miles per gallon lower than the average car.

The cost of a new Taurus SE was $19,535 in 2000 (Ward's 2000), and its expected fuel use is 8,111 gallons over a 15-year lifetime. Combining the net present value of the fuel cost of $8,389 with the sticker price gives the vehicle an equivalent cost to the consumer of nearly $28,000.[15]

A 45-MPG Family Car

In the most recent report analyzing fuel economy potential, DeCicco et al. packaged together several evolutionary conventional technologies to produce an advanced family car with a fuel economy rating of 45.8 mpg. This car uses an advanced engine and transmission and incorporates several load-reduction measures. The researchers evaluated the added cost for these technology additions to be $1,292 (DeCicco et al. 2001).

[15] Fuel costs are discounted at an annual rate of 5 percent and are based on an average gasoline price of about $1.40 in constant 2000 dollars per EIA 2000a. The total cost does not include maintenance, insurance, and finance costs. It also does not include the cost the vehicle places on society through its greenhouse-gas, toxic, and smog-forming emissions.

Table 7. The Evolutionary Family Car

Engine System		**Lifetime Costs**	
GDI, VVC, 4-valves per cylinder engine with integrated starter-generator		Vehicle price	\$20,827
		Lifetime fuel costs	\$4,799
		Total cost	\$25,626
		Net Savings	**\$2,298**
Transmission			
Continuously variable		**Lifetime Impact**	
		Gasoline saved	3,741 gal.
Vehicle		GHG saved	41.6 tons
C_D reduced by 10%		Toxic emissions avoided	22.5 lb.
C_{rr} reduced by 20%		Reduction in smog-forming pollutants	48.7 lb.
2,660 lbs.			
Performance		Assumes a 15-year, 170,000-mile life (Davis 2000, 1995 NPTS). Average gasoline retail price used is \$1.40 between 2002 and 2017 (EIA 2000a). Emission rates are those used in table 1.	
0–60 in 10 seconds			
Fuel Economy			
CAFE test	45.8 mpg		
Real world	36.6 mpg		
Improvement	75%		

During the lifetime of this vehicle, over 3,700 gallons of gasoline would be saved; the net present value of the resulting fuel cost savings is equivalent to a rebate of \$3,590 when the car is first purchased. These savings more than offset the added cost of the fuel economy improvements.

A High-Fuel-Economy Hybrid Electric Family Car

A leap forward in fuel economy for the family car can be achieved by going to a hybrid electric drivetrain. DeCicco et al. combined the technologies in their advanced conventional Taurus with an electric motor and small battery pack. The design of this hybrid is similar to that of the Toyota Prius, with about 40 percent of the vehicle peak power supplied by the electric motor. The remaining 60 percent is supplied by a stoichiometric gasoline direct-injection, variable-valve-control engine. This family car should achieve a fuel economy rating of 59.3 mpg, with an estimated added cost of \$5,098 (DeCicco et al. 2001).[16]

[16] This cost is expected to apply within the next 10 years. As vehicle volumes increase, the cost of hybrid electric components is expected to decrease. By the 2015 to 2020 timeframe, the same vehicle is expected to achieve 60.6 mpg at an approximate incremental cost of \$4,633.

Table 8. Hybrid Family Car

Engine System		**Lifetime Costs**	
Advanced GDI engine, permanent magnet motor, and nickel metal hydride battery pack		Vehicle price	$24,633
		Tax credit	–$3,500
		Lifetime fuel costs	$3,707
		Total cost	$24,840
Transmission		**Net savings**	**$3,085**
Integrated gearset			
		Lifetime Impact	
Vehicle		Gasoline saved	4,572 gal.
C_D reduced by 10%		GHG saved	54.2 tons
C_{rr} reduced by 20%		Toxic emissions avoided	29.4 lb.
2,782 lbs.		Reduction in smog-forming pollutants	63.5 lb.
Performance		Assumes a 15-year, 170,000-mile life (Davis 2000, 1995 NPTS). Average gasoline retail price over the life is $1.40 (EIA 2000a). Emission rates are those used in table 1. Tax credit is currently proposed in the US Senate and House of Representatives.	
0–60 in 10 seconds			
Fuel Economy			
CAFE test	59.3 mpg		
Real world	47.4 mpg		
Improvement	125%		

Compared with the baseline Taurus, this hybrid family car saves 4,572 gallons of gasoline—a 55 percent reduction in fuel use. This is equivalent to $4,683 rebate at time of purchase. These savings nearly offset the added cost of the fuel economy improvements.

Recognizing the value of high-fuel-economy hybrids, legislators have introduced many proposals over the past several years that would provide tax credits for the purchase of advanced technology vehicles. The most recent advanced vehicle tax credit bill, the CLEAR ACT bill, was introduced into the US Senate in April 2001 as S.B. 761 and into the US House of Representatives as H.R. 1861 in May 2001. This bill authorizes significant tax credits to compensate for the initial high costs of these vehicles, allowing time for the vehicles to increase in popularity and achieve lower costs. If this bill passes, purchasers of a hybrid vehicle similar to the one analyzed by DeCicco et al. would receive a credit toward their tax bill of $3,500. This tax credit covers nearly 70 percent of the added cost of the fuel economy improvement and enables the consumer to achieve a net savings of over $3,000 when fuel savings are factored in.

The Fuel-Efficient Sport Utility Vehicle

The symbol of the dramatic rise in popularity of light trucks is the sport utility vehicle. Since 1975, the SUV has grown from 2 percent to 20 percent of the total US vehicle sales mix. This growth is exemplified by the fact that the Ford Explorer SUV outsold the Honda Accord and the Ford Taurus in 1999. The fuel economy of this flagship SUV is just over 20 mpg, depending on the model.

The cost of a new V6, overhead-valve model Explorer was $29,915 in 2000 (Ward's 2000). The expected fuel use is 10,468 gallons over a 15-year lifetime for a cost of $10,827. These two expenses combined result in a consumer cost of $40,742.[17]

A 40-MPG SUV

The majority of the conventional technologies applied to the advanced family car can also be used for an advanced family truck. The SUV analyzed in DeCicco et al. achieves a fuel economy rating

Table 9. The Evolutionary SUV

Drivetrain	
GDI, VVC, four valves per cylinder engine	
Transmission	
5-speed automatic	
Vehicle	
C_D reduced by 10%	
C_{rr} reduced by 20%	
2,633 lbs.	
Performance	
0–60 in 11 seconds	
Fuel Economy	
CAFE test	40.1 mpg
Real world	32.1 mpg
Improvement	97%

Lifetime Costs	
Vehicle price	$32,002
Lifetime fuel costs	$5,481
Total cost	$37,483
Net savings	**$3,259**
Lifetime Impact	
Gasoline saved	5,169 gal.
GHG saved	61.9 tons
Toxic emissions avoided	33.5 lb.
Reduction in smog-forming pollutants	72.5 lb.

Assumes a 15-year, 170,000-mile life (Davis 2000, 1995 NPTS). Average gasoline retail price over the life is $1.40 (EIA 2000a). Emission rates are those used in table 1.

[17] This cost does not include maintenance, insurance, and finance costs. It also does not include the cost the vehicle places on society through its greenhouse-gas, toxic, and smog-forming emissions.

of 40.1 mpg. This SUV uses a larger version of the same stoichiometric gasoline direct-injection, variable-valve-control engine and substitutes an optimized five-speed automatic transmission for the existing four-speed version. The mass of the SUV is reduced by 33 percent in this advanced case, the aerodynamic drag coefficient is lower by 10 percent, and the rolling resistance is 20 percent below that of the baseline vehicle. The mass-reduction target is more aggressive than that used for the family car, for two reasons. First, since the SUV has yet to take advantage of unibody construction to produce a lighter but structurally sound frame, there are more opportunities for weight reduction.[18] In addition, the heavy and stiff body of today's SUVs is very dangerous to other drivers on the road; more aggressively reducing its weight and altering its design can improve the safety of other vehicles. The added cost for these technology additions was evaluated to be $2,087 (DeCicco et al. 2001).

Table 10. Hybrid SUV

Engine	
Advanced GDI engine, permanent magnet motor, and nickel metal hydride battery pack	
Transmission	
Integrated gearset	
Vehicle	
C_D reduced by 10%	
C_{rr} reduced by 20%	
2,749 lbs.	
Performance	
0–60 in 11 seconds	
Fuel Economy	
CAFE test	53.4 mpg
Real world	42.7 mpg
Improvement	163%

Lifetime Costs	
Vehicle price	$35,387
Tax credit	–$3,000
Lifetime fuel costs	$4,116
Total cost	$36,503
Net Savings	**$4,239**
Lifetime Impact	
Gasoline saved	6,489 gal.
GHG saved	77.7 tons
Toxic emissions avoided	42.1 lb.
Reduction in smog-forming pollutants	91.0 lb.

Assumes a 15-year, 170,000-mile life (Davis 2000, 1995 NPTS). Average gasoline retail price over the life is $1.40 (EIA 2000a). Emission rates are those used in table 1. Tax credit is currently proposed in the US Senate and House of Representatives.

[18] Most light trucks use the body-on-frame technique, whereby the frame and the body parts are separate pieces that must be attached. The strong but lighter alternative used in most cars is unibody construction, where a single-piece body functions both as a weight-bearing structure and the sheet-metal body itself.

The improved fuel economy of this SUV results in a savings of over 5,150 gallons of gasoline. The net present value of the gasoline savings is $5,346. As with the family car, this represents the equivalent of a significant rebate at the time of vehicle purchase. In this case, the equivalent rebate is over two times the added cost for the fuel economy improvements.

The Hybrid SUV

Ford is expected to produce hybrid versions of its Explorer and its Escape within the 2003–05 time frame. In the case of the Explorer, it is likely that the vehicle will be a milder hybrid, not drawing significant power from the motor and battery to drive the vehicle. DeCicco et al. analyze a fuller hybrid Explorer with the electric motor providing about 40 percent of the vehicle peak power. As with the hybrid Taurus, the remaining 60 percent is supplied by a stoichiometric gasoline direct-injection, variable-valve-control engine. The fuel economy of this full hybrid SUV reaches a rating of 53.4 mpg with a cost premium of $5,472 (DeCicco et al. 2001).

The gasoline savings with the hybrid SUV are nearly 6,500 gallons—a 62 percent drop. The associated fuel savings add up to over $6,700. These lifetime fuel savings represent a net reduction in cost of $1,239. This figure implies that a hybrid Ford Explorer could be cost effective even within the next 10 to 15 years. The $3,000 tax credit that would be available from the proposed CLEAR

Table 11. Fuel Economy Improvements for a Fuel-Efficient Vehicle Fleet

	Fuel Economy Improvement versus Baseline			
	Conventional Evolution, Stage I	Conventional Evolution, Stage II	Hybrid Electric, Stage I	Hybrid Electric, Stage II
Small Car	42%	57%	83%	106%
Family Sedan	56%	75%	101%	126%
Pickup Truck	37%	61%	86%	110%
Minivan	55%	85%	117%	145%
SUV	70%	98%	133%	163%
Fleet Average	52%	74%	103%	128%

Source: DeCicco et al. 2001

ACT would cover 55 percent of the incremental cost of fuel hybridization, resulting in a consumer net savings of $4,239.

A Fuel-Efficient Fleet

The technologies investigated are not limited to use in family cars and SUVs. All of the vehicles on the market, from compact cars to minivans to pickup trucks, can incorporate both the conventional and hybrid fuel economy improvements. In addition, the technologies can be applied to varying degrees, producing smaller or larger fuel economy impacts with associated reductions or increases in initial costs. Table 11 provides a summary of the potential fuel economy improvements across a spectrum of technology options, from the most accessible near-term evolutionary choice of moderate technology application to the application of full hybridization technologies.

Below is a detailed summary of the key technology packages for a full fleet of vehicles that could reach over 40 mpg, relying on the conventional evolution stage II technologies, and 55 mpg using the hybrid electric stage II technologies. These two packages represent realistic and cost-effective possibilities for the nation's new-vehicle fleets in 2012 and 2020. Additional information on the other packages of fuel economy improvements is included in appendix C.

Conventional Evolution, Stage II

Table 12 summarizes the fuel economy potential and savings for stage II evolutionary conventional vehicles representing each class of passenger vehicle. If all new cars and light trucks achieved the same fuel economy as these vehicles in the model year 2012, the average fuel economy of the new-car fleet would be about 42 mpg. This figure represents a 75 percent increase in fuel economy over today's values and a 43 percent reduction in gasoline use. Each consumer would also save between $1,500 and more than $3,000 over the lifetime of the vehicle.

The lifetime environmental savings associated with these evolutionary vehicles—summarized in table 12 for each vehicle—are quite significant. Thirty to 60 tons of greenhouse-gas emissions could be saved for each advanced vehicle sold, over its lifetime; 16 to 34 fewer pounds of toxic emissions and 35 to 72 fewer pounds of smog-forming emissions would be produced from the manufacture and distribution of the gasoline.

Table 12. Fuel Economy and Lifetime Savings from Stage II Evolutionary Conventional Vehicles

	CAFE Rated Fuel Economy[a] (mpg)	Real World Fuel Economy[b] (mpg)	Fuel Economy Improvement vs. baseline	Gasoline Saved[c] (gal.)	Cost of Fuel Economy Improvement[a]
Cavalier	48.4	38.7	57%	2,509	$1,125
Taurus	45.8	36.6	75%	3,471	$1,292
Silverado	33.8	27.0	61%	3,832	$2,291
Grand Caravan	41.3	33.0	85%	4,384	$2,134
Explorer	40.1	32.1	98%	5,169	$2,087
Fleet Average	41.8	33.4	74%	3,770	$1,693

a. Source: DeCicco et al. 2001
b. CAFE fuel economy reduced by 20%
c. Assumes a 15-year, 170,000-mile vehicle lifetime. Average life based on scrappage rates from Davis 2000. Vehicle mileage based on 1995 National Personal Transportation Survey (NPTS) data.

Table 12. (continued)

	Lifetime Fuel Cost Savings[d]	Net Savings (Equivalent Rebate)	Greenhouse-Gas Savings (tons)	Avoided Toxic Emissions (lb.)	Smog-Precursor Savings (lb.)
Cavalier	$2,595	$1,470	30	16	35
Taurus	$3,590	$2,298	42	23	49
Silverado	$3,964	$1,673	46	25	54
Grand Caravan	$4,534	$2,400	53	28	61
Explorer	$5,346	$3,259	62	34	72
Fleet Average	$3,900	$2,207	45	24	53

d. Based on an average gasoline cost of $1.40 per gallon (EIA 2000a).

Hybrid Electric Vehicles

The impact of hybrid electric vehicles (HEVs) is even more significant than that of the advanced conventional vehicles. The results shown in table 13 indicate that the application of hybrid technologies could bring passenger vehicle fuel economy up to more than 60 mpg for cars and about 50 mpg for light trucks. This situation would result in a fleet-wide new-car average fuel economy of 55 mpg, more than double the current value. If the proposed advanced-vehicle tax credits are included, the lifetime savings for the HEVs are on the order of $2,000 to $4,200.

In addition to the monetary savings they would realize, consumers buying a hybrid electric vehicle could have confidence that they were making their purchase decisions count by reducing their own impact on our environment. Over the lifetime of each vehicle sold, greenhouse-gas savings would range from 40 to nearly 80 tons, and toxic and smog-precursor emissions would be cut by more than one-half.

A comparison between the average vehicle in the hybrid fleet and the average vehicle in today's fleet indicates that consumers can come close to breaking even with HEVs in the near term, even without the inclusion of potential tax credits. The tax credits would, however, ensure that the near-term hybrids would be economically viable, setting the stage for the necessary market growth to ensure the technology's longer-term viability. In the meantime, over the lifetime of every hybrid vehicle sold nearly 5,000 gallons of gasoline would be saved and 60 tons of greenhouse-gas emissions would be avoided on average. Lifetime production of upstream toxic emissions would be reduced by 32 pounds, and upstream emissions of smog-forming pollutants would be reduced by 70 pounds.

These figures represent costs and performance within the next 10 to 15 years. Beyond that time, as hybrids are sold in greater volumes, the price is expected to drop and the fuel economy should improve as the technology is "learned-out." The drop in price will make HEVs cost effective without the use of tax credits, and the improved fuel economy will increase the greenhouse-gas, toxics, and smog-forming pollutant savings. The mass-production of HEVs will also bring down the cost of key components that can be shared with fuel cell vehicles, such as electric motors, power electronics, and advanced control systems.

Table 13. Fuel Economy and Lifetime Savings from Hybrid Electric Vehicles

	CAFE Rated Fuel Economy[a] (mpg)	Real-World Fuel Economy[b] (mpg)	Fuel Economy Improvement vs. Baseline	Gasoline Saved[c] (gal.)	Cost of Fuel Economy Improvement[a]
Cavalier	63.5	50.8	106%	3,553	$4,331
Taurus	59.3	47.4	126%	4,527	$5,098
Silverado	44.2	35.4	110%	5,311	$6,526
Grand Caravan	54.6	43.7	145%	5,637	$5,818
Explorer	53.4	42.7	163%	6,489	$5,472
Fleet Average	54.8	43.8	128%	4,976	$5,291

a. Source: DeCicco et al. 2001
b. CAFE fuel economy reduced by 20 percent.
c. Assumes a 15-year, 170,000-mile vehicle lifetime. Average life based on scrappage rates from Davis 2000. Vehicle mileage based on 1995 NPTS data.

Table 13. (continued)

	Lifetime Fuel Cost Savings[d]	Potential CLEAR ACT Tax Credit	Potential Net Savings (Equivalent Rebate)	Greenhouse-Gas Savings (tons)	Avoided Toxic Emissions (lb.)	Smog-Precursor Savings (lb.)
Cavalier	$3,675	$3,500	$2,844	43	23	50
Taurus	$4,683	$3,500	$3,085	54	29	63
Silverado	$5,494	$3,000	$1,968	64	34	74
Grand Caravan	$5,831	$3,500	$3,513	68	37	79
Explorer	$6,711	$3,000	$4,239	78	42	91
Fleet Average	$5,147	$3,293	$3,149	60	32	70

d. Based on an average gasoline cost of $1.40 per gallon (AEO 2001).

CHAPTER 5

THE BENEFITS OF A MORE FUEL-EFFICIENT FLEET

If we look forward to the year 2020, growth in driving, population, and vehicle ownership can be expected to increase the use of oil in the light-duty-vehicle market to 4.5 billion barrels per year[19]—an increase of 56 percent over our light-duty-vehicle oil use in 2000. This significant rise will lead to increased oil imports, rising oil prices, and large emissions of greenhouse gases, toxic gases, and smog-forming pollutants.

Policy Options

Given the example of the last 15 years without progress on fuel economy, this trend will not change unless policies are implemented to bring consumers a choice of fuel-efficient automobiles. To investigate the impact of different policy choices on our nation's oil use and our environment, UCS constructed four scenarios describing possible future policy options. For each scenario, fuel economy improvements begin in 2002 and last until the final goals are met for each year. The details of the scenario modeling are included in appendix D.

Baseline Scenario

The baseline scenario is based on a business-as-usual approach to fuel economy improvement. In this scenario, no policies are enacted to improve fuel economy, and automakers are not encouraged in any way to alter their current trends. The resulting assumption is that car and light-truck fuel economy stays the same, with cars at 28.1 and light trucks at 20.5 mpg. Further, the trend toward increased light-truck sales continues until a saturation point in 2015, when the new passenger vehicle fleet will be composed of 50 percent cars and 50 percent light trucks.[20]

[19] This figure is from the UCS baseline scenario.

[20] The fleet vehicle-miles traveled, new-vehicle sales, and fleet size for the UCS baseline scenario have been calibrated against the Energy Information *(cont.)*

All of the alternate scenarios use the same fleet sales and car/light-truck sales mix as this baseline scenario. Fleet vehicle-miles traveled are adjusted relative to the baseline using a rebound effect of 10 percent.[21] This rebound effect represents an increase in travel as vehicle fuel economy increases and the cost per mile of operation drops as a result (Greene 1998).

Voluntary Commitment Scenario

In July 2000 Ford Motor Company announced that it would be increasing the fuel economy of its sport utility vehicles by 25 percent by the 2005 calendar year (Ford 2000). General Motors and DaimlerChrysler later announced that they would both either match or beat Ford's planned improvements. General Motors plans to match Ford through an equivalent gain in GM's light-truck fleet, while DaimlerChrysler hopes to match Ford through a gain in DC's entire vehicle fleet. The GM commitment represents a 7 percent increase in its light-truck fuel economy, and the DC plan would mean an increase in its light-duty-vehicle fleet fuel economy of 5 percent.[22]

The second scenario is modeled after these commitments. This scenario assumes that all automakers voluntarily agree to improve their fleet fuel economy by 5 percent by 2005. This increase would result in an average new-vehicle fuel economy of 25.2 mpg in 2005 and the following years. Under this scenario, Ford, GM, and DaimlerChrysler would fulfill their public commitments. Companies such as Volkswagen, Honda, Toyota, Nissan, Hyundai, and Mitsubishi have not made such commitments and already have average fleet fuel economies that are at least 10 percent higher than

([20] cont.) Administration's (EIA) Annual Energy Outlook 2001 (AEO 01) (EIA 2000a). Energy use has also been calibrated to within +/- 2.5 percent of the AEO 01 projections given their fuel economy assumptions. EIA projects a small change in fuel economy such that the vehicle fleet reaches 27.5 mpg, a 14.5 percent increase, by 2020. Without external pressure, this increase seems unlikely. The baseline scenario therefore uses the assumptions of flat car and light-truck fuel economy and further assumes no change in vehicle sales as a result.

[21] In Greene 1998, an estimate of 10 percent in the short run and 20 percent in the long run is evaluated based on other literature results developed from past data. It is unclear, however, that past trends will apply to future fuel economy improvements. The marginal reduction in per-mile cost decreases as fuel economy is improved, and thus the impact should also be reduced versus past effects. In addition, as capital costs begin to far outweigh fuel costs, the continuing impact from operating costs on driving decisions should be reduced. As a result, UCS uses the short-run value for the lifetime of the vehicle.

[22] These numbers are based on 1999 sales data from Ward's 2000.

Ford, DaimlerChrysler, and GM (Morey et al. 2000). These companies would not have to make any alterations in their vehicle fleet to match the fuel economy levels proposed by Ford; further, some these companies' fleet fuel economies may drop during this time as they introduce more light trucks and full-line car models. This scenario assumes, however, that these companies do join in the voluntary agreement at the same level as the other three manufacturers. This represents an aggressive assumption for a voluntary case, since the same percentage increase in fuel economy represents a larger increase in average miles per gallon for the companies that already have more-fuel-efficient fleets.

The fuel economy level set in this scenario could easily be met through minor changes in car and light-truck technology. The light-truck market could meet the required fuel economy gains by moving from two to four valves per cylinder, optimizing transmission shift schedules, and lowering idle speeds at minimal cost. The car market could achieve the required improvements from similar changes in transmission shift control and idle speed reductions, along with increased penetration of variable-valve-controlled engines. Most of these technologies have the added advantage of enabling compliance with the next generation of tailpipe emissions standards.

Closing the Light-Truck Loophole Scenario

The light-truck loophole created with the original CAFE legislation allows minivans, SUVs, and pickup trucks to burn 33 percent more fuel for each mile they drive than the standard for cars allows. This disparity was created to protect rural residents, farmers, businesses, and other consumers from higher vehicle prices. Instead, it will cause Americans to spend $20 billion more on gasoline in 2001 than they would have without the light-truck loophole.[23]

The third UCS scenario assumes that the US Department of Transportation increases the fuel economy requirement of light trucks to 27.5 mpg, thus closing the light-truck loophole. In this scenario, this policy is phased in by 2008, after which fuel economy standards remain constant.

Since this scenario relies on improvement in light-truck fuel economy, a few more technologies would have to be implemented

[23] This UCS estimate assumes light-truck CAFE standards were originally set at 27.5 instead of 20.5. It also assumes today's projected average gasoline price of $1.54 per gallon (AEO 2001) and a rebound effect of 10 percent.

than would under the voluntary commitment scenario. The light trucks in this scenario could incorporate the variable-valve, four-valve-per-cylinder, overhead-cam engines used by Honda. In addition, modest vehicle-load reductions (weight, aerodynamic drag, and rolling resistance) could be applied to reduce the vehicle driving loads. Finally, an optimized transmission shift schedule or a five-speed automatic transmission could be included in the package. Together, these technologies would be sufficient to achieve an average light-truck fuel economy of 27 to 28 mpg (Mark 1999). In the case of pickup trucks, the performance could be maintained while achieving today's car fuel economy standards—eliminating the concerns over which the loophole was originally created. The incremental cost for such an option would be around $1,500 (DeCicco et al. 2001) and would be accompanied by annual gasoline savings of about $300 per year.

Stronger CAFE Standards Scenario

The final scenario is based on continuous introduction of fuel-efficient automobile technology over an 18-year period. In this scenario, moderate improvements are phased in to the new-car fleet beginning in 2002, producing a fleet of Stage I evolutionary conventional vehicles.[24] Stage II evolutionary conventional vehicles ultimately represent the majority of the near-term market, achieving a fleet fuel economy of 40 mpg by 2012. A new passenger vehicle fleet fuel economy of 55 mpg is then reached with the introduction of hybrid electric vehicles through 2020, when the majority of the new-car and light-truck fleet would be Prius-like hybrids.[25]

This scenario would rely on stronger CAFE standards as a key policy tool to achieve such fuel economy gains. Standards would begin ramping up in 2002, and by 2008 light-truck fuel economy would have to be around 30 mpg and car fuel economy would have to reach about 40 mpg. These and future fuel economy levels could be reached by increasing the car and light-truck fuel economy standards separately. Alternatively, these fuel economy levels could represent manufacturer choices under altered CAFE legislation. Such an altered version of CAFE would require that car and light-truck fleet fuel economies be harmonized into one averaged fleet standard.

[24] See appendix C for details on conventional evolution Stage I vehicles, which represent moderate application of conventional technologies.

[25] Early introduction of hybrid vehicles consists primarily of mild hybrids similar in design to the Honda Insight. Details on these Stage I hybrid electric vehicles are included in appendix C.

Fuel Cell and Hybrid Electric Vehicle Fleet Penetration

In all of these scenarios, fuel cell and hybrid electric vehicles play a role in improving fleet fuel economy. The baseline, voluntary commitment, and closing the light-truck loophole scenarios assume that hybrid electric and fuel cell vehicle penetration follows that required by the zero-emission-vehicle mandates in effect in California and several northeastern states, plus some spillover sales throughout the rest of the country.[26] These scenarios assume that required fuel economy levels are insufficient to spur automakers to significantly increase their offerings of hybrid and fuel cell vehicles far beyond minimum requirements. This is a conservative assumption, since consumers will presumably be interested in the driving and comfort features of HEVs, not solely in their fuel economy benefits.

In 2010, the number of vehicles that could qualify for advanced technology partial zero-emission vehicles (ATPZEVs) credit is approximately 0.87 percent of the cars and light trucks sold in the United States.[27] Sales of 1.75 percent are assumed for 2010, representing an approximate doubling in sales. In 2020, this fraction rises to 2.02 percent of the national new light-duty-vehicle fleet, and sales are assumed to reach 3.5 percent, a 75 percent increase.

The values above are used for the baseline and two moderate scenarios for HEVs. The requirements for pure ZEVs in 2010 and 2020 equate to about 0.07 percent and 0.36 percent of national vehicle sales, respectively, assuming all ZEVs are direct-hydrogen fuel cell vehicles and assuming manufacturers take full advantage of the ATPZEV category. These modest fuel cell vehicle penetrations are also incorporated in the baseline and two moderate scenarios.

The stronger CAFE scenario assumes that the higher fuel economy standards, along with increasing consumer acceptance of hybrid and fuel cell vehicles, drive up the penetrations of these technologies. By 2010, HEVs represent 10 percent of the national fleet, as automakers introduce these vehicles in preparation for

[26] Fleet requirement numbers have been modified to reflect measures adopted by CARB on January 25, 2001.

[27] This value assumes combined HEV sales required in California and the Northeast using a baseline of new-vehicle sales in those states representing 20 percent of the national sales of new cars (2000). Annual vehicle sales are assumed to be approximately 16 million new cars and light trucks. Exact CARB requirements had not been finalized as of the production of this report.

meeting the 55 mpg standard to take effect 10 years later. By 2020, over 90 percent of the new car sales would be hybrid electric vehicles.

Also under the stronger CAFE scenario, fuel cell vehicles would reach 0.6 percent of the market, or nearly 100,000 cars and light trucks nationwide, by 2010. This market penetration is assumed to increase by a factor of 10, to about 6 percent of annual sales, in 2020. Under this stronger CAFE scenario, 2020 fuel cell vehicle sales rise to about one million new cars and light trucks per year.

Scenario Results

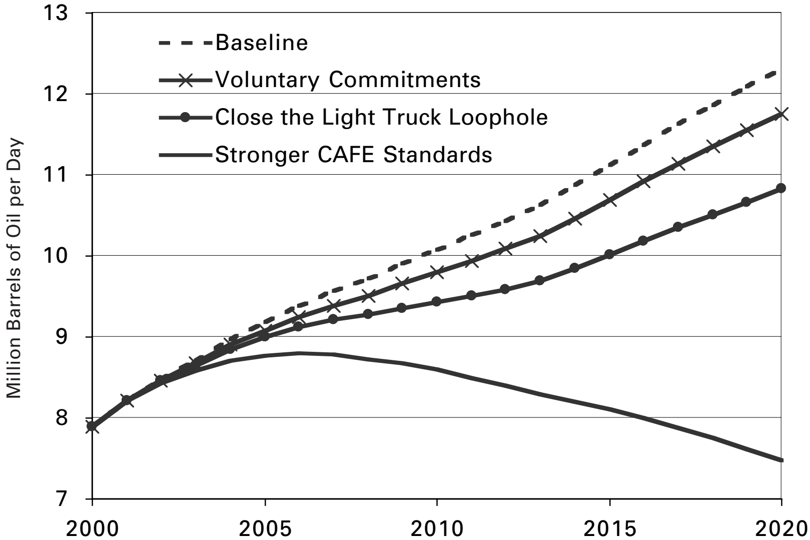
Any significant effort to change the current 15-year fuel economy stagnation would have positive benefits for consumers, the nation, and the environment. Voluntary commitments by automakers are certainly a welcome change, but current commitments fall far short of the potential for technology to deliver more substantial savings. Closing the light-truck loophole would be a strong move in the right direction, given the tremendous consequences resulting from booming sales of inefficient SUVs and other light trucks. But stronger CAFE standards requiring increases for both cars and trucks would deliver the greatest benefits. Such a policy could be supported by tax credit legislation to encourage early adoption of the most promising technologies. In addition, the government could lend its support through appropriate research and development for hybrid electric vehicles and fuel cell vehicles that both exceed current and future emissions standards and provide significant gains in fuel economy.

Oil Use

Pursuing the stronger CAFE standards scenario could have a great impact on oil use from the light-duty-vehicle sector. The results shown in figure 10 indicate that we could slow growth in car and light-truck oil use to zero by 2006. By 2017 oil use from this sector could be returned to 2000 levels and could continue dropping into the future.

The voluntary agreement scenario has a minor impact on oil consumption. The baseline's growth in oil use of 56 percent by 2020 is reduced to 49 percent, representing only a 4 percent reduction in oil use from the car and light-truck market compared with projected 2020 passenger vehicle oil requirements. In contrast, the stronger CAFE standards scenario represents nearly a 40 percent reduction in oil use from this sector by 2020, or a 10 times greater impact.

Figure 10. Oil Use in the Car and Light-Truck Markets under Various Fuel Economy Scenarios



Notes:
Close the Light-Truck Loophole: by 2008.
Stronger CAFE standards: 40 mpg in 2012, 55 mpg in 2020.

Closing the light-truck loophole results in a 12 percent reduction in oil use by 2020. While still not as significant as the results from the stronger CAFE scenario, this figure represents a tripling of the oil savings that would result from all automakers' adoption of the commitments made by Ford, GM, and Daimler-Chrysler.

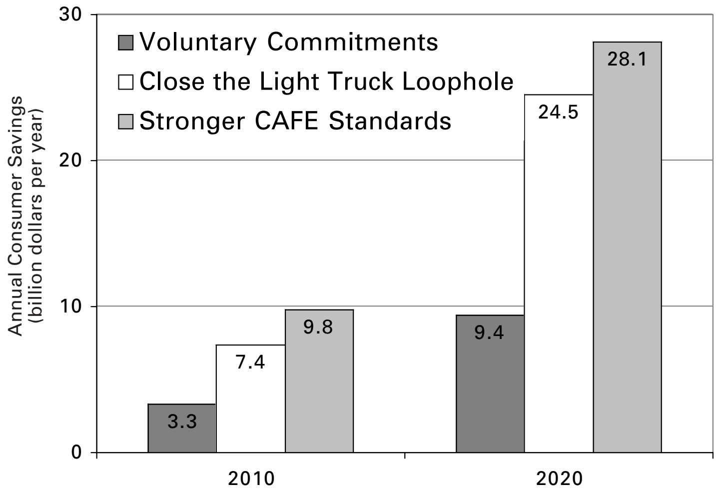
Net Consumer Savings

A typical concern with more aggressive fuel economy savings is that consumers will bear unreasonable costs to achieve the desired gains. A comparison of annual costs for fuel economy improvements and annual cost savings from the associated reduced fuel use show that the stronger CAFE standards scenario saves consumers more money both in the short and the long term.

In 2010, consumers save $9.8 billion as a result of the stronger CAFE standards scenario (figure 11). By the year 2020, the annual savings for this scenario nearly triples—reaching $28.3 billion per year.[28] All of these savings are achieved without any government assistance. By way of comparison, the voluntary commitments

[28] These savings represent the difference between the cost of fuel economy improvements and the fuel savings accrued. Only the costs and savings in that year are counted.

Figure 11. National Consumer Net Savings from Fuel Economy Improvements



scenario saves only one-tenth of the oil of the stronger CAFE scenario and therefore produces about one-third of the CAFE scenario savings in 2010 and in 2020. Overall, both the oil and monetary savings of the stronger CAFE scenario far outweigh those from any of the other scenarios.

Scenario Savings Summary

The details of the savings from the three alternate scenarios are shown in table 14 for 2010 and in table 15 for 2020. In all categories, the stronger CAFE standards scenario represents significant improvement in oil use, consumer pocketbook savings, and environmental impacts.

Achieving the same levels of environmental and oil savings under the base-case assumptions would require taking over 32 million cars and trucks off the road in 2010. In 2020, 96 million cars and trucks would have to be eliminated for these same savings. Alternatively, the average driver in the baseline scenario in 2020 would be restricted to driving only four days a week.

Tapping the Automakers' Ingenuity

The fuel savings that can result from improving vehicle technology far exceed the potential oil production from environmentally sensitive areas such as the Arctic National Wildlife Refuge in Alaska. Not only are the oil savings from fuel economy greater,

Table 14. 2010 Fuel Economy Scenario Summary

	Voluntary Agreements	Close the Light-Truck Loophole	Stronger CAFE Standards
Annual Oil Savings (billion barrels)	0.1	0.24	0.54
Cumulative Oil Savings (billion barrels)	0.47	0.97	2.16
Annual Consumer Savings (billion dollars)	3.3	7.4	9.8
Greenhouse-Gas Savings (million tons)	52	120	273
Avoided Toxic Emissions (million pounds)	28	65	148
Smog-Precursor Savings (million pounds)	61	140	320

Table 15. 2020 Fuel Economy Scenario Summary

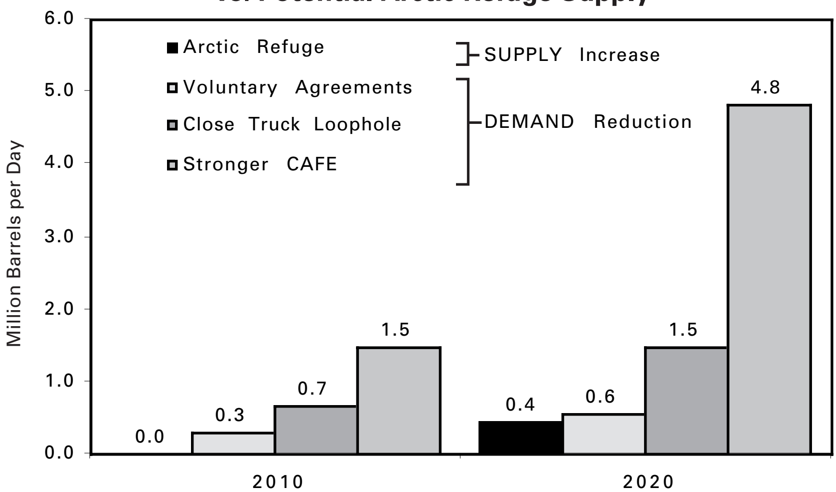
	Voluntary Agreements	Close the Light-Truck Loophole	Stronger CAFE Standards
Annual Oil Savings (billion barrels)	0.2	0.54	1.76
Cumulative Oil Savings (billion barrels)	2.08	5.12	14
Annual Consumer Savings (billion dollars)	9.4	24.5	28.1
Greenhouse-Gas Savings (million tons)	102	272	888
Avoided Toxic Emissions (million pounds)	55	147	481
Smog-Precursor Savings (million pounds)	119	319	1,039

they will be delivered faster. If the Arctic Refuge were opened for exploration today, oil would not begin flowing until around 2010, as it takes 7 to 12 years for lease sales, permitting, and environmental reviews to be finalized after leasing is approved (EIA 2000b).

The most recent estimate from the US Geological Survey puts the economically recoverable volume of oil in the Arctic Refuge at 3.2 billion barrels (USGS 1998).[29] By 2012, just as oil would begin flowing from new wells in Alaska, the stronger CAFE scenario would have saved more oil than this pristine wilderness is expected to produce. By 2020, fuel economy increases could save over four times the oil available in the Arctic Refuge.

Of course, not all of the Arctic Refuge's oil could be extracted at once. Drilling and operational limits would restrict the pace at which development could take place, so that only a portion of the oil could be brought on-line each year. Furthermore, oil wells produce only a fraction of their total volume in any given year (EIA 2000b). Thus, even if Arctic Refuge oil began flowing in 2010, it could take up to 60 years to extract all of the oil at historic production rates.

Figure 12. Oil Savings from Fuel Economy vs. Potential Arctic Refuge Supply



Notes:
1. Arctic Refuge production schedule based on UCS estimates using economically recoverable volume at projected world oil prices (USGS 1998) and projected development rates (EIA 2000b). See appendix E for details.
2. Demand reduction scenarios based on UCS modeling. See text for details.

[29] This figure is based on \$20 per barrel world oil price in 1996 dollars, or roughly \$22 per barrel in today's dollars. The average world oil price projected for the period 2010–20 is \$22.5 per barrel (EIA 2000a).

Both closing the light-truck loophole and overall stronger CAFE standards would save oil significantly faster than it could be extracted from the Arctic Refuge (figure 12). Closing the light-truck loophole would save three times more oil in 2020 than the Arctic Refuge could produce, and stronger CAFE standards across the board would save 11 times more oil in that year.

The irony of this comparison is that the amount of oil available from the Arctic Refuge is much too small to affect world oil prices and is thus unlikely to produce any consumer savings. Further, while reducing automotive fuel use lowers emissions of greenhouse gases, toxics, and smog-forming pollutants, drilling in the Arctic would increase these emissions. The sound alternative—both for the environment and for consumers—is to tap into the intelligence and skills of the automakers and encourage them to produce vehicles that won't thirst for so much oil. This future is possible.

CHAPTER 6

FUEL ECONOMY AND NATIONAL WEALTH

One of the key concerns of policymakers is the effect of increased fuel efficiency on American automakers, jobs, and national income. Success in today's global economy requires that domestic automakers rapidly adjust to new market circumstances and capitalize on opportunities. The investment in increased fuel economy can be an opportunity for automakers to increase their profits and for the general public to benefit as well. Reducing energy use can also help insulate the national economy from oil price shocks and other destabilizing factors.

Jobs, Wages, and National Income

As automakers pass the cost of fuel economy improvements on to consumers, and consumers find that fuel savings more than compensate for these costs, the US economy will benefit. Increased automaker income and consumer savings will stimulate investment, improve wages and salaries, and lead to an overall increase in national income levels.

To evaluate the magnitude of these effects, UCS modeled the economic and employment benefits from the stronger CAFE standards scenario using the IMPLAN input-output macroeconomic model.[30] Overall, the results indicate that jobs, wages, and national wealth all show net gains over a 10- and 20-year horizon. These results are consistent with other studies that have concluded that the cumulative benefits of enacting fuel-efficiency and other energy-reduction strategies for transportation far outweigh the costs (Bernow and Duckworth 1998, Alliance to Save Energy et al. 1997).

[30] IMPLAN (Impact Analysis for Planning Model) was originally developed by the US Department of Agriculture Forest Service and extended by the Minnesota IMPLAN Group *(www.mig-inc.com).* The model incorporates interactions among 528 different industrial sectors using 21 different economic variables. The approach used in this report is similar to that used by Geller, DeCicco, and Laitner 1992 and more recently by Goldberg et al. 1998.

Table 16 provides the results of one of the big winners in the stronger CAFE standards scenario, the motor vehicles and equipment sector. Jobs in this sector are expected to increase by 40,400 by 2010 and 103,700 in 2020. This increase in jobs is a direct result of increased vehicle costs leading to increased income for atuomakers. These costs are passed on to the public, but, as discussed in the previous two chapters, fuel cost savings more than compensate for the increase in vehicle costs.

Table 16. Macroeconomic Impacts of the Stronger CAFE Standards Scenario on the Motor Vehicles Sector

	Net Change in Jobs	Net Change in Wage and Salary Compensation (Millions of 2000 dollars)	Net Change GDP (Millions of 2000 dollars)
2010	+40,400 (4% increase)	$3,337	$5,474
2020	+103,700 (11% increase)	$10,411	$5,737

Based on current estimates, the motor vehicles and equipment sector had 942,000 wage and salary employees in January 2001 (BLS 2001b). The increased employment under this scenario represents a 4 percent increase over current levels in 2010 and an 11 percent increase in 2020. Recent Bureau of Labor Statistics projections also estimate that this sector is expected to lose 2,000 jobs by 2008; thus, the stronger CAFE standards scenario could compensate for the expected declines in the coming years (BLS 2001b).

The economic benefits of fuel efficiency are also anticipated to benefit most of the other sectors of the economy, including services, education, other manufacturing, finance, and metal durables. Sectors anticipated to shrink under the increased fuel economy scenario are those directly and indirectly related to fuel production and supply, such as oil and gas mining and oil refining.

The model results presented here should be viewed as indicative of the direction of impacts rather than as a definitive estimate of the impacts. These estimates do not include potential changes in vehicle sales due to the additional costs of fuel economy improvement; it is likely, however, that these impacts would be small and would be overwhelmed by the expected gains found here.

Overall, UCS's analysis indicates that both the US economy as a whole and the motor vehicles sector in particular would show improvements in jobs and overall productivity as a result of an investment in improving vehicle fuel economy.

Other Macroeconomic Impacts

Current macroeconomic models can estimate changes only at the margin of our economy. More radical impacts due to our growing use of oil and our increasing impact on the environment can be difficult to predict and even more difficult to value. For example, how do we know the point at which increasing energy costs may ignite a recession? How do we measure the costs of global climate change, the loss of a species, the desertification of a once-lush ecosystem? These more intangible costs and benefits have tremendous implications for national wealth and prosperity, yet they prove unwieldy for the models and are thus excluded from the analysis. Reducing energy usage and costs can insulate the economy from destabilizing events that do not figure into this economic model.

Insulating the Economy from Energy Price Fluctuations

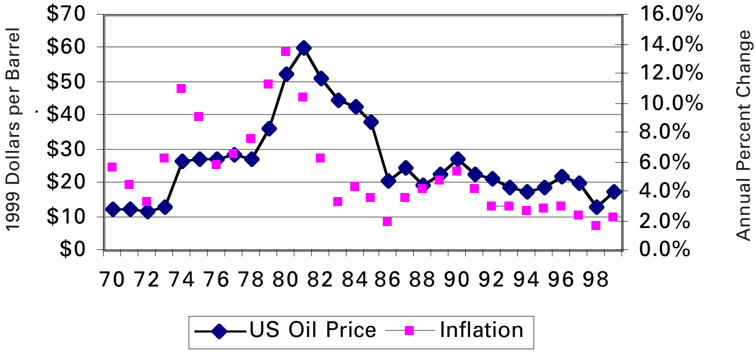
Reducing demand for oil will protect the economy from energy price shocks. Observable and dramatic changes in GDP growth have occurred as the world oil price has fluctuated (EIA 2001b). As figure 13 illustrates, inflation tracks movements in the US price of oil (EIA 2001b). Higher energy prices lead to greater costs of production, higher commodity prices, and ultimately an increase in the amount one pays at the check-out line for basic goods.

Our economy grows when oil prices and inflation are low. Alternatively, when oil prices skyrocket, inflation follows, and our economy suffers (figure 14). The three major oil price shocks in the last 30 years were all followed by recessions.[31]

The coupling of skyrocketing energy prices with recessions is particularly troubling given that 50 percent of our oil is imported and that share is expected to rise (EIA 2001b). In 1973, when OPEC's first price shocks reverberated through the economy, only 25 percent of our petroleum was imported. Given our increasing dependence on foreign oil, the US economy may be more vulnerable now to world price fluctuations. Reducing pressure on

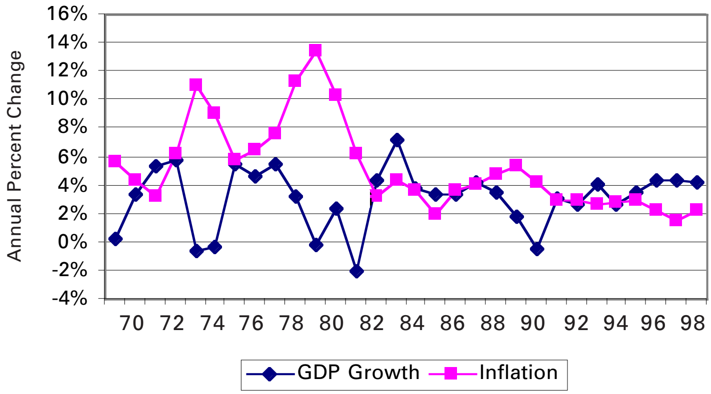
[31] The three oil price shocks and subsequent recessions occurred in the early 1970s, the late 1970s/early 1980s, and the early 1990s.

Figure 13. US Oil Price and Inflation



Notes:
1. Data for inflation: BLS 2001a.
2. World Oil Price: EIA 2001a.

Figure 14. Gross Domestic Product and Inflation



Notes:
1. Data for inflation: BLS 2001a.
2. Data for GDP: BEA 2001.

oil demand through fuel efficiency can help protect the economy from the destabilizing impacts of rising oil prices.

Reducing the Costs of Climate Change

Actions taken today to reduce greenhouse-gas emissions will reduce the price that we—and our children—pay in the future to address the effects of global climate change. The current trends in greenhouse-gas production may cause temperatures to rise as much as 5.8° Celsius (IPCC 2001). While cost estimates are laden with uncertainty, current studies based on a 2° to 3° Celsius warming indicate that the economic impacts of this small temperature change are on the order of a few percent of world GDP (IPCC 1995). These estimates may be conservative, since they assume that the impacts of climate change are not catastrophic. Climate change impacts such as rising sea levels, more frequent and intense extreme weather events, and shifts in regional climates have the potential to severely disrupt our ecological and economic systems far beyond the levels assumed in the IPCC report.

Industries are recognizing that the risks of global warming argue for both corporate and international action. The 33 corporate members of the Pew Center for Global Climate Change, for example—including Toyota, Shell, BP Amoco, and American Electric Power—support international greenhouse-gas limits (Coy 2001). Each of these businesses has made public commitments to reduce its greenhouse-gas emissions.[32]

[32] According to the Business Environmental Leadership Council, the industries have signed on to the following public statement: "We accept the views of most scientists that enough is known about the science and environmental impacts of climate change for us to take actions to address its consequences. Businesses can and should take concrete steps now in the US and abroad to assess opportunities for emission reductions, establish and meet emission reduction objectives, and invest in new, more efficient products, practices, and technologies." (BELC 2001).

CHAPTER 7

SAFETY AND FUEL ECONOMY

Automakers can utilize a variety of design and technology options for reducing fuel consumption. The only one that could have a significant impact on occupant safety during a crash, however, is vehicle weight reduction.[33] The auto industry has argued that weight reduction compromises safety and that public policy should not encourage further fuel economy improvements, since they would lead to vehicle weight reduction (as they did in the period from 1977 through 1985).

Contrary to this assumption, the relationship between safety and the weights of vehicles in the fleet is neither direct nor obvious. The factors that affect public safety on the road are so many and varied that actual road casualties can be only generally predicted. In particular, the concern over the safety of weight reduction is driven by the poor safety performance of the lighter vehicles in the fleet. This performance is misleading since it is partly due to two factors: (1) the lightest vehicles in the fleet tend to be the least expensive and thus incorporate the fewest safety advances, and (2) lighter vehicles tend to be driven by younger, more aggressive drivers.

Vehicle weight reduction is a reasonable strategy for fuel economy improvements if it is applied most aggressively to the SUVs, minivans, and pickup trucks used as private passenger vehicles. In addition, these weight reductions can be applied in combination with obvious and inexpensive safety improvements.

Principles of elementary physics imply that in a two-vehicle collision, a heavier vehicle should be safer than a lighter one. In practice, however, that is not necessarily always the case. In a two-vehicle crash, for example, if the heavier vehicle is struck in the side by the front of a lighter vehicle, the occupants of the heavier vehicle may be more at risk. Further, the potential for survival in

[33] Estimates show that a 10 percent reduction in vehicle weight could result in a 3 to 7 percent increase in fuel economy (NRC 1992; OTA 1991).

single-vehicle crashes (including rollovers) depends on many factors, only one minor one of which is vehicle weight.

When one considers road transportation generally, the difference in weight between vehicles is much more important to occupant safety than the average weight of all vehicles sharing the road. Furthermore, specific design features that affect the inherent safety of individual vehicles and their compatibility when they collide play a more important role than do the weights of the individual vehicles.

Driving on a Highly Skewed Field

When discussing motor vehicle crash losses, it is critical to consider the major shift toward light trucks over the past 25 years. Since half of all new light-duty vehicles are SUVs, pickups, and minivans, the nature of accidents and the spectrum of crashes have changed dramatically.

Some of the popularity of light trucks can be linked to the perception that they are safer than passenger cars and the fact that SUV drivers sit higher, giving them a more commanding view of traffic. While light trucks must meet essentially the same federal motor vehicle safety standards as passenger cars, two areas—rollover safety and compatibility of vehicles in two-vehicle crashes—are not covered or are inadequately covered in these standards. These two areas are critical to the safety of occupants of light trucks and occupants of vehicles that are hit by them.

Rollover Safety

A vehicle's rollover safety is a combination of its rollover propensity, restraint performance in rollovers, and roof strength. SUVs are roughly twice as likely to roll over as passenger cars. The National Highway Transportation Safety Administration recently began to provide static stability index (SSI) consumer information in its New Car Assessment Program on all light motor vehicles.[34] The SSI provides a strong indication of a vehicle's rollover propensity and confirms concerns regarding the rollover safety of many of the heavier vehicles. Federal motor vehicle safety standard (FMVSS) 216 governs roof strength, but the standard is so weak as to be virtually meaningless.[35]

Compatibility in Two-Vehicle Crashes

In two-vehicle collisions, compatibility refers to the degree to which each vehicle minimizes the potential for injury in both vehicles. Weight disparity is a major factor in compatibility, as light trucks are, on average, more than 1,000 pounds heavier than passenger cars.

The second factor in compatibility is the height of the primary structure of a vehicle. Passenger car manufacturers design cars with their primary structure set between 14 and 21 inches above the ground in order to meet federal bumper and side-impact standards. Light trucks are not subject to the bumper standards, and their primary structure is often well above that of passenger cars.[36] Thus, a light truck is likely to override the safety structure of a passenger car in a crash. This is particularly disastrous if a light truck strikes the side of a passenger car.

The third factor in compatibility is that the frames of heavier vehicles such as light trucks are generally stiffer than those of cars. These stiffer frames do not absorb their share of the energy of a crash and thus tend to force the other vehicle to deform more and absorb the majority of the crash energy. These impacts are important in both front and side crashes with all other vehicles on the road.

SUVs in general, and pickups in particular, seriously violate all of the principles of compatibility. On the other hand, the passenger car fleet has been moving toward increased compatibility. In the passenger car fleet, the disparity in vehicle weight has decreased dramatically over the past 25 years. Since the adoption of the CAFE standards, small passenger cars have become heavier while large passenger cars have become lighter, with the biggest growth in the new-car fleet coming in the middle with 3,500-pound cars. These cars went from 12.5 percent of the new-car fleet in 1975 to 51.9 percent in 2000 (Heavenrich and Hellman 2000). For the 1975 model year, cars with inertia weights of less than 2,500 pounds made up 10.8 percent of the new-car fleet but only 2.6 percent in model year 2000. In contrast, passenger cars in the over-4,500-pound weight class and above made up 50 percent of the new-car fleet in 1975 but only 0.9 percent in 2000. The net effect of these changes was a safer passenger car fleet, particularly when one considers the improved safety technology put into passenger cars.

[36] 49 CFR 581, Bumper Standard.

Safety by the Numbers

In 1979, the motor vehicle fleet consisted mostly of vehicles that had been designed before the energy crisis of 1973 to 1974.[37] At that time, light trucks still played a very small part in new-vehicle sales, and smaller vehicles had only begun to make their way into the market. Thus, 1979 provides a reasonable baseline against which to compare the two key trends over the past 20 years: (1) the dramatic increase in passenger car fuel economy and the attendant reduction in average car weight; and (2) the substantial increase in light trucks as a proportion of the total vehicle fleet.

The changes in vehicle registrations are shown in table 17. During that period, the proportion of light trucks in the fleet went from 22 percent to 37 percent. The number of light trucks today is 2.5 times the number of 20 years ago.

Table 17. Approximate Registrations of Various Types of Motor Vehicles in the United States

Year	Passenger Cars (millions)	Light Trucks[a] (millions)	Large Trucks (millions)
1979	103.5	28.9	5.9
1984	112.2	35.3	5.4
1989	122.8	47.1	6.2
1994	122.0	59.5	6.6
1999	126.9	73.1	7.8

a. Light trucks include pickup trucks, sport utility vehicles, and vans.
Source: US Department of Transportation 2000.

Over the last two decades, highway fatalities have gone down by nearly 20 percent, while travel has increased by more than 40 percent—a reduction of more than 50 percent in fatalities per mile traveled over 20 years. During the same period, pedestrian fatalities decreased by one-third, and motorcycle fatalities were cut by half. Passenger-car and light-truck occupant fatalities were down about 10 percent, mostly in single-vehicle, nonrollover crashes. Table 18 shows these and some other basic motor vehicle fleet and crash statistics characterizing the changes.

[37] The first downsized vehicles, full-sized General Motors B and C platform cars, were introduced as 1977 models. They were roughly 1,000 pounds lighter than the vehicles they replaced, but retained the same interior room and performance. It was not until the 1980 model year that a substantial portion of the new American vehicles were genuinely downsized vehicles.

Table 18. A Comparison of Basic US Motor Vehicle Statistics over the Last 20 Years

	1979	1999
Registered Motor Vehicles (% Passenger Cars / % Light Trucks)	144 M (72% / 20%)	212 M (59% / 35%)
Vehicle-Miles Traveled	1.5 billion	2.7 billion
People Killed As Passenger-Car Occupants	27,788	21,164
People Killed As Light-Truck and Van Occupants	7,119	10,647
Pedestrians and Pedalcyclists Killed	9,021	5,981
Heavy-Truck (>10,000 lbs.) Occupants Killed	1,087	936
Motorcycle Riders Killed	4,679	2,284

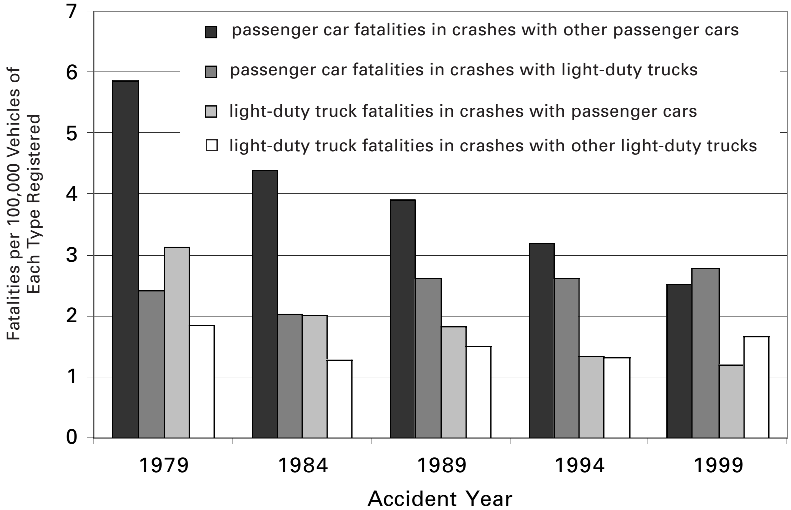
Source: NHTSA' s Fatal Accident Reporting System (FARS).

The reduction in light-vehicle occupant fatalities is a result of a number of factors, including a substantial increase in safety belt use, the almost universal installation of airbags in recent model light motor vehicles, and the implementation of the dynamic side-impact standard. Rollover fatalities have decreased modestly in passenger cars, but they have increased dramatically in pickup trucks and SUVs, consistent with the comparative growth in the number of these vehicles in the fleet. Overall, fatalities in rollovers of pickups and SUVs have more than doubled.

Two-vehicle crashes between passenger cars kill only about half as many people as they did 20 years ago, while fatalities in passenger-car/light-truck crashes have increased by nearly 50 percent. This fact further emphasizes the problem with the current disparity in the vehicles driven on the road today.

Figure 15 shows trends in two-vehicle fatal crashes in terms of the number of deaths for those driving a vehicle per number of registered vehicles of that type on the road (see also table F-1 in appendix F for the actual numbers of fatalities). This figure indicates a fatality risk based on the exposure of each type of vehicle. Had the ratio of light trucks to passenger cars remained as it was in 1979 (22 percent rather than the current 37 percent), nearly 1,000 fewer fatalities would have occurred in two-vehicle crashes between light vehicles.

Figure 15. Occupant Fatality Rates in Crashes Between Two Light-Duty Vehicles per Number of Victim's Type of Vehicles on the Road



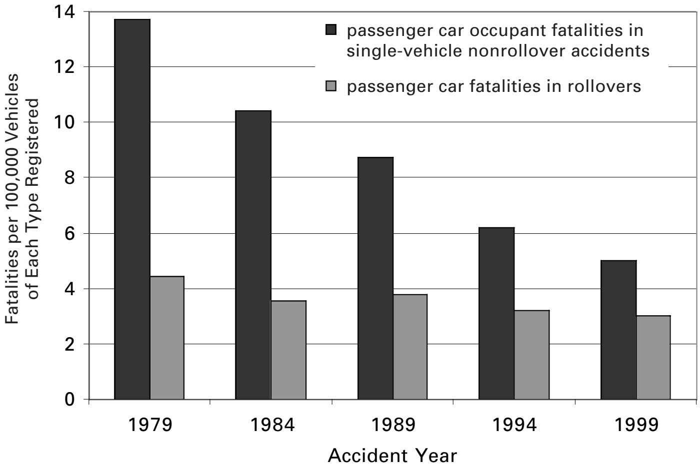
Source: NHTSA's Fatal Accident Reporting System (FARS)

Fatality rates per registered vehicle in single-vehicle crashes show a decline for all vehicles. Differences can be seen, however, for cars versus light trucks (figure 16 and figure 17).[38] The passenger-car nonrollover fatality rate per 100,000 registered passenger cars went from 13.7 in 1979 to 5.0 in 1999 , which represents a reduction in risk of over 60 percent (figure 16). For light trucks and vans, the rate went from 8.1 to 3.9, a reduction of 50 percent. Overall, cars have been making more safety progress in single-vehicle crashes than have light trucks.

In rollover crashes, cars showed an even greater improvement than light trucks. The passenger car fatality rate in a rollover decreased 30 percent, from 4.4 to 3.1, over the same 20 years, while the light-truck and van fatality rate in rollovers went down only half as much, from 6.8 to 5.8. Light-truck and van fatality rates in rollovers were twice as high as were passenger rates in 1999; SUV and pickup rollover rates are even higher.

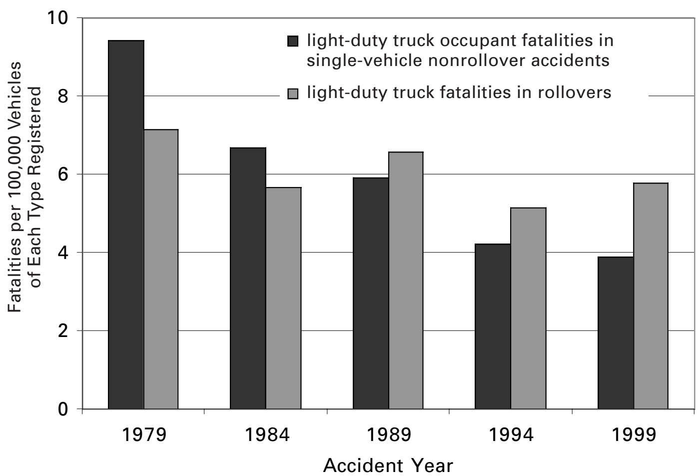
[38] Tables F-2 through F-4 in appendix F show fatalities in single-vehicle crashes of passenger cars, pickups, SUVs, and minivans.

Figure 16. Passenger Car Occupant Fatalities in Single-Vehicle Crashes and Rollovers



Source: NHTSA's Fatal Accident Reporting System (FARS)

Figure 17. Light-Truck Occupant Fatalities in Single-Vehicle Crashes and Rollovers



Source: NHTSA's Fatal Accident Reporting System (FARS)

Rollovers are potentially among the most benign motor vehicle crashes because the forces involved are much lower than the forces in major frontal and side-impact crashes. Approximately half of all serious to fatal casualties in rollovers are from passenger ejection and could be prevented by the virtually universal use of effective safety belts.[39] Many of the remaining casualties result from the collapse and buckling of the vehicle's roof in a rollover. Making adequately strong roofs in new motor vehicles is well within the technological capability of their manufacturers, would add only minimally to the vehicle's weight, and would cost well under $100 per vehicle.

The rate of single-vehicle crash fatalities of all types depends far more on the specific design and use characteristics of vehicles than on their weight. For example, simply increasing safety belt use by 10 percentage points would overwhelm almost any effect of reasonable weight reduction in these types of crashes.

In general, the data on the history of motor vehicle crash losses suggest several conclusions that will help in considering the potential impact of future changes in vehicle fuel economy on safety:

- The major increase in light trucks used as substitutes for passenger cars in the vehicle fleet has kept the number of light-vehicle occupant fatalities from falling as much as other crash statistics. The increased use of light trucks as substitutes for private passenger vehicles has produced at least 2,000 additional rollover fatalities annually.

- Fatalities in single-vehicle crashes went down more than 25 percent from 1979 to 1999, while light-duty vehicle occupant fatalities in two-vehicle crashes went down only about 10 percent. The reduction in single-vehicle crash fatalities was driven by a 45 percent reduction in passenger car single-vehicle crash fatalities, indicating that technologies were adopted that significantly improved vehicle safety. On the other hand, the greater number of light trucks in the US fleet increased passenger-car occupant fatalities in crashes with light trucks by more than 50 percent. This overwhelmed a decrease in passenger-car occupant fatalities in crashes with other passenger cars of under 50 percent. Overall, two-vehicle crashes would have killed nearly 1,000 fewer people without the major increase in light trucks as passenger car substitutes.

[39] Unfortunately, many current safety belts installed in these vehicles perform poorly in rollovers.

- If the disparity in weights between passenger cars and light trucks becomes wider, either because of the design and marketing practices of the automakers or because of continuing regulatory policies that differentially affect cars and light trucks, fatalities in these types of two-vehicle crashes will continue to increase relative to other types of automotive casualties. Reducing this weight disparity is likely to decrease casualties in two-vehicle crashes.

- No more than one out of four light-vehicle occupant fatalities would be influenced by changes in vehicle weight to improve fuel economy. Furthermore, the effect of weight disparity on these fatalities is marginal—almost certainly less than the effect on fatalities of the major increase in light trucks in the fleet. Had light-vehicle occupant fatalities in two-vehicle crashes decreased to the same degree as single-vehicle crash occupant fatalities (other than from rollovers), the effect would have been roughly 2,000 fewer fatalities (less than 5 percent of the total in 1999).

Weight Reduction to Improve Vehicle Fuel Economy

Historical data and the physics of crashes indicate that some crash fatalities are fundamentally dependent on the weights of the vehicles involved while others are not. In two-vehicle crashes, occupants of the lighter vehicle are at a disadvantage, according to past statistics. This effect has been exacerbated by the introduction of large numbers of light trucks into the US vehicle fleet, not only because of the light trucks' greater average weight, but because their structure is stiffer and higher than that of passenger cars. Just as large cars posed more of a hazard to small cars until the former were downsized, so large SUVs pose a hazard to small SUVs and pickups, as well as to all passenger cars.

In the 2000 model year, large SUVs weighing an average 5,439 pounds comprised 5.5 percent of new passenger vehicles (cars, trucks, and vans), while small SUVs were nearly 1,800 pounds lighter, at 3,670 pounds, making up 2.3 percent of the new passenger vehicle fleet. Just as large cars lost nearly 1,400 pounds in weight, from 5,142 pounds to 3,792 between 1975 and 2000, large SUVs could lose a similar amount of weight with a net resultant gain in fleet safety and fuel economy.

Many of the past statistical relationships between weight and crash safety are changing as the science of safety advances. Technologies for high-strength, lightweight materials have been under development by the aluminum and steel industries, both through the Partnership for the Next Generation of Vehicles and through autonomous development programs. The UltraLight Steel Auto Body and Light Truck Structure studies, along with findings from the Auto Aluminum Alliance, have indicated the ability to achieve significant reductions in car and light-truck weight without sacrificing safety (AISI 2001, ULSAB 2001, ULSAB-AVC 2001, Auto Aluminum Alliance 2001). Because these materials maintain strength while reducing weight, past historical data no longer apply, and the potential exists for vehicle weight reductions with improved crash characteristics.

Mass reductions of up to 40 percent have been demonstrated in production and prototype vehicles that rely on aluminum and other lightweight materials for much of the powertrain, vehicle structure, and body. While these lighter vehicles do carry additional costs, they are designed to maintain safety, strength, and durability (Ford 2001). In the late 1990s, both Ford and Chrysler built prototype cars of the size and carrying capacity of the Ford Taurus and Dodge Intrepid that weighed only about 2,000 pounds. These vehicles used aluminum and plastics extensively. Chrysler officials said that their 2,000-pound vehicle could eventually be built at a price equivalent to that of its current Dodge Intrepid because it used less material and because Chrysler had developed techniques that substantially simplified the assembly process for this lighter-weight vehicle.

Lighter Versus Less-Expensive Vehicles

For single-vehicle crashes, some estimates of the effect of weight have compared the performance of smaller, less-expensive cars with that of larger, more-expensive cars. This procedure overestimates the effect of weight reduction, because lighter vehicles are typically less expensive and feature less-sophisticated safety engineering. For example, smaller cars have higher rollover rates, but this is primarily because they have narrower track widths (and therefore lower static stability indices) and shorter wheelbases, not because they are lighter. If a larger vehicle is made lighter through substitution of lighter-weight material, rather than by making the vehicle shorter and narrower, such a large vehicle is not likely to have any greater propensity to roll over than it did with the heavier material.

The same reasoning holds true for single-vehicle nonrollover crashes. The structural performance of a lighter vehicle that retains its basic size and energy-management capability should be as good as that of the heavier vehicle it might replace. These principles were demonstrated more than 20 years ago with the National Highway Traffic Safety Administration's Research Safety Vehicle Program.

In two-vehicle crashes, reducing the weight of the heavier vehicle would reduce casualties in the lighter vehicle without necessarily increasing casualties in the heavier vehicle. Furthermore, in the case of SUVs, the trend is toward using passenger-car platforms for these vehicles. The Ford Escape and Acura MDX are two recent examples that join such vehicles as the Mercedes-Benz M Class, Lexus RX300, Honda CR-V, Toyota RAV4, and Subaru Forester.

Building an SUV on a passenger-car platform has two positive effects. First, it can reduce the weight of the vehicle for a given interior space and carrying capacity. It can also reduce the SUV's aggressivity, the danger the vehicle poses to others on the road. Since changing from a light-truck to a passenger-car platform for an SUV can be a technique for improving fuel economy, this change would increase safety for all vehicle occupants as it increases fuel economy.

Reducing light-vehicle weight is unlikely to have much effect on losses in crashes with large trucks, with cyclists, or with pedestrians, because the discrepancy between the weights of these vehicles and individuals is so great. Table 19 summarizes these conclusions.

Assuming that light trucks and vans remain a major part of the private passenger vehicle fleet, efforts to improve automotive fuel economy through weight reduction can most productively be applied first to these vehicles. This is particularly true for light trucks that are used as substitutes for passenger cars, as opposed to those used as commercial or farm vehicles. The opportunity to improve the fuel economy of light trucks is greater simply because of this class of vehicle's size, weight, and poor fuel economy. Because weight reduction has a more significant impact for light trucks than for cars, this report incorporates larger weight reductions for light trucks. The light truck weight reductions are also phased in earlier, to capitalize on the benefits as early as possible.

Previous Studies of Safety/Fuel Economy Trade-Offs

Many studies of the trade-off between safety and fuel economy assume that manufacturers will reduce the weight of their vehicles

Table 19. Motor Vehicle Crash Fatalities and Changes in the Average Weights of Particular Vehicle Classes

Crash Losses Not Significantly Affected by Vehicle Weight

Large Truck Crashes – 4,000 light-vehicle occupant fatalities
Large Truck Crashes – 730 large-truck occupant fatalities
Pedestrians and Pedalcyclists – 6,000 nonoccupant fatalities
Motorcyclists – 2,300 motorcycle-rider fatalities

Crash Losses in Light Vehicles Not Significantly Affected by Vehicle Weight

Rollovers – 9,000 fatalities
Other single-vehicle crashes – 9,200 fatalities
Passenger car/Passenger car – 3,200 fatalities
Light truck/Light truck – 1,200 fatalities

Crash Losses That May Increase or Decrease with Vehicle Weight

Passenger car/Light truck – 3,500 passenger-car occupant fatalities
Passenger car/Light truck – 860 light-truck and van occupant fatalities

Note: These figures are approximate averages derived from recent Fatal Accident Reporting System files.

to increase fuel economy. They also assume that manufacturers will not take advantage of offsetting technologies for increasing safety when vehicles are made lighter. The fact is that the variables that must be addressed in such a study are too many and too unpredictable to lend themselves to any kind of precise analysis.

In particular, many studies assume that the safety of a downsized full-sized car will be equivalent to the safety of a midsized car of the previous generation, for example. This is not necessarily the case, however, both because the configurations of the two vehicles will be different and because the more expensive full-sized car will probably have fewer design and material compromises than its midsized counterpart.

To improve safety in such crashes, more safety regulations are necessary. One example is the dynamic side-impact standard, FMVSS 214. This standard requires improved occupant safety under test conditions where a 3,000-pound, angled moving barrier impacts a vehicle at 33.5 mph. Under such standards, today's more fuel-efficient cars that tend to weigh less are required to include more safety technology and improvements because of the relatively higher change in velocity they experience in a crash compared with that of larger, luxury cars. In addition, increased consumer information is critical to ensuring that people can make reasonable choices. The National Highway Traffic Safety Administration's New Car Assessment Program (NCAP) should be expanded in scope and the information more widely publicized.

Safety Improvements That Remain to Be Widely Implemented

Under the assumption that safety is a societal priority, motor vehicle manufacturers must address vehicle safety measures independently of fuel economy requirements. Until they do, arguments about the nexus between safety and fuel economy have a hollow ring. A number of simple, inexpensive safety designs and technologies remain to be broadly implemented. These include:

- Effective safety-belt use inducements. Currently, 18,000 people who were not wearing safety belts die each year: 6,000 to 10,000 could be saved by effective belt-use inducements.

- Stronger roofs for rollover protection. Although a majority of casualties of rollovers are still unbelted and ejected, 2,000 belted occupants die annually, mostly because of roof crush. With increased belt use, the number of casualties from roof collapse and buckling is likely to increase as fewer people are ejected in rollovers. This further emphasizes the need to ensure that vehicles have safe roof designs.

- Improved safety belt design and performance, including belt pre-tensioners that trigger on rollover as well as on frontal and side crashes. An additional 3,000 to 5,000 people could be saved by an effective rollover protection system: a strong roof, belt pre-tensioners that trigger on rollover, the interior padding required by a new federal standard, and window curtain air bags.[40]

- Crash avoidance technologies such as smart cruise controls, yaw-control systems, nonpulsing anti-lock brakes, and

[40] Racing car drivers regularly survive very dramatic rollover crashes because they are protected by roll cages, five-point safety belts, and helmets. These features can be effectively emulated in ordinary passenger vehicles with a strong roof, well-designed safety belts that include pre-tensioners that trigger upon rollover, and the padding currently required by FMVSS 201 in head-impact areas. The cost of such improvements should be less than $100 for most new vehicles.

drowsy-driver warnings. New computer and communications technologies should provide major opportunities to reduce the possibility of crashes.

Overall, automakers have many opportunities to pursue an aggressive path of vehicle crash safety improvements. In addition, they can choose a strategy of careful application of vehicle weight reduction, along with the application of safety technology, to ensure that consumers have the option to drive vehicles that are both safe and fuel-efficient.

CHAPTER 8

FORGING A FUEL-EFFICIENT FUTURE

The results of the four scenario analyses indicate that our nation can turn back its thirst for oil in the car and light-truck markets to 2000 levels within a 15-year time frame. Achieving this goal is possible with a combination of technologies on the road today and others that are already in the prototype phase. Within the next 10 years, conventional technologies can allow cars to reach 40 mpg. By 2020, we can reach 55 mpg by relying on hybrid electric technologies entering the market today, supplemented by a growing fuel cell vehicle market. Throughout this time, the technologies applied will be as clean as they are efficient, requiring no trade-off between air quality and fuel economy.

It is unlikely that automakers' voluntary efforts will lead us down this necessary road. Instead, we must rely on a foundation of stronger Corporate Average Fuel Economy standards requiring automakers to provide consumers with a choice to save money at the pump while at the same time reducing their impact on our environment. The government can assist car manufacturers in meeting the new fuel economy standards through a combination of appropriate research and development funding, along with the provision of tax credits to encourage the early sales of hybrid electric and fuel cell vehicles.

The vehicles that will ultimately reach future fuel economy standards will not be too different from those we drive today. We will not be required to sacrifice performance and comfort, but instead will be able to purchase higher fuel economy versions of the same safe and reliable vehicles to which we have grown accustomed.

The icing on the cake from this path to improved fuel economy is that consumers will find that they are saving money each time they visit the gasoline pump and might even be able to skip a few fill-ups each month. The savings that consumers experience and the manufacture of higher fuel economy cars and light trucks will also lead to increased employment in the motor vehicle industry and throughout the US economy as a whole. At the same time, our nation will achieve both near-term and long-term reductions in our greenhouse-gas, toxics, and smog-precursor emissions. Along the way, we will also find that drilling for oil in environmentally sensitive areas becomes a notion of the past as we use our existing resources more efficiently. Following this path to higher fuel economy will lead us to turn back the clock on our car and truck oil use while significantly reducing the environmental footprint we leave behind—and all the while leaving more money in consumers' pockets.

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APPENDIX A

Emissions Calculations

Emissions associated with gasoline production and delivery, so-called upstream emissions, are based on the latest available version of a model developed by Argonne National Laboratory, GREET 1.5a (Wang 1999). The model uses average national emission rates and efficiencies to estimate emissions of key pollutants throughout the fuel cycle for various types of gasoline and alternative fuels. This report assumes that federal reformulated gasoline is used nationally, since environmental rules are forcing more conventional gasoline blends out of the market. In actuality, there is broad variation in the types of fuels used in the United States, but the emissions differences associated with their production are relatively small.

GREET accounts for several greenhouse gases—including methane, nitrous oxide, and carbon dioxide—expressing the results as CO_2-equivalent emissions based on their relative radiative forcing. The model also accounts for key criteria emissions associated with air pollution, including the volatile organic compounds and nitrogen oxides (smog precursors), carbon monoxide, sulfur oxides, and particulate matter.

In a separate analytical effort, Argonne National Laboratory developed preliminary estimates of toxic pollutant emissions associated with gasoline production (Winebrake et al. 2000). The study covers four major toxics associated with motor vehicles: benzene, formaldehyde, acetaldehyde, and butadiene. All toxics are expressed as benzene-equivalent emissions based on their relative cancer unit risk factors (EPA 2000; EPA 1993). The relative risks are: formaldehyde, 1.6; acetaldehyde, 0.3; and butadiene, 34.

Winebrake et al. 2000 do not estimate emissions of all potential air toxics. In particular, there is growing public health evidence linking emissions of diesel particulate matter (PM) to cancer. Moreover, diesel PM appears to be a more potent and prevalent toxic than the other four toxics traditionally associated with motor vehicle use. In the Los Angeles region, for example, diesel PM accounts for an estimated 71 percent of the cancer risk from outdoor air (SCAQMD 1999).

To include emissions of diesel PM, we ran GREET 1.5a to isolate diesel-powered equipment. We then assigned the cancer unit risk factor for diesel particulate matter from its recent listing as a toxic air contaminant (CARB 1998). The cancer unit risk factor for diesel PM is 36 times higher than that for benzene.

Based on the aforementioned calculations and modeling, we developed average per-gallon emissions associated with upstream activities (table A-1).

Table A-1. Emission Rates

(grams per gallon of fuel delivered)[a]

Greenhouse Gases[b]	
Upstream GHG	2,365
Tailpipe CO_2	8,500
Total (CO_2-equivalent)	10,865
Upstream Criteria	
VOC	1.93
CO	3.40
NO_x	4.43
PM10	0.39
SO_x	2.38
VOC+NO_x	6.36
Upstream Toxic	
Formaldehyde	0.023
Acetaldehyde	0.005
Butadiene	0.002
Benzene	0.029
Diesel PM	0.078
Total (Benzene-equivalent)[c]	2.942

a. UCS estimate based on full fuel cycle model, GREET 1.5a, for federal reformulated gasoline (Wang 1999; Winebrake et al. 2000).
b. All greenhouse gases are expressed as CO_2-equivalent emissions based on their relative radiative forcing.
c. All toxics are expressed as benzene-equivalent emissions based on their relative cancer unit risk factors (EPA 2000; EPA 1993; CARB 1998).

APPENDIX B

Technology Options for Improving Fuel Economy

The Evolution of Conventional Technology

Although automobiles have seen over one hundred years of development, more can still be done to improve their efficiency. These changes in technology represent an evolutionary path and include many technologies that are either on the road today in smaller volumes or can reasonably be expected to enter the market within the next decade. These technology options can be split into three categories: load reduction, engine improvements, and transmission improvements.

Vehicle Load Reduction

When a car or truck drives down the road, its engine has to provide enough power to overcome three obstacles that try to keep it from moving (not counting potholes). First, the vehicle has to provide enough power just to get its 1.5 to 2.5 tons of metal, plastic, and glass rolling; the faster it tries to accelerate, the more power it has to provide. Then, the instant the vehicle starts rolling, the tires grab onto the road and produce friction that requires additional energy to overcome. Further, as the vehicle gains speed, it has to push more and more air out of the way, which causes an aerodynamic drag effect. To make matters worse, additional power is drawn from the engine for accessories such as air conditioning, power steering, lights, air circulation, and any electronic equipment plugged into the car outlet.

Mass Reduction

The mass of today's cars and trucks can be reduced by increasing the use of plastics and aluminum, as well as through the application of high-strength steel. The steel industry has investigated lightweight car and truck designs through its UltraLight Steel Auto Body and Light Truck Structure studies (AISI 2001, ULSAB 2001, ULSAB-AVC 2001). These reports showed that the mass of cars and trucks could be reduced by about 5 to 8 percent at no cost or with cost reduction. In addition, the crash-worthiness of these vehicles was evaluated through computer simulations and was shown to be equal or superior to current standards.

Mass reductions of up to 40 percent have been demonstrated in production and prototype vehicles that rely on aluminum and other lightweight materials for much of the powertrain, vehicle structure, and body. While these lighter vehicles do carry additional costs, they are designed to maintain safety, strength, and durability (Ford 2001).

Aerodynamics

Today's cars look a lot different from those of 10 or 20 years ago. Their bodies are defined by more curves, windshields are more slanted, and the front grilles are almost invisible. These new shapes are a combination of style and functionality, since the drag that a vehicle feels from the wind is a function of both its frontal area and a shape factor called the coefficient of drag (C_D).

The C_D of today's cars is around 0.30 to 0.35, while that of light trucks is around 0.40 to 0.45 (DeCicco et al. 2001). The difference between the two should not be too surprising when one compares the tall, wide, and flat front of a truck with the front of today's cars. In both cases, however, improvements can be made to reduce the aerodynamic drag. Various studies have estimated that the drag coefficient of cars can be reduced by 10 to 25 percent, while the C_D of light trucks could drop by about 10 percent (DeCicco and Ross 1993; EEA 1991; NRC 1992). In addition, real-world examples of low-drag vehicles include the GM electric vehicle EV1, with a C_D of 0.19; the Honda hybrid electric vehicle, with a C_D of 0.25; and the Opel Calibra, a GM vehicle made in Germany, which achieves a C_D of 0.26 (GM 2001, InsightCentral 2001, DeCicco et al. 2001).

Tires

The stickiness of a tire on the road is measured by its coefficient of rolling resistance (C_{rr}). The value of the C_{rr} indicates the pounds of resistance created by the tires based on the vehicle mass. A typical estimate of today's rolling resistance is 0.009, indicating that 0.9 pounds of resistance are created for every 100 pounds of vehicle mass. Rolling resistance can be reduced both by making the vehicle lighter and by using better tires.

To improve the efficiency characteristics of the tires requires the use of improved rubber, increased inflation pressures, and changes in tread design. Estimates show that such changes can reduce the C_{rr} by 15 to 30 percent without compromising vehicle handling and safety (DeCicco et al. 2001).

Efficient Engines

At the heart of most cars and trucks is an internal combustion engine that burns gasoline to produce the power required to overcome the vehicle loads and make the vehicle move. The problem with these engines is that the vast majority of the energy in the gasoline is turned into wasted heat—only 20 to 25 percent of the energy can be used to move the vehicle down the road under typical driving conditions. As with vehicle loads, however, technologies exist to improve the efficiency of the internal combustion engine.

Improved Conventional Engines

Internal combustion engines have seen continuous evolution over the 125 years since the technology was first developed. The basic workings of the spark-ignition engine, however, have not radically changed. What has changed is the myriad detailed components and designs that can have significant impacts on engine efficiency. Some of the most recent advances are combined in the Honda VTEC engine. The key characteristics of the engine are the use of variable valve control (VVC), four valves per cylinder, aluminum as a major engine component, reduced friction, and improved intake and exhaust designs. Some versions of the VTEC engine also use a reduced idle speed to minimize the amount of fuel that is wasted when the vehicle is sitting in traffic.

According to one measure of an engine's efficiency, the VTEC-E engines used by Honda are over 15 percent more efficient than the average car engine and over 25 percent more efficient than the average engine in all passenger vehicles.[1] Just as impressive as the engine efficiency is the fact that the VTEC line of engines is used in over 60 percent of the cars and trucks Honda sells in the United States (DeCicco and Kleisch 2001).

[1] Specific power measures how effective an engine is at producing power given its size; this measurement can be used as a proxy for engine efficiency. The Honda VTEC-E achieves a specific power of 54 kW/liter (Honda 2001) compared with the average car and light-truck specific power of 43 kW/liter (DeCicco et al. 2001) and the average car specific power of 46.9 kW/liter (EPA 2000).

Direct-Injection Gasoline Engines

The car of the 1970s used a carburetor to mix air and fuel together before it went into the cylinder to be burned. This method of mixing was not very efficient and made it difficult to control the amount of fuel that was introduced. Over the past 30 years, fuel injection has been introduced and is now the standard. Fuel injection sprays fuel into the air just before the air enters the cylinder and allows for more-precise metering of the fuel as well as the production of smaller drops that mix more easily with the air. The fuel spray is constrained by the amount of time the valve is open, however, and by the timing of the opening, making the control better than with the carburetor but not ideal.

The next evolution of the internal combustion engine is the use of direct-injection technology. Direct injection sprays fuel directly into the cylinder at high pressure. This allows for more fine-tuned control of the amount of fuel injected and injection timing that is independent from the valve timing. These engines can still use variable valve control and four valves per cylinder as the VTEC engines do, but will achieve even higher efficiencies. Overall, these engines show both higher efficiency and a broader range of operating conditions under which their efficiency maintains reasonable levels.

Some versions of gasoline direct-injection engines operate in a "lean" mode where excess air is provided. This helps improve the efficiency of the engine even further, but makes it very difficult for today's emissions-control systems to reduce the amount of nitrogen oxides—a key pollutant in the formation of smog—emitted by the vehicle. Until "lean-NO_x" emissions-control systems can be adequately developed, these GDI engines will have to avoid lean operation to ensure that public health is protected and that current and future emissions standards are met.

Integrated Starter-Generators

When you ask people how fuel efficient their cars are, they will likely tell you how many miles they can travel per gallon of fuel they use. This is a great measure for the average efficiency of a car. But when you are sitting in traffic or sitting at a stoplight, your engine is running but you are going nowhere; your miles-per-gallon rating at that time is zero. Depending on driving conditions, 5 to 15 percent of the fuel Americans put in their tanks is used up during these idling conditions.

The problem for today's vehicles is that it is not convenient to simply turn off your car when you are stuck in traffic or sitting at a light. Within the next few years, however, many of the major automobile manufacturers are expected to introduce cars that will shut off instead of idling and will then automatically start up and move as soon as the gas pedal is pressed. This feature requires the use of a small motor/generator that will be attached directly to the engine. The "integrated starter-generator" will replace both the current starter motor and the alternator and will even enable some of the energy in the battery to be tapped by adding a small burst of power when the car first starts moving.

Integrated starter-generator (ISG) systems will be operated at 42 volts instead of using the 12-volt systems of today's cars. The added power will allow automakers to shift accessories such as power steering and air conditioning to run off the electricity supplied by the ISG instead of being driven by belts connected to the engine—belts that waste energy via friction. The 42-volt ISG systems will also increase the efficiency of any other system or accessory that typically runs at 12 volts.

Improved Transmissions

The function of the transmission is to take the power that the engine generates and move it to the axle to drive the wheels and move the car down the road. The simplest and most efficient way to accomplish this would be to use a single gear between the engine and the axle. This system is not possible with the engines in today's cars, however. The current internal combustion engines can operate only within a limited speed, and at very low speed the engine can produce very little torque. Further, there is an even smaller operating region outside of which the efficiency of the engine is relatively poor. To account for this limitation, transmissions use several gears to allow the vehicle both to accelerate quickly and to travel at high speeds, while also attempting to keep the engine operating within a relatively efficient window.

The vast majority of the transmissions in vehicles today are "automatic" transmissions, which take the burden of shifting between gears off the driver. Accomplishing this requires complex and inefficient hydraulic systems. Typical automatic transmissions are about 80 percent efficient; when combined with the average efficiency of a gasoline internal combustion engine, only 15 percent to 20 percent of the energy ever reaches the wheels.

Five- and Six-Speed Automatic Transmissions

The typical way transmissions have been used to improve the efficiency of the vehicle is by adding more gears. Since 1980, nearly all of the automatic transmissions in cars and trucks have been converted from three speeds to four. The additional gear means that the engine can spend more time operating in the speed and torque ranges where it is the most efficient.

The late 1990s saw the initial introduction of five-speed automatic transmissions. Again, this added speed increases the opportunities for the engine to run near its "sweet spot" and achieve a higher overall average efficiency. Only about 7 percent of today's cars and light trucks use five-speed automatic transmissions, so there is a great potential for this technology to spread. The next step would be to introduce six-speed versions.

Continuously Variable Transmissions

Going further than five or six speeds in a conventional automatic transmission introduces added weight and complexity and is likely not worth the effort. There is significant benefit, however, to going "all the way" and having an infinite number of gears. This may seem impossible, but a technology called the continuously variable transmission (CVT) allows for an infinite number of variations in gear between minimum and maximum levels. With this infinite variation, the engine speed and torque can be chosen to maximize the engine efficiency over a much wider range of operation than with conventional multispeed transmissions.

Several manufacturers are currently offering CVT versions of their cars, and several more are expected to do so in the near future. The Honda Civic HX has been available with a CVT for the last several years. Audi has offered a CVT version of its A6 since 1999 and even boasts that its CVT version has superior performance to both the automatic and manual transmission models (Audi A6 2000).

The main weakness of the CVT in the past was its inability to work in anything but very small cars. This limitation has been overcome for cars, but the CVT does still have torque limitations that make it unclear how widespread its use can be with light trucks.

"Automatic" Manual Transmissions

The advantage of a manual transmission over an automatic is that the use of inefficient hydraulic controls is not required when the driver does the shifting. The simplicity of manual transmissions translates into operating efficiencies in the mid-90 percent range, compared with the low 80 percent range for the automatics. The disadvantage of the manual transmission is that the driver is required to put forth more effort and attention, especially in increasingly congested driving conditions. Over the past 10 to 15 years, the inconvenience of the manual transmission has cause its use to drop in half, from about 25 percent to just over 12 percent of car and light-truck transmissions.

An alternative to the standard manual transmission is an automated manual transmission that uses small electric motors to shift gears at the command of a computer control system. The intention of this system is to combine the convenience of the automatic transmission with the efficiency of the manual. Various versions of this technology have made small penetrations into the market, primarily in sports cars. The main concern is whether these systems can mimic the relatively smooth shifting of an automatic and still maintain their performance. With continued development, these transmissions may be an excellent alternative to five- and six-speed automatic transmissions for light trucks.

Advanced Vehicle Technology Options

Advanced vehicle technologies represent a step in technology rather than the evolution of conventional technologies. These technologies are in the later stages of development or are just emerging from the final prototype stages. It is likely that these vehicle options will be cost effective within the next 10 years or so. The two most promising options are hybrid electric and fuel cell vehicles.

Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) combine the electric motor and energy-storage system of an electric vehicle with the engine of a conventional internal combustion engine vehicle. The hybrid then has the ability to incorporate many of the advantages of electric vehicles as well as the conveniences of an internal combustion engine vehicle.

Regenerative Braking

Around one-third of the energy used to drive a vehicle down the road is eventually wasted when the brakes are applied to stop the car or slow it down. With a hybrid electric vehicle, operating the electric motor in reverse can capture the previously wasted energy. This process, called regenerative braking, turns the motor into a generator, which recharges the battery. While not all of the braking energy can be captured in this manner, enough can be recovered to reduce the amount of energy required to drive by 10 to 20 percent. The amount of improvement depends on the size of the motor and energy storage, as well as on the level of sophistication in the electronics used to control the process.

Efficient Engine Operation

The operating efficiency of the engine in a hybrid electric vehicle can be improved in two ways. First, since some of the driving power comes from the motor, the engine can be smaller than an internal combustion engine. The smaller the engine, the more time it will spend operating under more-efficient conditions, such as moderate speed and moderate to higher torque. This is one of the reasons vehicles with less acceleration tend to be more fuel efficient. With hybrid vehicles, however, you can have your cake and eat it too: the smaller engine results in more fuel efficiency, but the electric motor enables the vehicle performance to be the same as or better than that of a conventional vehicle with a larger engine.

The second way hybridization improves engine operating efficiency is by avoiding use of the engine when it would be most inefficient. Driving around at low speeds in the city and driving in heavy stop-and-go conditions force an engine to operate at low speed and low torque, where engine efficiency can be in the low- to midteens. Hybrid electric vehicles can do some or all of this lower-speed driving solely under the power of the electric motor (all-electric mode), turning the engine on only when a computer control system determines that it is needed for performance or when it will be more efficient.

An added benefit to operating in all-electric mode is that engine idling can be eliminated. The advantages here are similar to those of using an integrated starter-generator, with the potential to reduce fuel consumption by 5 to 15 percent, depending on driving conditions.

Hybrids on the Road

In the last two years, Honda and Toyota have brought HEVs to the market in the United States. The Toyota Prius is a five-seat compact car that is rated at 52 mpg in the city and 45 mpg on the highway. Toyota is expected to sell about 12,000 Prius HEVs in 2001, and there is currently a four- to six-month waiting list for the car (Fitzgerald 2001). The Honda Insight is a two-seat commuter car rated at 61 mpg in the city and 68 mpg on the highway. Honda originally set a target of 4,000 Insights to be sold in the first year, but significant demand caused the company to increase that number to 6,500 (Fitzgerald 2001). The Insight takes advantage of lightweight materials and improved aerodynamics, along with the hybridization, to reach its impressive fuel economy rating, while the Prius relies on a greater degree of hybridization and the use of an advanced gasoline engine. Both Honda and Toyota are also expected to expand their line of hybrid vehicles in the years to come.

Within the next few years, nearly every major manufacturer is expected to offer a hybrid. Ford plans to produce a hybrid version of its Escape SUV that could achieve up to 40 mpg in the city. GM has introduced the ParadiGM, a concept hybrid vehicle, and expects to produce a hybrid version of a full-sized pickup beginning in 2004. DaimlerChrysler has announced that it will offer a hybrid Dodge Durango with a modest 20 percent increase in fuel economy in 2003.

Fuel Cell Vehicles

Of the various automotive technologies currently under development, the fuel cell vehicle has the greatest promise for increasing fuel economy, reducing harmful emissions, and minimizing or eliminating the oil used for passenger transportation. The fuel cells under consideration for automotive applications combine hydrogen and oxygen to produce electricity, which then runs an electric motor. This fuel-cell/motor combination completely replaces the internal combustion engine and can be combined with a small battery pack or power storage device, adding the ability to recover braking energy. Current expectations are that a family-sized fuel cell vehicle could have a fuel economy of 80 mpg, triple that of a conventional vehicle.

The cleanest version of a fuel cell vehicle stores hydrogen on board the vehicle and produces water as the only exhaust from the tailpipe. The cleanest method of producing hydrogen is the use of electricity generated from solar power to split water into hydrogen and oxygen, ultimately producing an energy cycle often referred to as the hydrogen energy economy. In the nearer term, hydrogen may be produced from natural gas or methanol. The use of these other feedstocks to produce hydrogen does create some emissions, but the overall amounts will be significantly smaller than those from conventional internal combustion engines.

Fuel Cells on the Road

As with hybrid vehicles, every major automobile manufacturer is putting significant resources into the development of fuel cell vehicles. Several prototype vehicles have already been placed on the road, including the Necar 4 from DaimlerChrysler, the P2000 Fuel Cell Vehicle from Ford, the Opel Zafira from GM, and the FCX3 from Honda. Given current technology developments and the zero-emission-vehicle requirements in California and the Northeast states, it seems likely that most or all of these companies will have early production model fuel cell vehicles fueled by hydrogen on the road by 2010.

In California, a unique partnership has been developed to demonstrate fuel cell vehicles under real-world conditions. The group expects to have up to 70 fuel cell cars and buses on the road by 2003. The California Fuel Cell Partnership includes the eight automobile manufacturers responsible for over 90 percent of the car and light-truck sales in the United States, three of the world's largest oil companies, the top two North American fuel cell developers, and many government and associate partners (CFCP 2001). All parties hope that this partnership and other efforts by the automobile manufacturers will lead to significant market penetration for clean and efficient fuel cell vehicles within the next decade or two.

APPENDIX C

Technology Package Results

While the conventional evolution-stage II and hybrid electric-stage II technologies represent key transition points in our analysis, conventional evolution-stage I and hybrid electric-stage I technologies represent less-aggressive applications of similar technologies. Below is a detailed summary of the key packages for the various technology options. All packages are based on those used in DeCicco et al. 2001.

Conventional Evolution, Stage I

Table C-1 summarizes the technologies used in the stage I evolutionary technology conventional vehicles. The fuel economy potential and savings when these technologies are applied are shown in table C-2. If all new cars and light trucks achieved this same fuel economy, the average fuel economy of the new-car fleet would be about 36 mpg. This represents more than a 50 percent increase in fuel economy over today's values and a 34 percent reduction in gasoline use. Each consumer also would save between $1,100 and over $2,500 during the lifetime of the vehicle. In addition, each of these stage I conventional vehicles would produce significant environmental savings.

Table C-1. Stage I Evolutionary Technologies for Fuel Economy Improvement

Vehicle Load Reduction • 10% reduction in aerodynamic drag • 20% reduction in rolling resistance • 0% mass reduction for small cars, 10% for midsize and large cars, and 20% for light trucks
Variable valve control, 4-valve-per-cylinder VTEC-type engine with individual cylinder control
Integrated starter-generator with idle off and torque smoothing
Continuously variable transmission for cars and 5-speed automatic transmission for light trucks

Table C-2. Fuel Economy and Lifetime Savings from Stage I Evolutionary Conventional Vehicles

	CAFE Rated Fuel Economy[a] (mpg)	Real-World Fuel Economy[b] (mpg)	Fuel Economy Improvement vs. Baseline	Gasoline Saved[c] (gal.)	Cost of Fuel Economy Improvement[a]
Cavalier	43.7	35.0	42%	2,037	$ 944
Taurus	40.8	32.6	56%	2,902	$1,036
Silverado	28.7	23.0	37%	2,715	$1,515
Grand Caravan	34.5	27.6	55%	3,370	$1,500
Explorer	34.6	27.7	70%	3,938	$1,440
Fleet Average	36.4	29.1	52%	3,016	$1,243

a. Source: DeCicco et al. 2001
b. CAFE fuel economy reduced by 20%.
c. Assumes a 15-year, 170,000-mile vehicle lifetime. Average life based on scrappage rates from Davis 2000. Vehicle mileage based on 1995 NPTS data.

Table C-2. (continued)

	Lifetime Fuel Cost Savings[d]	Net Savings (Equivalent Rebate)	Greenhouse-Gas Savings (tons)	Avoided Toxic Emissions (lb.)	Smog-Precursor Savings (lb.)
Cavalier	$2,107	$1,163	24	13	29
Taurus	$3,002	$1,966	35	19	41
Silverado	$2,808	$1,293	33	18	38
Grand Caravan	$3,485	$1,985	40	22	47
Explorer	$4,073	$2,633	47	26	55
Fleet Average	$3,120	$1,877	36	20	42

d. Based on an average gasoline cost of $1.40 per gallon (AEO 2001).

Conventional Evolution, Stage II

For completeness, we include the stage II evolutionary conventional technologies discussed in chapter 3. The technologies used are summarized in table C-3, and the results are in table C-4.

Table C-3. Stage II Evolutionary Technologies for Fuel Economy Improvement

Vehicle Load Reduction • 10% reduction in aerodynamic drag • 20% reduction in rolling resistance • 10% mass reduction for small cars, 20% for midsize and large cars, and 33% for light trucks
Stoichiometric burn gasoline direct-injection engine with variable valve control, 4-valve-per-cylinder VTEC-type engine with individual cylinder control
Integrated starter-generator with idle off and torque smoothing
Continuously variable transmission for cars and 6-speed automatic transmission for light trucks

Hybrid Electric Vehicles, Stage I

One could develop a near-infinite combination of electric motor, battery, and engine sizes to produce different levels of hybridization. To provide examples, DeCicco et al. investigated HEV configurations similar to those of the two hybrid electric vehicles on the road today, the Toyota Prius and the Honda Insight. The stage II HEVs represent vehicles with 40 percent of their peak power coming from the electric motor, similar to the Prius. With the stage I hybrid electric vehicles, only 15 percent of their peak power is provided by an electric motor, similar to the Insight. This hybrid electric vehicle configuration is sometimes referred to as a "mild hybrid." Table C-5 summarizes the potential performance and savings for this level of hybridization. Other than the use of hybrid technology, the stage I hybrid configuration uses the same technologies shown in table C-1 for the stage I conventional evolution technologies.

Under the mild-hybrid scenario assumed for stage I HEV technology, the fleet could achieve a fuel economy of 48.6 mpg, or more than a doubling of fuel economy from today's values. Car fuel economy would reach 48.5 mpg, while light-truck fuel economy would be raised to 43.8 mpg. The lifetime savings for the mild HEVs, including the proposed advanced vehicle tax credits, are on the order of $2,300 to $3,600. These savings would be accompanied by an average reduction in greenhouse-gas emissions of 54 tons over the lifetime of a vehicle, along with significant reductions in the emissions of toxic and smog-forming pollutants.

Table C-4. Fuel Economy and Lifetime Savings from Stage II Evolutionary Conventional Vehicles

	CAFE Rated Fuel Economy[a] (mpg)	Real-World Fuel Economy[b] (mpg)	Fuel Economy Improvement vs. Baseline	Gasoline Saved[c] (gal.)	Cost of Fuel Economy Improvement[a]
Cavalier	48.4	38.7	57%	2,509	$1,125
Taurus	45.8	36.6	75%	3,471	$1,292
Silverado	33.8	27.0	61%	3,832	$2,292
Grand Caravan	41.3	33.0	85%	4,384	$2,134
Explorer	40.1	32.1	98%	5,169	$2,087
Fleet Average	41.8	33.4	74%	3,770	$1,693

a. Source: DeCicco et al. 2001
b. CAFE fuel economy reduced by 20%
c. Assumes a 15-year, 170,000-mile vehicle lifetime. Average life based on scrappage rates from Davis 2000. Vehicle mileage based on 1995 NPTS data.

Table C-4. (continued)

	Lifetime Fuel Cost Savings[d]	Net Savings (Equivalent Rebate)	Greenhouse-Gas Savings (tons)	Avoided Toxic Emissions (lb.)	Smog-Precursor Savings (lb.)
Cavalier	$2,595	$1,470	30	16	35
Taurus	$3,590	$2,298	42	23	49
Silverado	$3,964	$1,673	46	25	54
Grand Caravan	$4,534	$2,400	53	28	61
Explorer	$5,346	$3,259	62	34	72
Fleet Average	$3,900	$2,207	45	24	53

d. Based on an average gasoline cost of $1.40 per gallon (AEO 2001).

Table C-5. Fuel Economy and Lifetime Savings from Hybrid Electric Vehicles, Stage I

	CAFE Rated Fuel Economy[a] (mpg)	Real-World Fuel Economy[b] (mpg)	Fuel Economy Improvement vs. Baseline	Gasoline Saved[c] (gal.)	Cost of Fuel Economy Improvement[a]
Cavalier	56.3	45.1	83%	3,125	$3,118
Taurus	52.6	42.1	101%	4,071	$3,522
Silverado	39.2	31.3	86%	4,698	$4,547
Grand Caravan	48.4	38.7	117%	5,139	$4,169
Explorer	47.4	37.9	133%	5,689	$4,358
Fleet Average	48.6	38.9	103%	4,482	$3,879

a. Source: DeCicco et al. 2001
b. CAFE fuel economy reduced by 20%
c. Assumes a 15 year, 170,000 mile vehicle lifetime. Average life based on scrappage rates from Davis 2000. Vehicle mileage based on 1995 NPTS data.

Table C-5. (continued)

	Lifetime Fuel Cost Savings[d]	Potential CLEAR ACT Tax Credit	Potential Net Savings (Equivalent Rebate)	Greenhouse-Gas Savings (tons)	Avoided Toxic Emissions (lb.)	Smog-Precursor Savings (lb.)
Cavalier	$3,232	$2,500	$2,614	37	20	44
Taurus	$4,211	$2,000	$2,689	49	26	57
Silverado	$4,859	$2,000	$2,312	56	30	66
Grand Caravan	$5,315	$2,500	$3,646	62	33	72
Explorer	$5,885	$2,000	$3,527	68	37	80
Fleet Average	$4,636	$2,159	$2,916	54	29	63

d. Based on an average gasoline cost of $1.40 per gallon (AEO 2001).

Hybrid Electric Vehicles, Stage II

For completeness, we include the stage II hybrid electric vehicles discussed in chapter 3. The technologies used are the same as those summarized in table C-3 for the stage II evolutionary conventional technology vehicles, plus the addition of hybridization. The fuel economy and savings for these vehicles are shown in table C-6.

Table C-6. Fuel Economy and Lifetime Savings from Hybrid Electric Vehicles, Stage II

	CAFE Rated Fuel Economy[a] (mpg)	Real-World Fuel Economy[b] (mpg)	Fuel Economy Improvement vs. Baseline	Gasoline Saved[c] (gal.)	Cost of Fuel Economy Improvement[a]
Cavalier	63.5	50.8	106%	3,553	$4,331
Taurus	59.3	47.4	126%	4,527	$5,098
Silverado	44.2	35.4	110%	5,311	$6,526
Grand Caravan	54.6	43.7	145%	5,637	$5,818
Explorer	53.4	42.7	163%	6,489	$5,472
Fleet Average	54.8	43.8	128%	4,976	$5,291

a. Source: DeCicco et al. 2001
b. CAFE fuel economy reduced by 20%
c. Assumes a 15-year, 170,000-mile vehicle lifetime. Average life based on scrappage rates from Davis 2000. Vehicle mileage based on 1995 NPTS data.

Table C-6. (continued)

	Lifetime Fuel Cost Savings[d]	Potential CLEAR ACT Tax Credit	Potential Net Savings (Equivalent Rebate)	Greenhouse-Gas Savings (tons)	Avoided Toxic Emissions (lb.)	Smog-Precursor Savings (lb.)
Cavalier	$3,675	$3,500	$2,844	43	23	50
Taurus	$4,683	$3,500	$3,085	54	29	63
Silverado	$5,494	$3,000	$1,968	64	34	74
Grand Caravan	$5,831	$3,500	$3,513	68	37	79
Explorer	$6,711	$3,000	$4,239	78	42	91
Fleet Average	$5,147	$3,293	$3,149	60	32	70

d. Based on an average gasoline cost of $1.40 per gallon (AEO 2001).

APPENDIX D

Scenario Model Development

To evaluate the oil, gasoline, monetary, and emissions savings from the various scenarios, we developed and calibrated a stock model covering the period 2000 to 2020. This model uses the annual sales and fuel economy of new vehicles, along with other key input data, to predict annual fleet gasoline use. Table D-1 provides a listing of the key inputs required by the model, each of which is discussed below.

Our baseline model is calibrated against the Annual Energy Outlook 2001 report by the Energy Information Administration. (EIA 2000a). Annual fleet energy use is kept to within +/- 2.5 percent of the AEO results, using their new vehicle fuel economy values as inputs.

- **Annual new-car and light-truck sales.** Annual sales from 2000 to 2020 are based on EIA 2000a. Sales from previous years are based on Ward's 2000.

Table D-1. Key Input Data for the UCS Stock Model

Input Data	
Vehicle Data (1965–2020)	**Gasoline Data (2000–2020)**
• Annual new-car and light-truck sales • New-car and light-truck CAFE fuel economy • Vehicle-miles traveled as a function of vehicle age • Car and light-truck survival rates • Real-world vs. CAFE certified fuel economy • Cost of fuel economy improvements • Greenhouse-gas emission rates per gallon of gasoline used (tailpipe)	• Annual average gasoline cost • Greenhouse-gas emissions rate per gallon of gasoline supplied (upstream) • Toxic emissions rate per gallon of gasoline supplied (upstream) • Smog-precursor emissions rate per gallon of gasoline supplied (upstream)

- **New-car and light-truck CAFE fuel economy.** Fuel economy for 1965 to 2001 is based on Ward's 2000 and EPA 2000. Fuel economy for 2002 and beyond is determined separately for each scenario.

- **Vehicle-miles traveled as a function of vehicle age.** The 1995 National Personal Transportation Survey provides the most recent breakdown of vehicle mileage versus age. The data used in our model is based on a sample size of more than 30,000 vehicles ranging in model year from 1970 to 1996 *(www.cta.ornl.gov/npts/1995/doc/index.shtml).* We also assumed an annual growth rate of 1 percent per year for the combined fleet vehicle-miles traveled.

  Vehicle-miles traveled have also been increased in the cases where fuel economy is raised over the baseline values. This increase accounts for a potential rebound effect of -10 percent, which accounts for the tendency of people to drive more if the cost per mile of driving drops. Our assumed value implies that if the fuel economy goes up 100 percent, the cost of driving goes down 50 percent and people will drive 5 percent more than they would have otherwise.

- **Car and light-truck survival rates.** Survival rates are based on Davis 2000. The median life of a 1990 model-year car is reported to be 14 years, while the median life of a 1990 model-year light truck is reported to be 15.2 years. Trends in Davis 2000 suggest that these survival rates are increasing for cars and decreasing for light trucks. Combined data suggest an average lifetime of over 16 years for 1990 model cars and light trucks.

- **Real-world vs. CAFE certified fuel economy.** Values for the relative difference between real-world and CAFE fuel economy are taken from EIA 2000 for 1999 through 2020. These values vary between 17 percent and 19.6 percent. Changes in traffic congestion and vehicle-use patterns are not included in these values.

- **Cost of fuel economy improvements.** Costs for stage I and stage II conventional evolutionary technologies are based on DeCicco et al. 2001. Before 2015, stage I and stage II hybrid electric vehicle costs are also based on DeCicco et al. 2001. Beginning in 2015, HEV costs and fuel economy improvements are altered based on UCS estimates. A more detailed discussion on the development of cost curves for this model is included at the end of this appendix.

- **Annual average gasoline cost.** Average gasoline costs for the period 2000 to 2020 are based on EIA 2000 and have been converted to 2000 dollars. Given recent trends, these costs are likely low and can therefore be considered conservative. The values used are as follows:

Table D-2. Annual Average Gasoline Cost

Year	Average Cost per Gallon	Year	Average Cost per Gallon
2000	$1.54	2011	$1.39
2001	$1.45	2012	$1.39
2002	$1.39	2013	$1.39
2003	$1.36	2014	$1.39
2004	$1.37	2015	$1.38
2005	$1.37	2016	$1.38
2006	$1.39	2017	$1.38
2007	$1.42	2018	$1.38
2008	$1.40	2019	$1.37
2009	$1.39	2020	$1.38
2010	$1.41		

- **Emission Rates.** The emission rates used for greenhouse gases, toxic emissions, and smog precursors are based on GREET modeling as described in appendix A.

Table D-3 lists the major outputs of our model. All outputs are presented on an annual basis. Oil use is calculated from gasoline consumption, assuming gasoline is produced at an efficiency of 90 percent and accounting for the 10 percent difference in density between gasoline and oil. The two effects cancel each other out, and the result is a 1:1 ratio of gasoline gallons to oil gallons.

Table D-3. Key Output Data from the UCS Stock Model

Output Data

Annual Vehicle Data (2000–2020)	Annual Impacts (2000–2020)
• Total number of vehicles on the road • Total number of vehicle-miles traveled for the fleet • Fleet fuel economy, real world and CAFE certified • Total energy use from cars and light trucks (gallons of gasoline and MMBTU) • Total cost for fuel economy improvements	• Total dollars spent on fuel • Total passenger car and light-truck oil demand • Total greenhouse-gas emissions • Total toxic emissions • Total smog-precursor emissions

Table D-4. Report Terminology

This Study	DeCicco et al. 2001
Conventional Evolution, Stage I	Moderate
Conventional Evolution, Stage II	Advanced
Hybrid Electric, Stage I	Mild Hybrid
Hybrid Electric, Stage II	Full Hybrid

Development of Fuel Economy Cost Curves

The results from DeCicco et al. 2001 are provided for four levels of technology application. DeCicco et al. refer to the technologies as moderate, advanced, mild hybrid, and full hybrid. Table D-4 provides a quick reference to translate between DeCicco et al.'s terminology and ours.

A true cost curve would seek to characterize the retail cost of fuel economy improvement through a stepped application of technologies. As each technology is added, its fuel economy and associated cost could be mapped out, producing a supply curve for fuel economy improvements.[2] The data in DeCicco et al. 2001

[2] This approach represents a simplified cost curve. A detailed and rigorous study accounting for many steps in technological change would provide a more detailed cost curve.

Table D-5. Fuel Economy and Associated Costs from 2000 to 2014

	Conventional Evolution, Stage I	Conventional Evolution, Stage II	Hybrid Electric, Stage I	Hybrid Electric, Stage II
Passenger Car Fuel Economy	42.1	47.0	54.2	61.2
Passenger Car Incremental Cost	$995	$1,217	$3,611	$5,581
Light-Truck Fuel Economy	31.5	37.0	43.3	48.8
Light-Truck Incremental Cost	$1,478	$2,252	$4,574	$6,982

provide only a series of coarse steps with which to construct such a curve, but these data represent the best source given the scope of this work.

Rather than develop supply curves for each vehicle, we grouped DeCicco et al.'s results into two standard categories, passenger cars and light trucks. Fuel economies in each category were harmonically averaged based on 2000 sales data, and the cost for these fuel economy improvements were averaged on a sales-weighted basis. Table D-5 provides the aggregated results.

These fuel economy and cost levels then represent four points along a passenger car cost curve and four points along a light-truck cost curve. To interpolate between each point, we assume that each fuel economy level is achieved by a mix of sales between each surrounding point. The cost for each of these internal points is a sales-weighted average between the two, and the fuel economy is a harmonic sales-weighted average. For example, a sales mix of 50 percent conventional evolution-stage II light trucks combined with 50 percent hybrid electric-stage I light trucks achieves a sales-weighted harmonic average fuel economy of 40.3 mpg and a sales-weighted cost of $3,255. Fuel economies lower than the conventional evolution-stage I technologies are achieved through a blend of today's vehicles and the stage I vehicles.

In 2015 and beyond, we continue to use the cost estimates and fuel economy levels from DeCicco et al. for conventional technologies. For hybrid technologies, however, we assume a small increase in fuel economy due to control and system optimization. We also assume a drop in costs based on analysis done by Energy and Environmental Analysis (1998) on the potential future cost of hybrid electric vehicle components for the Toyota Prius. The resulting fuel economy and cost figures are presented in table D-6.

Fuel Cell Vehicle Characteristics

Fuel cell vehicle costs and fuel economies are not included in the cost curves, since each scenario assumes a specific penetration of fuel cell vehicles. The fuel economy and incremental costs were estimated based on a recent study by MIT and another performed by Lipman et al. (Weiss et al. 2000, Lipman et al. 2000). The fuel economy of passenger cars was set to 80 mpg.[3] The fuel economy of the light truck was set to 80 percent of the passenger fuel economy based on the average difference seen between the car and light-truck fuel economies in tables D-4, D-5, and D-6. The incremental cost of the fuel cell passenger car was set to $7,500 in 2010

Table D-6. Fuel Economy and Associated Costs from 2015 to 2020

	Hybrid Electric, Stage I	Hybrid Electric, Stage II
Passenger Car Fuel Economy	55	62.6
Passenger Car Incremental Cost	$3,082	$4,357
Light-Truck Fuel Economy	44.4	50.8
Light-Truck Incremental Cost	$4,018	$5,540

and $5,000 in 2020.[4] The incremental cost of the fuel cell light truck was set to 1.5 times that of the car. In all cases, the market penetration of the fuel cell vehicles was small enough that the specific fuel economy and cost values chosen do not have a significant impact on the overall findings.

[3] Lipman et al. and Weiss et al. both studied a family-sized car, and thus their fuel economy levels should be lower than those expected from the passenger car fleet as a whole. Weiss et al. assumed a fuel economy of 94 mpg, and Lipman et al. modeled a fuel economy of 65 mpg.

[4] Lipman et al. report an incremental cost of $4,000 to $6,000 in 2020, while Weiss et al. report an incremental cost of $4,900 in 2020.

APPENDIX E

Arctic Oil Production Estimates

The Energy Information Administration recently estimated a potential production schedule for the Arctic National Wildlife Refuge using historic development rates in the region and engineering judgments of practical drilling and operational limits (EIA 2000b). EIA estimates production schedules for the technically recoverable volume of oil only, with three cases based on statistical estimates. These estimates assume a low and high development rate for each case, based on EIA's estimate of the speed with which new wells can be developed (table E-1).

Table E-1. Development Rates for the Arctic Refuge

Case	Technically Recoverable (billion barrels)	Development Rate (million barrels per year)	
		Low	High
95% Probability	5.7	250	400
Mean (Expected)	10.3	400	600
5% Probability	16.0	600	800

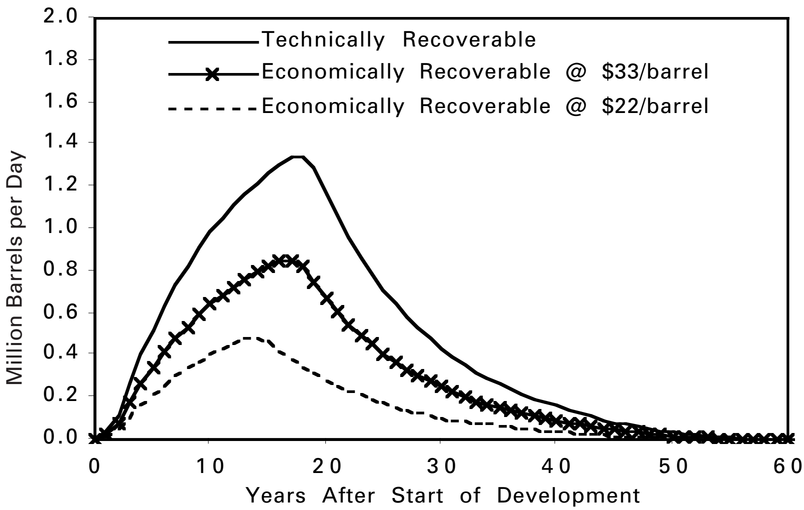
Source: EIA 2000b

EIA further assumes that each volume developed in a year has a 40-year life, with a three-year ramp up to full production at roughly 10 percent of total volume and an exponential decline in annual production at 10 percent per year thereafter (EIA 2000b).

We have adopted EIA's methodology to estimate the production schedule for the lower volumes projected to be economically recoverable, namely 3.2 billion barrels at $22/barrel and 6.3 billion barrels at $33/barrel (USGS 1998). For the 6.3 billion barrel volume, we adopt EIA's high development rate for the 95 percent probability case, 400 million barrels per year. For the 3.2 billion barrel economically recoverable volume, we adopt EIA's low development rate, 250 million barrels per year. In both cases, we use EIA's estimates of production over the life of each volume developed each year—whether it is 250 or 400 million barrels per year.

Our analysis suggests that, in all cases, annual production would peak between 15 and 20 years after development begins (figure E-1). Projected world oil prices for the 2010 to 2020 period, when development might begin, average $22.5 per barrel (EIA 2000a). Thus, we use the $22 per barrel production curve in our analysis, since it fairly represents projected future oil prices.

Figure E-1. Projected Production Schedules for the Arctic Refuge



Notes:
1. Technically recoverable schedule based on a "high" development rate of 600 million barrels per year (EIA 2000b). Total recoverable volume is 10.3 billion barrels (USGS 1998).
2. Economically recoverable schedule based on UCS modeling using EIA production schedules for each annual development volume.
3. $33/barrel schedule based on 6.3 billion barrels recoverable at a world oil price of $33 per barrel (2000$), equivalent to the USGS $30/barrel case (1996$) (USGS 1998).96
4. $22/barrel schedule based on 3.2 billion barrels recoverable at a world oil price of $22 per barrel (2000$), equivalent to the USGS $20/barrel case (1996$) (USGS 1998).

APPENDIX F

Actual Motor Vehicle Crash Statistics

The following data are fatality counts from the Fatal Accident Reporting System (FARS).

Table F-1a. Passenger Car Fatalities in Two-Vehicle Crashes Between Passenger Cars and Vehicles Listed

Accident Year	Passenger Cars	Pickup Trucks	SUVs	Minivans	Total
1979	6,049	1,929	129	439	8,546
1984	4,917	1,708	156	417	7,198
1989	4,809	2,181	411	643	8,044
1994	3,911	2,268	649	288	7,116
1999	3,199	2,205	911	406	6,721

Table F-1b. Pickup Fatalities in Two-Vehicle Crashes Between Pickup Trucks and Vehicles Listed

Accident Year	Passenger Cars	Pickup Trucks	SUVs	Minivans	Total
1979	684	390	17	43	1,134
1984	559	298	20	65	942
1989	625	416	52	87	1,180
1994	569	464	88	38	1,159
1999	499	538	156	68	1,261

Table F-1c. SUV Fatalities in Two-Vehicle Crashes Between SUVs and Vehicles Listed

Accident Year	Passenger Cars	Pickup Trucks	SUVs	Minivans	Total
1979	60	24	-	4	88
1984	69	21	5	1	96
1989	103	50	4	11	168
1994	163	77	21	8	269
1999	228	164	60	38	490

Table F-1d. Minivan Fatalities in Two-Vehicle Crashes Between Minivans and Vehicles Listed

Accident Year	Passenger Cars	Pick-up Trucks	SUVs	Minivans	Total
1979	157	43	-	10	210
1984	85	37	1	6	129
1989	129	54	10	18	211
1994	72	64	17	12	165
1999	137	121	50	23	331

Table F-2. Single-Vehicle Passenger Car Crash Fatalities

	Nonrollovers		Rollovers		
Accident Year	Non-ejected	Ejected	Restrained	Un-restrained	Ejected
1979	12,356	1,874	111	1,976	2,506
1984	9,918	1,774	126	1,428	2,466
1989	8,973	1,772	702	1,304	2,678
1994	6,275	1,316	1,046	907	1,985
1999	5,305	1,069	1,104	833	1,892

Table F-3. Single-Vehicle Pickup Truck Crash Fatalities

	Nonrollovers		Rollovers		
Accident Year	Non-ejected	Ejected	Restrained	Un-restrained	Ejected
1979	1,836	385	14	580	930
1984	1,576	354	23	486	944
1989	1,700	504	166	619	1,471
1994	1,520	496	278	445	1,355
1999	1,599	471	382	504	1,527

Table F-4. Single-Vehicle SUV Crash Fatalities

	Nonrollovers		Rollovers		
Accident Year	Non-ejected	Ejected	Restrained	Un-restrained	Ejected
1979	79	50	20	55	228
1984	94	70	31	61	274
1989	152	76	73	75	399
1994	249	97	183	92	536
1999	354	135	354	230	925

Table F-5. Single-Vehicle Minivan Crash Fatalities

	Nonrollovers		Rollovers		
Accident Year	Non-ejected	Ejected	Restrained	Un-restrained	Ejected
1979	263	109	9	88	140
1984	206	59	8	55	116
1989	269	91	34	61	193
1994	114	38	49	24	100
1999	212	74	88	46	169