POTENTIAL FOR REDUCING FUEL CONSUMPTION AND GREENHOUSE GAS EMISSIONS FROM THE U.S. LIGHT-DUTY VEHICLE FLEET

by

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Abstract

Greenhouse gases, such as carbon dioxide, trap solar heat in the atmosphere, raising its temperature. While comprising only about 5% of global population, the U.S. is responsible for nearly one fourth of global annual CO_2 emissions. Transportation accounts for a third of all carbon dioxide emissions in the country, and about one fourth worldwide. U.S. passenger cars and light trucks accounting for nearly two thirds of the net carbon equivalent emissions from transportation, any successful national strategy to reduce greenhouse gas emissions would need to address transportation sector emissions.

Building upon a vehicle technology assessment conducted at MIT ("On the Road in 2020", Weiss *et al.*, 2000), this study assesses the potential for reducing the U.S. light-duty vehicle fleet fuel consumption and energy use. The vehicles technologies considered are an evolving gasoline-fueled baseline vehicle with steadily decreasing fuel consumption, and a gasoline internal combustion engine hybrid vehicle with an advanced body design.

Using a vehicle fleet turnover model, the impact on the light-duty fleet of various technology penetration scenarios is assessed. The effects of other factors including the light-duty vehicle stock growth, the increasing per-vehicle annual distance traveled and the sales share of light-duty trucks are evaluated as well. The reduction of new vehicle fuel consumption achieved on the evolving baseline and advanced ICE-Hybrids vehicles provides the most significant savings in fleet energy use over all the other considered measures. Actions aiming at reducing the stock and the total distance traveled growth rate appear to have significant effects on fleet fuel consumption as well, while an increasing share of light-duty trucks will have only a modest impact.

Finally, various policy options are discussed. Actions will need to be taken by the Federal Government and the other stakeholders if significant petroleum and greenhouse gas emissions reductions are to be achieved.

<u>Thesis Advisor</u>: John B. Heywood,
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Chapter 1: Introduction

Background

The fuel consumption of successive model years of US new cars and light trucks have been essentially constant for the past decade – the new car and new light-duty truck fleet estimated on-road fuel consumption were 9.7 and 13.3 L/100km in 1988 and 9.7 and 13.6 L/100km in 1998. Further, the market share of more fuel consuming light trucks has climbed dramatically, from about 20% in 1975 to 30% in 1988 and 43% in 1998 – and today, the light-duty truck share is nearly 50%. Thus, each year, the fuel economy of the new light-duty vehicle fleet (passenger car and light trucks) has actually declined during the past decade.

Despite this record of increasing average light-duty vehicle fuel consumption, technologies that positively affect vehicle fuel conversion effectiveness have continually entered the fleet during this period. These include fuel injection, 4-valve per cylinder engines, variable valve timing, 4- (and recently 5)- speed electronically controlled automatic transmissions with lockup, growing use of lightweight materials and structural redesign for weight reduction, tires with lower rolling resistance, and improved aerodynamics. Efficiency improvements offered by these technologies have been offset, however, by changes that negatively affect fuel economy – increased horsepower yielding better acceleration performance and higher top speeds; weight increases due to increased body stiffness and more power and safety equipment as well as increased interior space; and other factors. These trends are hardly surprising given the prevailing low price of gasoline in the U.S. and the resulting consumer disinterest in fuel saving.

While new light-duty vehicle fleet fuel consumption has actually increased since 1988, travel demand has been growing steadily, with total highway vehicle kilometers rising by approximately 3% per year since 1970. This growth has outpaced the growth in the vehicle population with the distance traveled per vehicle rising at a rate of 0.5% per year over the same period of time. The result is that the fuel use and greenhouse gas emissions of the light-duty highway fleet are growing at a significant rate – the 1998 fleet energy use was 16% higher than the 1988 value.

This thesis builds upon a study conducted at MIT from 1998 to 2000 which evaluated in a consistent way major new passenger car vehicle and fuel technologies that have the potential to reduce significantly the emissions of greenhouse gases in the future (20 to 30 years from now). These are evaluations of total vehicle systems over their entire "well-to-wheel" life cycles. The focus was the effect of new technologies on all the major stakeholder groups, i.e. all the groups affected ranging from fuel manufacturers to vehicle purchasers and users. Those effects include estimating the technical characteristics of new technologies, characteristics such as greenhouse gas and other emissions, energy efficiencies, and costs. They also include other characteristics such as consumer-perceived performance, convenience, safety, and reliability.

The technologies assessed were:

- Improved gasoline and diesel internal combustion engines (ICE) with mechanical drivetrain,
- Gasoline, diesel and compressed natural gas (CNG) internal combustion engines in a parallel hybrid system utilizing both thermal and electric power plants,
- Gasoline, methanol, and hydrogen fueled fuel cell hybrid systems with electric drivetrain,
- Pure battery electric drivetrain
- Light weight materials for chassis and body
- More efficient auxiliary systems
- Bodies with lower aerodynamic drag,
- Tires with lower rolling resistance.

One major finding of this first study was that vehicles with hybrid propulsion systems using either internal combustion engines or fuel cell power plants are the most efficient and lowest emitting technologies assessed (on a total life cycle basis). In general, internal combustion engine hybrids appear to have advantages over fuel cells hybrids with respect to life cycle greenhouse gas emissions, energy efficiency, and vehicle cost, but the differences are within uncertainties of the results and depend strongly on the source of fuel energy (methanol, gasoline or natural gas).

Objectives and Scope

This thesis builds upon the MIT technology assessment and evaluates the effects of different technology penetration scenarios in the U.S. light-duty vehicle fleet within the timeframe (2001-2030). Energy reduction sensitivity analyses to key variables (sales mix, new sales growth and annual distance traveled growth rate) are also performed. The objective is not to predict the future but to understand the dynamics of new technology introduction and the effect of different scenarios on the U.S. light duty fleet greenhouse gas emissions and energy consumption; this understanding will be used as a basis to design new policies and propose improvements on existing ones.

This study provides a deeper understanding of the relationship between car technology performance and the overall fleet performance and dynamics. The study also underlines potential barriers that would affect the introduction of such technologies at the desired rate (market forces, technology limitations, infrastructure and production capacity limitations, stakeholder resistance, etc). These barriers will have to be overcome to achieve a more sustainable transportation in the U.S.

The scope is limited to the U.S. light-duty vehicle fleet, i.e. vehicle of Gross Vehicle Weight under 10,000 pounds, which account for nearly 80% of the U.S. road transportation fuel consumption. Moreover, two types of vehicles were considered for the evaluation of the light duty vehicle fleet energy use: the evolving gasoline-fueled baseline and the gasoline ICE-hybrid vehicles with advanced body design. The evolving baseline and the advanced ICE-hybrids represent low resistance alternative paths to fuel cell hybrids and can help achieve, as we will see, significant savings in the fleet energy use within the timeframe of the study. From a life cycle analysis point of view, this study focuses on the usage part of the life of the vehicle and considers only petroleum-based fuels. Thus, the energy use and the level of emissions of CO_2 is directly related to the quantity of fuel used.

Methodology

The methodology is based on a detailed model of the U.S. light-duty vehicle fleet. This model simulates the dynamics of the fleet by tracking each model year vehicle and calculates the aggregate performance of the fleet in terms of fuel use and energy consumption according to different scenarios.

Five technology scenarios were evaluated for the fleet fuel use assessment. The first one is a reference scenario where the current fuel consumption of cars and light trucks is assumed to remain constant at today's values until 2030. The second scenario projects a 100% market penetration of the evolving baseline vehicle with steadily decreasing vehicle fuel consumption till 2030. The third, fourth and fifth scenarios account for the introduction of advanced ICE-hybrid vehicles to the baseline, with different penetration levels (long run market share in 2030 of 25%, 50% and 75%).

Chapter 2 discusses the role of the transportation sector and especially road transportation in the U.S. energy use and greenhouse gas emissions. A review of automotive technologies to reduce vehicle fuel consumption is made in chapter 3, followed by a review of the methodology and results of the MIT technology assessment study. In chapter 4, the assumptions made to project the vehicle performance improvement into the light vehicle fleet are presented and discussed, while the results of the different scenarios considered are displayed and evaluated in chapter 5. In light of the results obtained, previous policy initiatives to reduce the U.S. light-duty vehicle fleet energy use and fuel consumption are analyzed in chapter 6, and directions for improvement are proposed.

Chapter 2: The Role of Transportation in the U.S. Energy Consumption and Greenhouse Gas Emissions

Greenhouse gases, such as carbon dioxide, trap solar heat in the atmosphere, raising its temperature. Since the beginning of the industrial age, human activities, mostly the burning of fossils fuels, land use changes and agriculture have been the principal sources for observed increases in the atmosphere of carbon dioxide (up 30%), methane (up 145%), and nitrous oxide (up 15%). The Intergovernmental panel on Climate Change (IPCC) has concluded that these increases have had a discernable impact on the Earth's climate and are believed to be responsible for a significant increase in the average global temperature since pre-industrial times. Even if carbon dioxide emissions could be returned to 1994 levels, scientists have estimated that the atmospheric concentration of the gas would double by the end of the century. In fact, carbon emissions are growing worldwide, and will continue to do so as long as the combustion of carbon fuels and resulting emissions continue to increase. The precise consequences of continued greenhouse gas emissions are not well understood, but potential adverse consequences include major changes in precipitation and temperature patterns, increased catastrophic storm activity, and higher sea level.

On a greenhouse warming potential basis, U.S. emissions of CO_2 constitute more than 80% of the nation's total greenhouse gas emissions. While comprising only about 5% of global population, the U.S. is responsible for nearly one fourth of global annual CO_2 emissions. Transportation accounts for a third of all carbon dioxide emissions in the country, and about one fourth worldwide. U.S. passenger cars and light truck account for nearly two thirds of the net carbon equivalent emissions from transportation, or 16% of U.S. total greenhouse gas emissions. The EIA projects that, between 1997 and 2020, CO_2 emissions from transportation fuel use will grow faster than any other sector at 1.7% annually, increasing by 50% over the period.

Overall, reducing U.S. petroleum consumption has wide support in the environmental community, because of concerns about rising oil imports and their increasing impact on the energy and economic security of the U.S., the emissions of greenhouse gases and a host of other environmental concerns associated with oil use.

Although transportation has shared trends towards higher energy efficiency with other sectors of the U.S. economy, the other sectors have succeeded in greatly reducing oil's overall role in their energy use, but transportation has not. Electricity generation, for example, has virtually eliminated its use of oil, except in some diesel and combustion turbine peaking generation and some small-scale operations, amounting to a few percent of total fuel use. According to the Energy Information Administration, electric utilities reduced their petroleum use from 17% of electricity generated in 1973 to 1.5% in 2000. Electricity and natural gas have replaced much of oil's share of the residential and commercial heating market, and most new construction no longer treats oil as a viable option.

In contrast, transportation still uses oil for more than 97% of its energy requirements in 1999 (Davis, 2000), which account for about two thirds of all the oil consumed by the U.S. economy. Furthermore, the fleet of light duty vehicles represents about 60% of transportation energy use in 1999, and will still represent over 50% in 2015 if the current trend persists (EIA, 1999). Future demand for transportation fuel will depend on the size of the vehicle fleet, rates of travel, and vehicle fuel consumption. If the fuel consumption of light vehicles remains at current levels, while vehicle kilometers of travel and the stock of light vehicles continue to grow, this segment might require 680 billion liters of gasoline per year by 2020, 75% more than the 1990 level.

Nearly all transportation modes, including air, rail, and highway, became much more energy efficient after the energy crises in the early 1970s. However, low fuel prices during the past 15 years have greatly weakened demand for reduced fuel consumption. Average new car fuel consumption has not improved for more than a decade. In addition, light trucks (pickups, vans, minivans and sport utility vehicles) that consume more fuel than cars, are increasingly being used in place of automobiles. The fuel consumption of new light vehicles (cars and trucks combined) dropped from the 1973 value until 1987 and has since increased more than 0.8 L/100km as the share of light trucks has increased to about 50% of light vehicle sales.

The U.S. still faces growing transportation fuel use, growing oil imports and growing emissions of greenhouse gases, and the previous statistics suggest that any successful national strategy to reduce greenhouse gas emissions would need to address transportation sector emissions.

Chapter 3: Vehicle Technology Assessment

Introduction

This chapter builds upon the vehicle technology assessment study conducted at MIT ("On the Road in 2020", Weiss *et al.*, 2000). The first section reviews different technologies that could improve the future fuel consumption of light-duty vehicles. Section 3.2 presents the technologies assessed as well as the methodology of the MIT study whose results are summarized in the third section. Finally, section 3.4 discusses the rationale for choosing the technologies that will be considered to evaluate the potential for reducing the U.S. light-duty vehicle fleet energy consumption.

3.1 Review of Technologies

There are two general way of reducing vehicle fuel consumption. The first one is to increase the overall efficiency of the power train (engine, transmission) and the second one is to reduce the tractive loads (mass, aerodynamic drag and tire rolling resistance). Hybrid electric vehicles that represent an important evolution in powertrain architecture are also examined.

3.1.1 Powertrain Technologies

Engine Technologies

Several technologies for increasing energy efficiency of engines by reducing mechanical losses and/or improving combustion and engine management can be available in production in the near term (some are already available on production models). They include continuous refinement and optimization of engine design by more sophisticated tools and computer-aided engineering, advanced low-friction designs and lubricants, multi-valve and overhead camshaft valvetrains. Beginning with the Honda V-TEC engines, variable valve timing is a proven technology that has potential for further market penetration, and variable valve lift and timing offer even further benefits. More, Mercedes has introduced cylinder de-activation ("Active Cylinder Control") in its new high-end V-12 engine while BMW is installing its "Valvetronic" intake valve throttling technology on the M-Series sport sedans. Progress in engine specific power allows for downsizing and turbocharging and engine accessory improvement (cooling systems, etc.) can be considered. According to the National Research Council report on CAFÉ standards (NRC, 2001), reductions in vehicle fuel consumption of up to about fifteen percent can be expected with these technologies.

Technologies needing more R&D effort include the stratified charge direct injection gasoline and diesel engines. These engines can have significant efficiency improvement over their conventional counterpart but more work is needed to reduce NO_x emissions and particulates in order to comply with the federal Tier 2 and the California LEV II emissions standards.

Transmissions

A number of opportunities exist for substantial gains in transmission efficiency. Five speed automatic transmissions and six-speed are becoming available. Moreover, several versions of continuously variable transmissions (CVT) are in production today. CVTs offer a broad span of gear ratios and lower frictional losses than conventional fluid coupled automatic transmissions, but as noted by (NRC, 2001), production costs, torque limitation and customer acceptance have to be taken into consideration.

Other technologies exist like the automatic clutch mechanisms allowing the replacement of the hydraulic torque converter in automatic transmissions and the semi-automatic transmissions with motorized gear shift (DeCicco, 2001).

3.1.2 Technologies Reducing Tractive Load

Mass Reduction

The potential for reducing vehicle's mass is significant. Automakers have identified approaches to achieve as much as 40% mass reduction, and are working on ways to bring down the costs (DeCicco, 2001). Actual net mass reductions are achievable by redirecting product design priorities and taking advantage of more marked material changes, such as aluminum-based structures, and new ways to design components and structures, such as composite panels on space frames. Moreover, the reduced body mass allows for secondary weight savings on suspension, chassis and other components.

Streamlining

Streamlining is a way of reducing aerodynamic drag. Drag is proportional to the product of a vehicle's frontal area and a dimensionless drag coefficient related to a vehicle's shape. DeCicco, (2001) points out that fleetwide drag coefficient has decreased about 2.5% per year over the past two decades and that it is not uncommon to see a 15% reduction when a vehicle is redesigned. However streamlining benefits have been partly offset by vehicle upsizing (through the increase of the frontal area).

Reduction of Tire Rolling Resistance

Continued advances in tire technologies are directed towards reducing rolling resistance without deteriorating vehicle attributes such as handling, noise, comfort and braking performance. Lower-energy-loss tires continue to be introduced as original equipment although shifts toward larger tires for reasons of performance and image partly offset the benefits. Increasing tire pressure can also reduce the rolling resistance but doing so also reduces tire grip. Ensuring adequate tire pressure during the vehicle operation proves to be a fuel saving as well as a safety measure for vehicles.

3.1.3 Hybrids

Moving to a hybrid drivetrain is often cited as a mean to achieve very low levels of fuel consumption. Hybrids combine an electric drivetrain with a power source, often an internal combustion engine (ICE), sometimes a fuel cell or even a turbine. The power source may be linked to the electric motor in series, with a generator allowing the power source to recharge the battery or directly drive the electric motor. The power source may also operate in parallel so that both electric motor and engine can drive the wheels. Although the number of operating strategies is important, hybrids generally save energy by regenerative braking, by operating the power source on ranges of high efficiency and by requiring a relatively small engine.

3.2 Methodology and Technologies Assessed

Note: The majority of section 3.2 and 3.3 draw on the technology assessment study "On the Road in 2020" conducted at MIT by Weiss *et al.* (2000). Additional details can be found in the corresponding report.

Weiss *et al.* (2000) examined several potentially promising future powerplants and vehicle technology combinations for passenger cars, using a propulsion system in a vehicle computer simulation. The simulation model calculates the fuel consumed and thus the carbon dioxide emissions produced by the modeled vehicle for a specified driving cycle. Inputs for the calculation are the vehicle driving resistances (mass, aerodynamic drag and tire rolling resistance), and the operating characteristics of each of the major propulsion system components. These vehicle fuel consumption predictions were made for 2020, for technologies that could plausibly be in mass production at that time. Their estimated performance characteristics relative to today's performance include improvements that were judged to be likely to be implemented in production in 2020. However, the most sophisticated of these technology combinations, which could provide substantially improved fuel economy, are likely to be significantly more expensive.

The response of consumers to these less fuel consuming but more expensive vehicles is uncertain, and market acceptance is essential for any large-scale production. Therefore, the results of this technology assessment indicate a potential for improvement in fuel consumption and CO_2 emissions in 2020 of various future vehicle technologies.

The vehicle technologies that were examined comprise:

- Improved gasoline and diesel internal combustion (ICE) engines with mechanical drivetrain,
- Gasoline, diesel and compressed natural gas (CNG) internal combustion engines in a parallel hybrid system utilizing both thermal and electric power plants,
- Gasoline, methanol, and hydrogen fueled fuel cell hybrid systems with electric drivetrain,
- Pure battery electric drivetrain
- Light weight materials for chassis and body
- More efficient auxiliary systems
- Bodies with lower aerodynamic drag,
- Tires with lower rolling resistance.

These technologies were chosen from a larger set of possible powertrain and vehicle developments as having the highest potential for reaching production and the market. The following figure categorizes the combinations of propulsion system (power unit and transmission) and fuels examined into three families: mechanical, hybrid, and electrical.

Table 3-1: Powerplants and fuel combinations examined, from Weiss *et al.* (2000)

FAMILY	TRANSMISSION	POWER UNIT	FUEL
Mechanical	Auto-Clutch	Spark Ignition (SI) ICE	Gasoline
		Compression Ignition (CI) ICE	Diesel
Dual	Continuously Variable (CVT)	ICE with Batteries and Electric Motor	Gasoline, Diesel, CNG
Electrical	Single Ratio	Fuel Cell (FC), with reformer for gasoline, methanol	Gasoline, Methanol, Hydrogen
		Battery	Electricity

An important issue in this future car technology assessment is the relevant baseline. The baseline used was an average-size U.S. passenger car, i.e. a steadily improving gasoline-fueled spark-ignition engine, a more efficient conventional technology transmission and a low cost vehicle weight and drag reductions. The baseline technology improvements were based on historical and current technology trends, and were projected to 2020. The baseline vehicle represents the likely average passenger cars technology in 2020 that will not incur extra costs other than those necessary to keep up with the market.

Although it was not possible to deal quantitatively with some of the performance and vehicle characteristics like drivability issues, the simulation was designed to ensure that each vehicle and powerplant combination provide as much as possible the same acceleration, driving range, refueling ease, interior driver and passenger space, trunk storage space, and meet the applicable safety and air pollutant emissions standards. However, some reserves were made concerning the meeting of future emissions standards by the diesel ICE.

Table 3-2: Technologies assessed, form Weiss *et al.* (2000)

Year and Technology	Fuel	Powerplant	Transmission
1996 (Reference)	Gasoline	SI	Auto
2020 Evolutionary Baseline	Gasoline	Direct Injection (DI) SI	Auto-Clutch
2020 Advanced ICE	Gasoline	DI SI	Auto-Clutch
	Diesel	DI CI	Auto-Clutch
2020 Advanced ICE Hybrid	Gasoline	DI SI + Battery	CVT
	Diesel	DI CI + Battery	CVT
	CNG	DI SI + Battery	CVT
2020 Advanced Fuel Cell Hybrid	Gasoline	Reformer-FC + Battery	Direct
	Methanol	Reformer-FC + Battery	Direct
	Hydrogen	FC + Battery	Direct
2020 Advanced Electric Vehicle	Electricity	Battery	Direct

3.3 Results and Comments

The results of the vehicle calculations are summarized in table 3-3.

The fuel consumption numbers presented are for the standard combination: 55% urban and 45% highway Federal Test Procedure cycles, and were not adjusted to on-road fuel consumption value using the EPA empirical factors of 0.90 for city and 0.78 for highway. Combined fuel consumption numbers are expressed in gasoline equivalent of the energy used.

A detailed retail price analysis was conducted. The retail price of the vehicles was obtained by adding or subtracting the price of vehicle components that are added to or removed from the configuration of a particular vehicle, to or from the price of the 1996 reference vehicle.

Table 3-3: Vehicle Calculation summary, from Weiss *et al.* (2000)

Technology	Fuel	Loaded Mass (kg)	Power/ Weight, (W/kg)	Fuel Consumption MJ/km	L/100km	% of base	Purchase Price 1997$	% of base
Reference, SI-ICE	Gasoline	1444	76.0	2.73	8.46	156	$17,200	96
Baseline, evolutionary SI-ICE	Gasoline	1236	75.0	1.75	5.44	100	$18,000	100
Advanced SI-ICE	Gasoline	1136	75.0	1.54	4.79	88	$19,400	108
Advanced CI_ICE	Diesel	1191	75.0	1.36	4.20	77	$20,500	114
Hybrid SI-ICE	Gasoline	1154	75.0	1.07	3.32	61	$21,100	117
Hybrid CI_ICE	Diesel	1192	75.0	0.92	2.86	53	$22,100	123
Hybrid SI-ICE	CNG	1172	75.0	1.03	3.20	59	$21,600	120
Hybrid Reformer FC	Gasoline	1458	75.0	1.79	5.56	102	$23,400	130
Hybrid Reformer FC	Methanol	1375	75.0	1.33	4.14	76	$23,200	129
Hybrid FC	Hydrogen	1314	75.0	0.81	2.50	46	$22,100	123
Battery Electric	Electricity	1312	75.0	0.51	1.58	29	$27,000	150

The 2020 evolutionary baseline improvements, which are likely to be driven by market and regulatory pressures, are significant: a 15% reduction in vehicle mass and a 35% reduction in fuel consumption, at about a 5% increase in price, as compared to the reference car.

The advanced SI ICE car, with lower vehicle resistances (mass, aerodynamic drag and tire rolling resistance) and with the same improved baseline gasoline engine and improved transmission, decreases the fuel consumption by a further 12% relative to the 2020 evolving baseline car. The mass is reduced by an additional 8% and the price increase is about 8% relative to the reference car. The same vehicle powered by an advanced diesel engine has a 10% better gasoline-equivalent fuel consumption than its gasoline-powered counterpart (a 23% reduction relative to the baseline) at an additional $1000 increase.

The internal combustion engine hybrid vehicles show an additional reduction in fuel consumption of about 30% relative to their non-hybrid equivalent vehicles, for gasoline, CNG and diesel-powered versions. Part of this is due to the hybrid features, part is due to the CVT. The car prices are about 20% higher than the 2020 baseline. The diesel hybrid is some 10-15% lower in energy consumption that the gasoline and CNG hybrids.

The fuel cell system projections underline the importance of the fuel supply issue. The high efficiency of the direct hydrogen-fueled cell, augmented by the hybrid features, leads to energy consumption levels that are some 50% lower than the 2020 evolving baseline conventional vehicle (which has a less advanced body and chassis). However, adding the gasoline or methanol reformer to make these vehicles more practical in terms of market introduction reduces substantially this fuel cell benefit relative to equivalent gasoline or diesel hybrids. The methanol-reformer fuel cell hybrid energy consumption lies between that of the advanced gasoline ICE and the gasoline ICE hybrid vehicles. The gasoline-reformer fuel cell hybrid fuel consumption is comparable to that of the evolving baseline gasoline ICE vehicle. The fuel cell hybrids prices are some 25 to 30% higher than the 2020 evolving baseline, with the lowest increase for the direct H_2-fueled system.

While battery electric propulsion systems require the lowest energy input (as electricity) to the vehicle, even with optimistic assumptions about future battery technology, when allowance is made for the efficiency of electricity production and distribution, the total energy input to the electrical system is larger than the gasoline or diesel hybrid, and the price is higher, with the battery technology considered.

3.4 Technologies Retained to Assess the Potential for Reduction of the Fleet Energy Use

To evaluate the technological potential for reducing the light-duty fleet energy use and greenhouse gas emissions, one must consider a life cycle analysis (well to wheels). The MIT assessment concluded that the baseline technology could result in 2020 vehicles that reduce energy consumption and greenhouse gas emissions by about one third from comparable current vehicles at about a 5% increase in car cost. In addition, more advanced technologies for propulsion systems and other vehicle components could yield additional reduction in life cycle greenhouse gas emissions at increased vehicle price.
More, vehicles with hybrid propulsion using either internal combustion engines or fuel cell power plant are the most-efficient and lowest emitting technologies assessed, with ICE hybrids appearing to have advantages over fuel cell hybrids relative to life cycle greenhouse gas emissions, energy efficiency, and vehicle cost. However, the differences were within the uncertainties of the results and depend on the source of fuel.
Finally, if vehicles with lower greenhouse gas emissions are needed in the very long run (in 30 to 50 years or more), hydrogen and electrical energy produced from non-fossil sources of primary energy or from fossil primary energy with carbon sequestration are the only identified options for fuels.

Two types of vehicles and one type of fuel were considered for the evaluation of the light duty vehicle fleet energy use: the evolving gasoline-fueled baseline and the gasoline ICE-hybrid vehicles with advanced body design. The reasons for such a choice are twofold. First, these technologies are the ones that are most in continuity with today's auto industry capability and consumer acceptance. Supposedly, moving towards this direction will not imply major investments and risks or structural modifications, as may be required by more drastic technological paths. Internal combustion engines are by far the dominant design in today's powertrain technology. Toyota and Honda are already producing ICE-hybrids and other major automakers have committed to build production models in the near term. For fuels, only gasoline was considered since no significant fuel substitution is likely to happen over the next decade or even through 2020.

Second, these options provide significant reduction in fuel consumption and life cycle greenhouse gas emissions compared to the current levels. In addition, introducing more advanced technologies will have only a small effect on the fleet energy use reduction within the considered time frame (2000-2030), because of the lead time of the development process and the relatively limited level of penetration of these technologies in the light duty vehicle fleet by that time.

The underlying vehicle technology assumptions and the technologies chosen for the assessment of the fleetwide impact represent a low-risk evolutionary path to future designs. Therefore, this assessment is one that is conservative in regard to others recent studies (DeCicco *et al.* 2001, and NRC, 2001) and declarations made by automakers (25% improvement in fuel consumption by 2005 of their SUV fleets).

Five technology scenarios were evaluated for the fleet fuel use assessment. The first one is a reference scenario where the current fuel consumption of cars and light trucks is assumed to remain constant until 2030. The second scenario projects a 100% market penetration of the evolving baseline vehicle with steadily decreasing vehicle fuel consumption till 2030. The third, fourth and fifth scenarios account for the introduction of advanced ICE-hybrid vehicles to the baseline, with different penetration levels (long run market share in 2030 of 25%, 50% and 75%).

In absence of a light-duty vehicle technology assessment, it is assumed that the fuel consumption improvements that can be obtained are the same that the ones evaluated for passenger cars. However, recent light duty vehicle technology assessment (NRC, 2001) claimed that the potential for improvement of the light trucks fuel consumption is even bigger than the one for cars.

Chapter 4: Projection of Fleetwide Impacts

Introduction

This chapter describes the methodology and the general modeling assumptions used to assess the effects of different technology penetration scenarios on the light-duty vehicle fleet greenhouse gas emissions and energy use.

4.1 Methodology

Analyzing the different scenarios require a stock turnover model. This model calculates the effects of the introduction of advanced technology vehicles on the U.S. light-duty vehicle fleet fuel and energy use, relative to a reference scenario. Each model year vehicle is tracked and the aggregate performance of the fleet in terms of fuel consumption and energy use is estimated. From a life cycle point of view, the model deals with the usage part of the life of the vehicle and considers only petroleum-based fuels.

The model is written in Microsoft EXCEL and consists in worksheets that define the population, travel, fuel use and average fleet fuel consumption for different light-duty vehicle technology penetration scenarios. Passenger cars and light trucks are considered separately in the model to better deal with changes in the market share and performance of these two types of vehicles. No further distinctions in light duty vehicles classes are made.

Modeling two different fleets has several benefits:

- A variation in the mix Cars/Light Truck in the new vehicles sales can also be interpreted as a change in average vehicle characteristics, including mass for the light duty vehicle with the known consequences for the average new vehicle fuel consumption.

- The structure of the model can be replicated to allow a separate tracking of given technologies (i.e. Alternative Fuel Vehicles whose effects on the fleet energy use need more refinement than the aggregate fuel use calculation done in the current version of the model)
- The model can also be easily upgraded to include Heavy Duty Vehicles
- The dynamics and relative impacts of both fleets can be analyzed separately.

Four major parameters are used as inputs for the model. They are (1) the historical time series (2000-2030) for average fuel consumption for a given vehicle and its market penetration scenario, (2) the estimated average annual growth rate of new vehicle sales, (3) the annual growth rate of the average per-vehicle kilometers of travel and (4) the evolution of the share of light trucks in new light duty vehicle sales.

Outputs comprise the projected light duty vehicle fleet composition, the projected annual distance traveled and the levels of fleet fuel consumption and energy use.

In the reference scenario ("Business as usual" or "No change"), the following input parameters remain constant, i.e. the average new car and light truck fuel consumption from 2000 to 2030, the estimated average annual growth rate of new vehicle sales (0.8% per year), the annual growth rate of the average per-vehicle kilometers of travel (0.5% per year) and the evolution of the share of light trucks in new light duty vehicle sales (60% market share in 2030). Further description of the modeling assumption is done in the following sections. Detailed outputs from the model are displayed in the appendix.

4.2 Structure and General Modeling Assumptions

Several worksheets are needed to assess the impact of the introduction of technologies that reduce fuel consumption on the light duty vehicle fleet energy use.

Three general modules can be highlighted:

(1) The first one relates to the light vehicle population estimates with the new sales and the sales mix, the retirement of vehicles with the model year-specific scrappage rates and the resulting stock calculation.
(2) The second module deals with the vehicle usage and calculates the vehicle kilometers of travel as well as the total fleet energy and fuel use,
(3) The third module estimates the average new fleet fuel consumption by taking into account each technology characteristics and their interaction according to the technology scenarios.

This section describes the model structure in detail and discusses the underlying assumptions.

4.2.1 Module 1: Light Vehicle Population

New Sales and Sales Mix

The "Sales Mix" worksheet includes the projections of new passenger cars and light-duty trucks sales for each calendar year. The historical data is taken from the Transportation Energy Data Book, Ed 20.

The level of new cars and light-duty truck sales are derived from two parameters: the total light-duty vehicle sales and the light-duty truck share of those sales. In the reference case, the total light-duty vehicle sales are estimated to grow at the same rate as the U.S. population (0.8% per year on average from 2000 to 2030, according to the medium projection of the U.S. bureau of census). The light-duty truck share is modeled by extrapolating the historical data to a given 2030 market share by a second order polynomial curve. It is assumed in the reference case that the current trend of increasing popularity of light truck will continue and level off to 60% market share in 2030.

The two parameters (new sales growth and 2030 light-duty trucks market share of new sales) can be varied to allow a series of sensitivity analyses.

Table 4-1: Historical and Projected Sales of New Light-Duty Vehicles

	New Sales (million vehicles)					New Sales (million vehicles)			
Calendar Year	Cars	Light Trucks	Total Light Duty	Light Truck Share	Calendar Year	Cars	Light Trucks	Total Light Duty	Light Truck Share
1970	8.404	1.463	9.867	14.8%	**2001**	7.974	7.837	15.811	49.6%
1971	10.249	1.757	12.006	14.6%	**2002**	7.925	8.013	15.938	50.3%
1972	10.950	2.239	13.189	17.0%	**2003**	7.878	8.188	16.065	51.0%
1973	11.439	2.745	14.184	19.4%	**2004**	7.834	8.360	16.194	51.6%
1974	8.853	2.338	11.191	20.9%	**2005**	7.792	8.531	16.324	52.3%
1975	8.624	2.281	10.905	20.9%	**2006**	7.754	8.700	16.454	52.9%
1976	10.110	2.956	13.066	22.6%	**2007**	7.719	8.867	16.586	53.5%
1977	11.183	3.430	14.613	23.5%	**2008**	7.687	9.032	16.718	54.0%
1978	11.314	3.808	15.122	25.2%	**2009**	7.658	9.194	16.852	54.6%
1979	10.673	3.311	13.984	23.7%	**2010**	7.633	9.354	16.987	55.1%
1980	8.979	2.440	11.419	21.4%	**2011**	7.610	9.512	17.123	55.6%
1981	8.536	2.189	10.725	20.4%	**2012**	7.592	9.668	17.260	56.0%
1982	7.982	2.470	10.452	23.6%	**2013**	7.577	9.821	17.398	56.4%
1983	9.182	2.984	12.166	24.5%	**2014**	7.566	9.972	17.537	56.9%
1984	10.391	3.863	14.254	27.1%	**2015**	7.558	10.119	17.677	57.2%
1985	11.043	4.458	15.501	28.8%	**2016**	7.554	10.264	17.819	57.6%
1986	11.453	4.594	16.047	28.6%	**2017**	7.555	10.407	17.961	57.9%
1987	10.278	4.610	14.888	31.0%	**2018**	7.559	10.546	18.105	58.2%
1988	10.626	4.800	15.426	31.1%	**2019**	7.568	10.682	18.250	58.5%
1989	9.898	4.610	14.508	31.8%	**2020**	7.581	10.815	18.396	58.8%
1990	9.301	4.548	13.849	32.8%	**2021**	7.598	10.945	18.543	59.0%
1991	8.175	4.123	12.298	33.5%	**2022**	7.620	11.072	18.691	59.2%
1992	8.213	4.629	12.842	36.0%	**2023**	7.646	11.195	18.841	59.4%
1993	8.518	5.351	13.869	38.6%	**2024**	7.677	11.315	18.992	59.6%
1994	8.990	6.033	15.023	40.2%	**2025**	7.713	11.431	19.144	59.7%
1995	8.635	6.053	14.688	41.2%	**2026**	7.754	11.543	19.297	59.8%
1996	8.527	6.519	15.046	43.3%	**2027**	7.800	11.652	19.451	59.9%
1997	8.272	6.797	15.069	45.1%	**2028**	7.851	11.756	19.607	60.0%
1998	8.139	7.299	15.438	47.3%	**2029**	7.907	11.857	19.764	60.0%
1999	8.082	7.480	15.562	48.1%	**2030**	7.969	11.953	19.922	60.0%
2000	8.027	7.659	15.686	48.8%					

Source: Transportation Energy Data Book Ed. 19; extrapolated for post-1998.

Scrappage rates

This worksheet is used to generate the survival rates needed for the stock calculation. The historical data are taken from the Transportation Energy Data Book, Ed. 19 for model year 1970, 1980 and 1990. The survival rate data for each given model year is fitted using the following equation:

$$1 - \text{Survival Rate (t)} = \frac{1}{1+e^{-\beta(t-t_0)}} ,$$

where,

- t_0 is the median age of the corresponding model year
- t, the age on a given year
- and β , a growth parameter translating how fast vehicles are retired around t_0.

The historical data (survival rates for model years 1970, 1980 and 1990) show an increase of the median age of automobiles and a small decrease in the median age of light-duty trucks. The intermediate median age data are linearly interpolated for both fleets (passenger cars and light duty trucks). However, extrapolating this trend would lead to excessively high values for the median lifetime of light vehicles. The median age is kept constant after the model year 2000 because of insufficient evidence on the potential for increasing vehicle durability. Therefore, the scrappage figures assumed for the years 2000 to 2030 are constant and do not allow for the assessment of related policy alternatives like early retirement plans, and technical or consumer behavior changes like increased durability and extended use of light duty vehicles.

Table 4-2: Median Age (years)

	Model Year 1970	Model Year 1980	Model Year 1990
Cars	10.7	12.1	13.7
Light Trucks	16.0	15.7	15.2

Source: Transportation Energy Data Book Ed. 19

Stock

This worksheet calculates for both fleets (passenger cars and light-duty trucks) the number of vehicles in use for each model year and at any calendar year between 1960 and 2030. For each calendar year and for each fleet, the number of surviving vehicles (or vehicles in use) is computed (new vehicle sales * survival rate). The total stock is obtained by aggregating the vehicles in use for each calendar year.

Since the calculation starts for model year 1960, the calculated total stock composition matches the data accurately only after 10 to 15 years (1970, 1975), when the number of vehicles from model years prior to 1960 is negligible relative to the total stock.

The calculated stock is compared to the data in the "Stock Summary" worksheet.

Table 4-3: Historical and Projected Stock of Light-Duty Vehicles (million vehicles)

Year	Cars	Light Trucks	Total Light Duty	Year	Cars	Light Trucks	Total Light Duty
1980	110.346	31.173	141.519	2006	119.714	103.159	222.872
1981	110.747	32.309	143.056	2007	119.650	106.450	226.100
1982	110.447	33.606	144.053	2008	119.646	109.677	229.323
1983	111.216	35.282	146.498	2009	119.686	112.833	232.519
1984	113.089	37.682	150.771	2010	119.756	115.915	235.671
1985	115.533	40.520	156.054	2011	119.842	118.922	238.765
1986	118.328	43.345	161.673	2012	119.932	121.854	241.786
1987	119.919	46.037	165.955	2013	120.012	124.712	244.723
1988	121.832	48.759	170.591	2014	120.068	127.498	247.566
1989	123.013	51.144	174.157	2015	120.091	130.216	250.307
1990	123.620	53.315	176.935	2016	120.075	132.870	252.945
1991	123.156	54.925	178.081	2017	120.022	135.463	255.485
1992	122.793	56.877	179.670	2018	119.939	137.999	257.939
1993	122.804	59.378	182.182	2019	119.839	140.481	260.320
1994	123.326	62.385	185.711	2020	119.735	142.912	262.646
1995	123.513	65.255	188.767	2021	119.641	145.291	264.932
1996	123.569	68.416	191.984	2022	119.570	147.624	267.194
1997	123.325	71.681	195.006	2023	119.532	149.910	269.442
1998	122.911	75.259	198.170	2024	119.537	152.148	271.685
1999	122.416	78.834	201.250	2025	119.592	154.339	273.931
2000	121.879	82.396	204.275	2026	119.700	156.483	276.184
2001	121.341	85.942	207.282	2027	119.869	158.579	278.448
2002	120.843	89.463	210.306	2028	120.100	160.626	280.725
2003	120.419	92.952	213.371	2029	120.396	162.623	283.020
2004	120.088	96.403	216.491	2030	120.762	164.570	285.332
2005	119.855	99.807	219.662				

The "summary" work sheet collects the calculated stock, distance travelled, Fuel Use and calculates the fuel consumption for the passenger car fleet, for the light duty truck fleet and for the total light duty vehicle fleet.

4.2.2 Module 2: Usage and Fuel Use

Vehicle Kilometers of Travel (VKT) and Fuel Use

- **Vehicle Kilometers of Travel**

The modeling of the vehicle kilometers of travel accounts for the fact that vehicles tend to drive less over time. Each calendar year, the annual distance traveled per vehicle is allowed to decrease at a rate of 4.5% per year of vehicle age (Greene *et al.*, 1990), i.e. in 1990, 5-year old vehicles will drive 4.5% less than 4-year old vehicles. Not taking this phenomenon into account would lead to overestimate the inertia of the old fleet.

The distance traveled is computed for each calendar year. The model estimates VKT per year as a function of vehicle age. The key parameters are miles per year for a new vehicle and a usage degradation rate.

$$\text{VKT (age } i) = \text{VKT}_{new} * e^{(\text{-usage degradation rate}*i)}$$

The usage degradation rate is kept constant in the model at 0.045 (a 4.5% annual decrease in per-vehicle VKT). However, the distance traveled per year for a new vehicle (VKT_{new}) is allowed to evolve for each calendar year.

Due to the lack of a consistent set of data, a distribution determined by Greene *et al.*, (1990) is used here. The annual VKT distributions for the years 1970 to 1998 are calculated by varying the previous distribution according to the evolution of the ratio Total VKT/Stock.

The annual growth rate of the average new vehicle VKT is a key parameter in the model. This parameter depends on economic conditions and particularly on the price of fuel. On average, this rate has been 0.5% per year during the 1970-1998 period. In the reference case, it is assumed to remain at 0.5% per year from 2000 to 2030.

In this model, total VKT growth is directly determined by the stock growth and the average per-vehicle annual VKT growth. Factors affecting VKT growth which were not assessed in detail comprise among other things:

- The level of economic activity,
- The trend of shift in population from regions with lower VKT per vehicle (Northeast, Midwest) to regions with higher VKT per vehicle (West, South),
- The reduction in vehicle occupancy rates,
- The aging of population
- Improved transportation infrastructure allowing faster travel and lower commuting time
- The cost of driving.

With the 0.8% annual growth rate for the new sales considered in the reference case and the extrapolated 0.5% average per-vehicle annual VKT growth, the annual fleet VKT growth rate decreases from a value of 1.8% in 2000 and stabilizes at 1.2% in 2025.

The total VKT is obtained using the following formula:

$$\text{VKT (year } j) = \sum_{age\ i} \text{\# of vehicles of age } i \text{ in year } j \;*\; \text{Average annual VKT for vehicles of age } i \text{ in year } j$$

- **Fuel Use**

Given the historical and projected VKT and average new vehicle fuel consumption for each model year, this part of the worksheet calculates similarly the fuel use for each fleet by aggregating the fuel use of different model year.

$$\text{Fuel use (year } j) = \sum_{age\ i} \text{\# of vehicles of age } i \text{ in year } j$$

$$* \text{ Average annual VKT for vehicles of age } i \text{ in year } j$$

$$* \text{ Fuel consumption of corresponding model year}$$

4.2.3 Module 3: New Vehicle Fuel Consumption

The "Fuel Consumption" worksheet allows for the modeling of the technology scenarios. This is done by extrapolating the historical fuel consumption data of the average new vehicle, for passenger cars and light-duty trucks, according to five technology scenarios.

For each scenario, this worksheet consolidates the performance characteristics of each considered technology and calculates the average new vehicle on-road fuel consumption for the passenger cars and light-duty trucks fleet. These projected new vehicle fuel consumptions serve as an input to the fuel use estimates. The subsequent calculations of the model allow no distinction between the different technologies and use the average new vehicle fuel consumption for passenger cars and light-duty truck fleet instead of tracking each technology itself. The latter alternative is not needed for the purpose of this study since only petroleum-based fuels are considered. Alternative fuels would have necessitated a separate tracking for each technology. If needed, tracking the different technologies is still possible by replicating the separate fleet models for each type of vehicle.

In all the considered scenarios, the percentage improvement of light-duty trucks fuel consumption relative is assumed to be the same as the improvement for passenger cars. Historically, compared to the 1976 fuel consumption values, the light-duty trucks fuel consumption decrease has been about 62% of passenger cars fuel consumption improvement (1976-1999 average). However, several automakers claim that there is a bigger potential for improving light-duty trucks fuel consumption (NRC, 2001).

The new vehicle fuel consumption data that are fed in the model are non-adjusted EPA and vehicle calculation values. A 17% increase has been applied to adjust fuel consumption of new vehicle to on-road values. All the vehicle fuel consumption values used in the model's calculations are adjusted to on-road values. The estimation of the correction factor is presented in table 4-4. The decrease in the percentage difference between non-adjusted and adjusted values is due to the increasingly more important reduction in fuel consumption on the highway driving cycle relative to the city driving cycle. The 17% adjustment factor was also applied to ICE-Hybrid vehicles since no experimental data is available for on-road fuel consumption for this type of vehicle.

Potential Extensions of the Model

The model could be extended to include alternative fuel vehicles by duplicating the cars-specific and light truck-specific section and apply them for the new technology vehicle to take into account different patterns like the energy density of the fuel or reduced travel (i.e. reduced range of battery-electric vehicles).

In addition, similar to the fuel use calculation, a simple worksheet could be used to estimate the fleet emissions other than CO_2. However a certain level of aggregation among technologies is needed to avoid the complexity of dealing with too many technology-based fleets.

Finally, the model can easily be extended to Heavy Duty Vehicles.

Table 4-4: Estimated On-Road Fuel Consumption for New Cars, 1975-1999

CARS

MODEL YEAR	mpg City	mpg Highway	mpg 55/45 combined Unadjusted	mpg 55/45 combined Adjusted	mpg 55/45 combined % Difference	L/100km City	L/100km Highway	L/100km 55/45 combined Unadjusted	L/100km 55/45 combined Adjusted	L/100km 55/45 combined % Diff.
1975	13.7	19.5	15.8	13.5	17.4%	17.2	12.1	14.9	17.4	17.4%
1976	15.2	21.3	17.4	14.9	17.4%	15.5	11.0	13.5	15.8	17.4%
1977	16.0	22.3	18.3	15.6	17.4%	14.7	10.5	12.8	15.1	17.4%
1978	17.2	24.5	19.9	16.9	17.3%	13.7	9.6	11.8	13.9	17.3%
1979	17.7	24.6	20.3	17.2	17.4%	13.3	9.6	11.6	13.6	17.4%
1980	20.3	29.0	23.5	20.0	17.3%	11.6	8.1	10.0	11.8	17.3%
1981	21.7	31.1	25.1	21.4	17.3%	10.8	7.6	9.4	11.0	17.3%
1982	22.3	32.7	26.0	22.2	17.2%	10.5	7.2	9.0	10.6	17.2%
1983	22.1	32.7	25.9	22.1	17.2%	10.6	7.2	9.1	10.7	17.2%
1984	22.4	33.3	26.3	22.4	17.2%	10.5	7.1	9.0	10.5	17.2%
1985	23.0	34.3	27.0	23.0	17.2%	10.2	6.9	8.7	10.2	17.2%
1986	23.7	35.5	27.9	23.8	17.1%	9.9	6.6	8.4	9.9	17.1%
1987	23.9	35.9	28.1	24.0	17.1%	9.8	6.6	8.4	9.8	17.1%
1988	24.2	36.6	28.6	24.4	17.1%	9.7	6.4	8.2	9.6	17.1%
1989	23.8	36.3	28.2	24.1	17.1%	9.9	6.5	8.4	9.8	17.1%
1990	23.4	36.0	27.8	23.7	17.0%	10.1	6.5	8.5	9.9	17.0%
1991	23.6	36.3	28.0	23.9	17.0%	10.0	6.5	8.4	9.8	17.0%
1992	23.1	36.3	27.6	23.6	17.0%	10.2	6.5	8.5	10.0	17.0%
1993	23.6	37.0	28.2	24.1	17.0%	10.0	6.4	8.3	9.8	17.0%
1994	23.4	36.9	28.0	24.0	17.0%	10.1	6.4	8.4	9.8	17.0%
1995	23.6	37.6	28.4	24.2	16.9%	10.0	6.3	8.3	9.7	16.9%
1996	23.5	37.6	28.3	24.2	16.9%	10.0	6.3	8.3	9.7	16.9%
1997	23.7	37.7	28.5	24.3	16.9%	9.9	6.2	8.3	9.7	16.9%
1998	23.8	38.2	28.7	24.5	16.9%	9.9	6.2	8.2	9.6	16.9%
1999	23.4	37.3	28.1	24.0	16.9%	10.1	6.3	8.4	9.8	16.9%
				Avg.	**17.1%**				**Avg.**	**17.1%**

Source: EPA, Transportation Energy Data Book Ed. 19

4.3 Projections of Technology Penetration

In all the technology scenarios, the input parameters other than the new vehicle fuel consumption remain constant, i.e. the estimated average annual growth rate of new vehicle sales (0.8% per year), the annual growth rate of the average per-vehicle kilometers of travel (0.5% per year) and the evolution of the share of light trucks in new light duty vehicle sales (60% market share in 2030).

The five technology scenarios that were considered are following:

(1) Reference Scenario (No change)

The new car and light duty trucks fuel consumption remain at the levels of 1999 until 2030 (estimated on-road fuel consumption of 9.8 L/100km for cars and 13.7 L/100km for light trucks). The likelihood of no progress over such a period of time is small. However, this scenario constitutes a useful reference for comparison.

(2) Baseline

The baseline scenario assumes a steadily decreasing fuel consumption of new vehicles as technologies for reducing vehicle fuel consumption are progressively being rolled out into the automakers' fleets, provided that the performance increase is not traded for weight and other amenities, which was the case during the past decade.

The fuel consumption decreases by 5% in 2005 and reaches in 2020 the 35% reduction calculated in the technology assessment study "On the Road in 2020" (Weiss *et al.*, 2000). Further decrease is assumed to be less important (down to 50% of 1999 fuel consumption in 2030), allowing for diminishing returns in fuel consumption reduction. The relative improvements are the same for all light duty vehicles.

(3), (4), and (5) Advanced Vehicles with Internal Combustion Engines-Hybrids

To drastically reduce fuel consumption, one has to consider more advanced technologies relative to the conventional ones accounted for in the baseline. In this study, we consider vehicles having an advanced body design (further reduction in mass, drag and tire rolling resistance), and powered by Internal Combustion Engine-Hybrid. Three scenarios were designed to model the introduction of ICE-Hybrids in the light duty vehicle fleet. Here again, the relative improvement for light duty trucks is supposed to be the same as for passenger cars.

The current average fuel consumption of hybrids is determined by evaluating the fuel consumption the TOYOTA PRIUS would have if this vehicle had a mass equal to the average mass of new passenger cars. Ideally, this adjustment should have been done relative to the mass of the vehicle without the powertrain. Due to the unavailability of data, the total mass was considered. The 2020 fuel consumption is the one calculated by the MIT technology assessment for the advanced gasoline ICE-Hybrid vehicle. Between these two levels, we assume a linear decrease. However, extrapolating this trend to 2030 would lead to a 72% reduction relative to the 1999 baseline fuel consumption level, which appears to be excessive. Therefore, we assumed a less steep slope, leading to a 66% improvement (5% better than the 2020 value) relative to the 1999 baseline fuel consumption in 2030.

In addition to the hybrid vehicle performance improvement pattern developed above, a market penetration scenario is needed. Three cases were considered:

- a low penetration scenario with a long run market share of 25%,
- a medium penetration scenario with a long run market share of 50%,
- a high penetration scenario with a long run market share of 75%.

Given these parameters, sales-weighted fuel consumption is calculated for each calendar year and for both passenger cars and light duty trucks fleet and serves as an input to the fuel use calculations.

Table 4-5: Market Penetration Scenarios for ICE-Hybrids Vehicles

	LOW		MEDIUM		HIGH	
Year	**%**	**Thousand Vehicles**	**%**	**Thousand Vehicles**	**%**	**Thousand Vehicles**
2005	0.5%	82	1.0%	163	1.5%	245
2010	2.1%	357	4.2%	713	6.2%	1,053
2015	7.2%	1,273	14.5%	2,563	22%	3,836
2020	16%	2,962	32%	5,942	48%	8,904
2030	24%	4,841	48%	9,702	73%	14,543

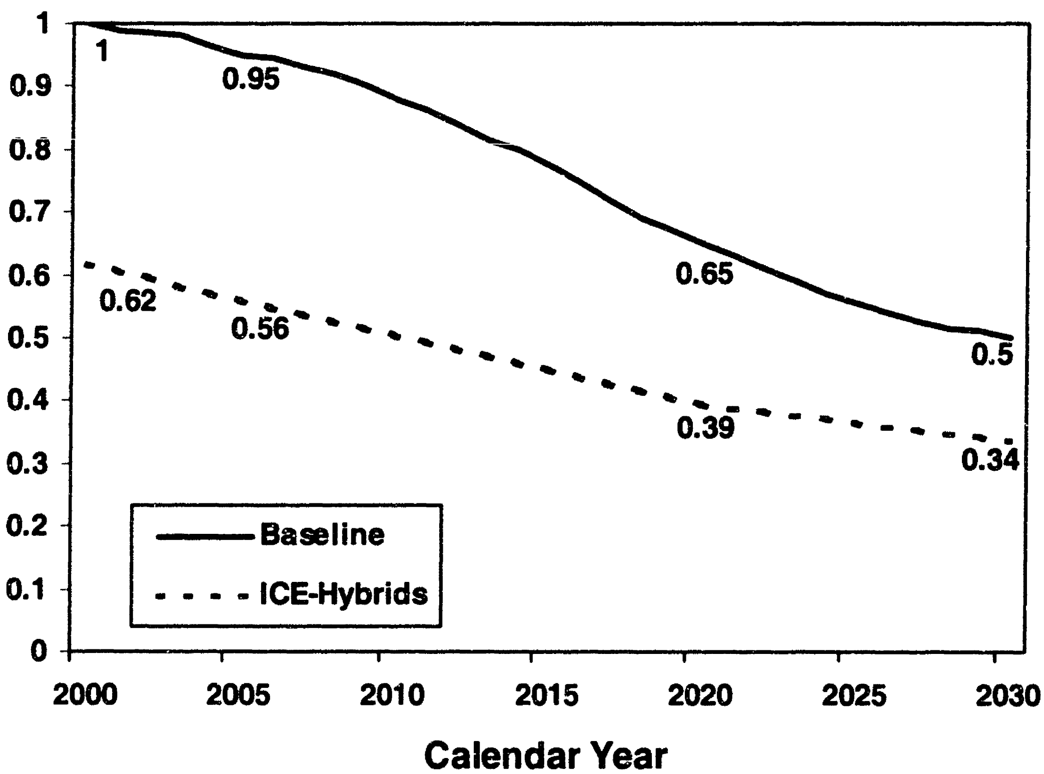

Figure 4-1: Relative Improvement in Fuel Consumption Over the 1999 New Car Average

Chapter 5: Scenarios and Analysis

Introduction

In this chapter, the previously described projections of new light-duty vehicle sales, passenger cars and light truck mix, and the vehicle kilometers of travel are combined and a reference or "No Change" scenario is constructed. The total light-duty vehicle fleet fuel consumption and energy use are calculated for the projected stock composition and travel. Four alternative technology scenarios are then developed, taking into account various levels of fuel consumption reduction from the vehicle technologies identified in chapter 3.

The reference scenario as well as the other technology scenarios assumes a continued light vehicle sales growth (0.8%), and a constant growth rate of the average annual per-vehicle kilometers of travel (0.5%). Due to the stabilization of the stock composition (the median age is kept constant after 2000), the total annual VKT growth rate decreases from a value of 1.8% in 2000 to 1.2% in 2025.

The share of light-duty trucks in total new light-duty vehicle sales is assumed to continue its evolution from the current level of about 50% and stabilize at a 60% market share in 2030. Consequently, the number of light trucks in the fleet equals the number of cars in 2011 and in 2030, light trucks account for 57% of the fleet, while their share of energy and fuel use is even bigger.

A sensitivity analysis to other input parameters is performed in section 5.2. Section 5.3 aggregates improvements resulting from the introduction of technology, reduced share of light trucks, reduced new vehicle sales and VKT growth to build a composite scenario. Finally, the results are discussed in section 5.4

Because the costs of adopting one technology rather than another were not analyzed, and because the tradeoffs were not assessed, this study does not identify a "best" alternative to reduce the U.S. light duty vehicle fleet energy use. The objective is rather to provide estimates of the improvements that can be expected from each alternative.

5.1 Technology Scenarios and Results

5.1.1 Reference Scenario

This scenario assumes that light vehicle fuel consumption is not reduced over the next 30 years. This trend continues the evolution witnessed during the last ten years with fuel economy being traded for performance, power, weight and other amenities while the CAFÉ standards remained unchanged. The likelihood of no progress over such a period of time is small. However, this scenario constitutes a useful reference for comparison.

Actually, significant technological improvements have occurred over the last decade, but despite the recent announcement of fuel economy improvement initiatives by Ford, General Motors and DaimlerChrysler, there is no clear reason why the general trend would change if not forced by regulation.

The figure below shows the light duty vehicle fuel use estimates according to the reference scenario. Total fuel use grows steadily because of the stock and VKT growth. The 2020 level (680 billion liters of gasoline per year) is nearly 75% higher than the 1990 level (390 billion liters per year, about million barrels per day) with light trucks accounting for about two thirds of the total fuel use in 2020.

Fleet Fuel Use for the Reference Case

Year	Billion Liters	Million Barrels per Day (Mbd)
1990	390	6.7
2000	475	8.2
2010	580	10.0
2020	680	11.7

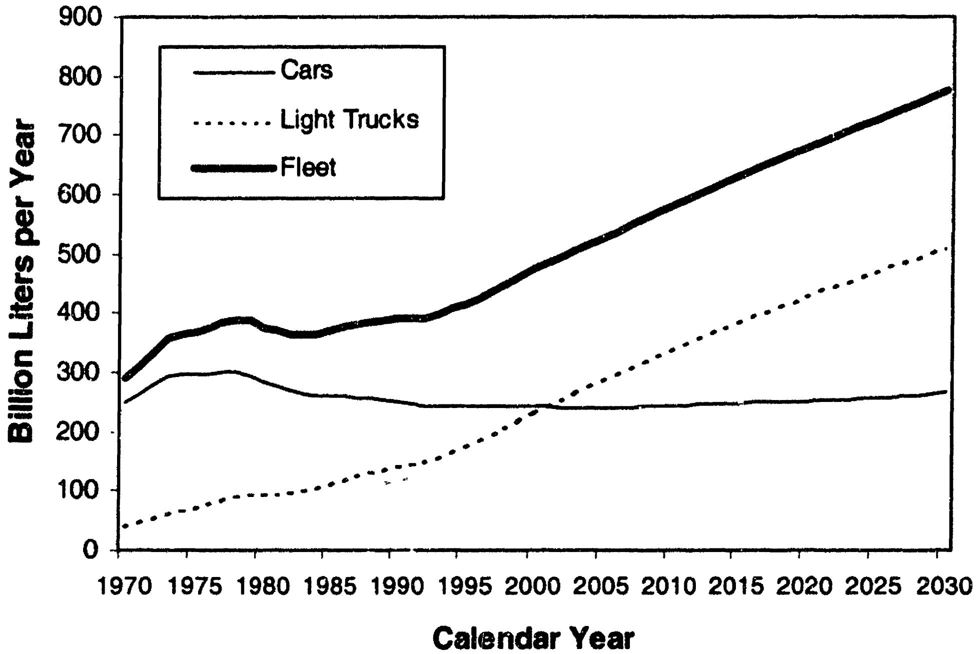

Figure 5-1: Light-Duty Vehicles Fuel Use under the Reference Scenario

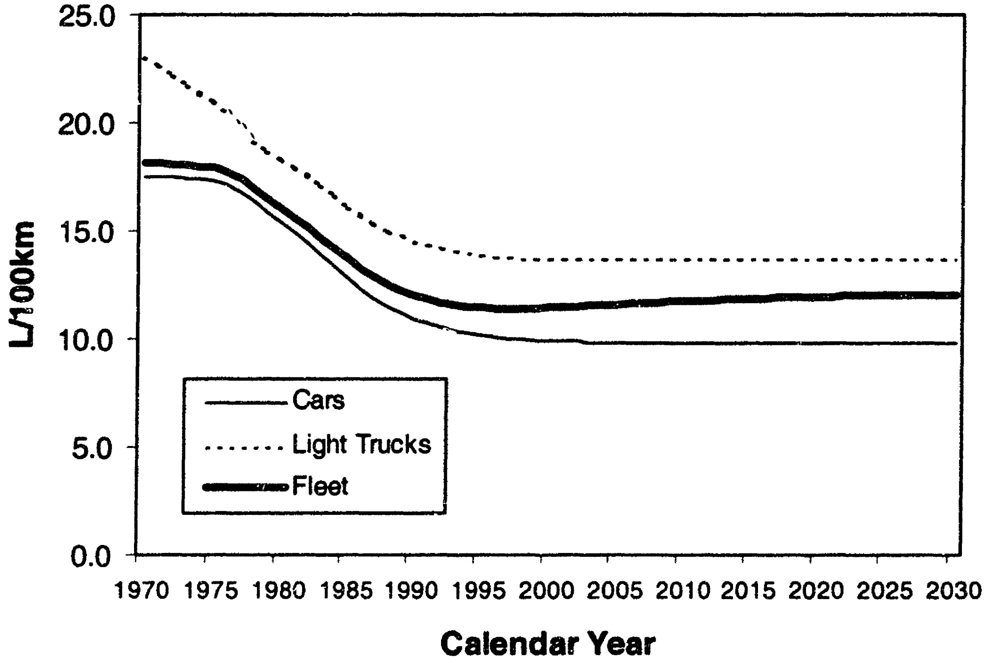

Figure 5-2: Average Light-Duty Vehicles Fuel Consumption under the Reference Scenario

5.1.2 Baseline Scenario

Relative to the reference case, this scenario assumes that fuel economy is no longer completely traded for performance. Indeed, technologies aiming at reducing vehicle fuel consumption are progressively rolled out into the fleets. As a result, the average new car fuel consumption decreases steadily, by 5% in 2005 relative to the 1999 level and by 35% in 2020 as calculated in the previous MIT technology assessment study. The improvement in fuel consumption is then extrapolated to 50% of the 1999 level in 2030.

As mentioned in chapter 4, the same percentage improvement in fuel consumption is applied for new light trucks in absence of a specific technology assessment. In 2020, new cars and new light trucks estimated on-road fuel consumption average 6.4 L/100km and 8.9 L/100km compared to the 1999 values of 9.8 L/100km and 13.7 L/100km respectively.

Moreover, this scenario assumes a 100% sales penetration each year of the appropriate baseline technology (Fig. 4-1). This situation is likely to occur if regulatory mandates like CAFÉ are sufficiently tightened in the future.

The cumulative effect of less fuel consuming new light duty vehicle allows significant fuel savings compared to the reference case. Around 2015, the fuel consumption reduction offsets the growth in the stock and VKT and the total fuel and energy use begin to decrease. The maximum fleet fuel use under the baseline scenario is 562 billion liters of gasoline per year in 2015. The 2020 level of energy use represents a 20% reduction over the reference case (40% reduction in 2030). However, that level is still 40% higher than the 1990 level and the 2030 level of energy use is 19% higher than the 1990 level.

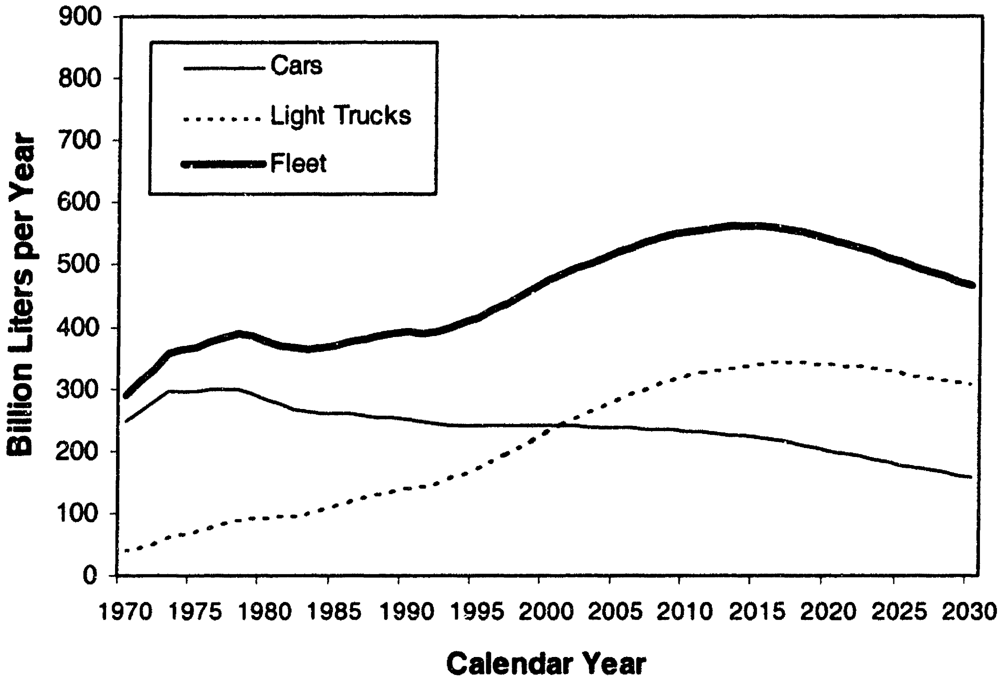

Figure 5-3: Light-Duty Vehicles Fuel Use under the Baseline Scenario

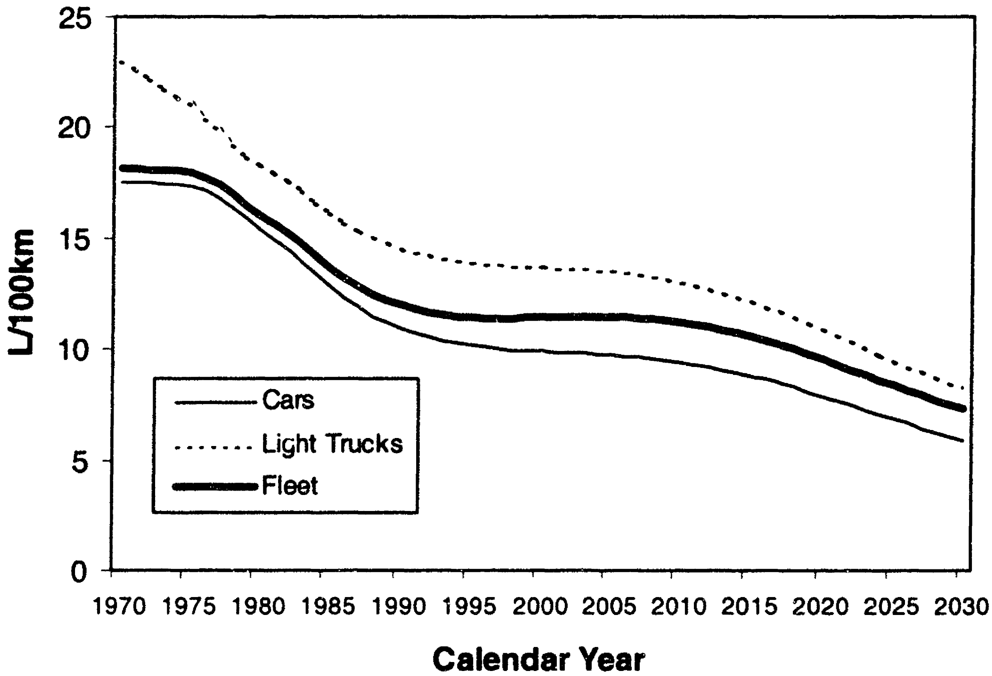

Figure 5-4: Average Light-Duty Vehicles Fuel Consumption under the Baseline Scenario

5.1.3 Baseline + Advanced ICE-Hybrids

In this scenario, ICE-Hybrids vehicles with advanced body design are substituted progressively for the baseline vehicles defined above. According to three sub-cases, Low Medium and High, the hybrid vehicles market share gradually increases to 25%, 50% and 75% of the light vehicle market share in the long run. Here again, light trucks are supposed to gain the same percentage improvement in fuel consumption and the share of hybrids in new light vehicle is assumed to be identical for cars and light trucks.

Relative to the model year 1999 average new car, the hybrid technology allows a fuel consumption reduction of 39% in 2000, 44% in 2005, 61% in 2020, and 66% in 2030. Therefore, ICE-Hybrids cars and trucks have an estimated on-road fuel consumption of 6.1 L/100km and 8.4 L/100km in 2000, 3.9 L/100km and 5.4 L/100km in 2020 respectively.

Qualitatively, the evolution for the level of fuel use is the same than for the baseline scenario: it peaks around 2013 and starts to decline steadily as new car fuel consumption reduction offsets total stock and VKT growth. The additional improvements in total fuel use allow decreasing the baseline fuel use figures by 2.6%, 5.2%, and 7.9% for the low, medium and high market share cases in 2020 and by 6.2%, 12.4% and 18.6% in 2030.

The relatively small improvements are mostly due to dynamics of the stock of light-duty vehicles. Changes in new vehicle characteristics take between 10 to 15 years to affect significantly the fleet performance. This is the reason why, the decrease of the level of the light vehicle fleet energy use happens only after the year 2013 and the incremental improvements due to the introduction of hybrids becomes to be significant around 2030. The same reason explains why, all things being equal, the constant level of fuel consumption over the past decade will cause fleet fuel use to increase over the next 10 to 15 years due to VKT and stock growth. In any case, this matter of fact indicates that if any of the presented paths were to be taken, the sooner the better.

All things being equal, sustaining the decrease in the fleet energy use or stabilizing it requires a steady fuel consumption reduction for new vehicles to counterbalance the effect of stock growth and increasing VKT. This issue is addressed in section 5.4.

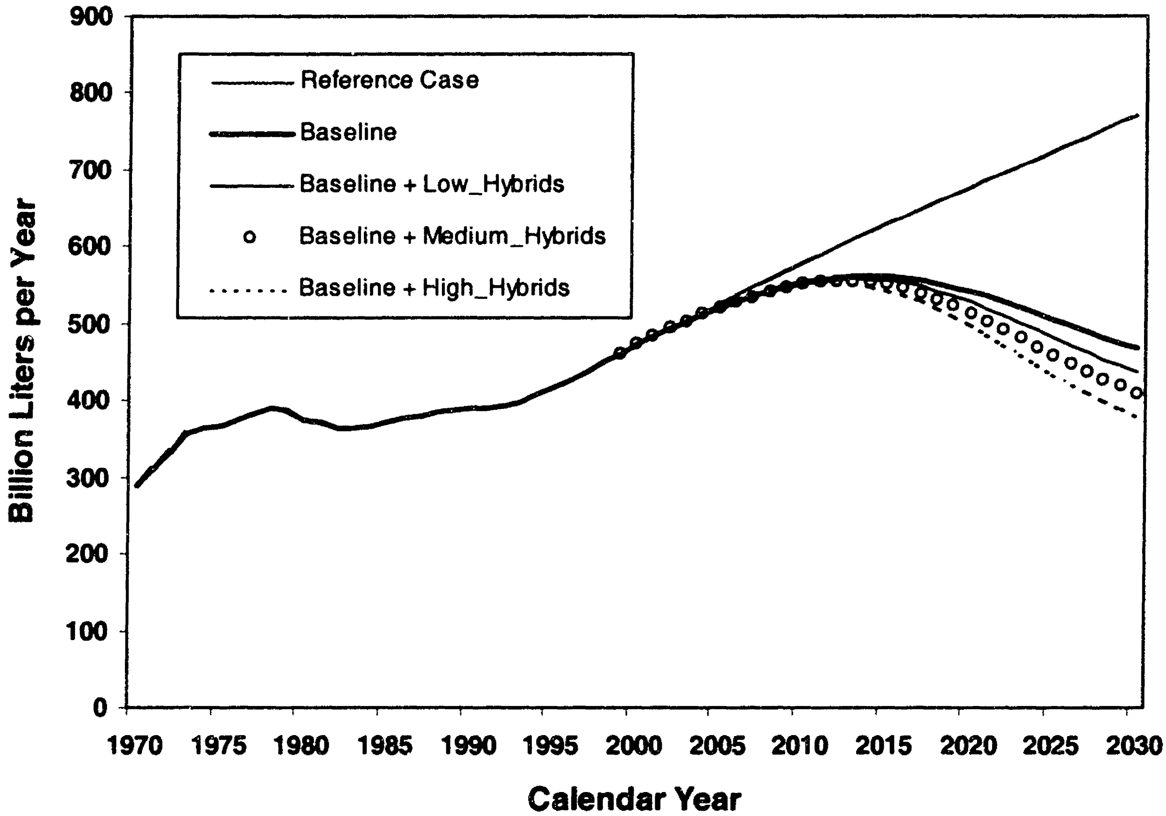

Figure 5-5: Light-Duty Fleet Fuel Use for Various Technology Scenarios

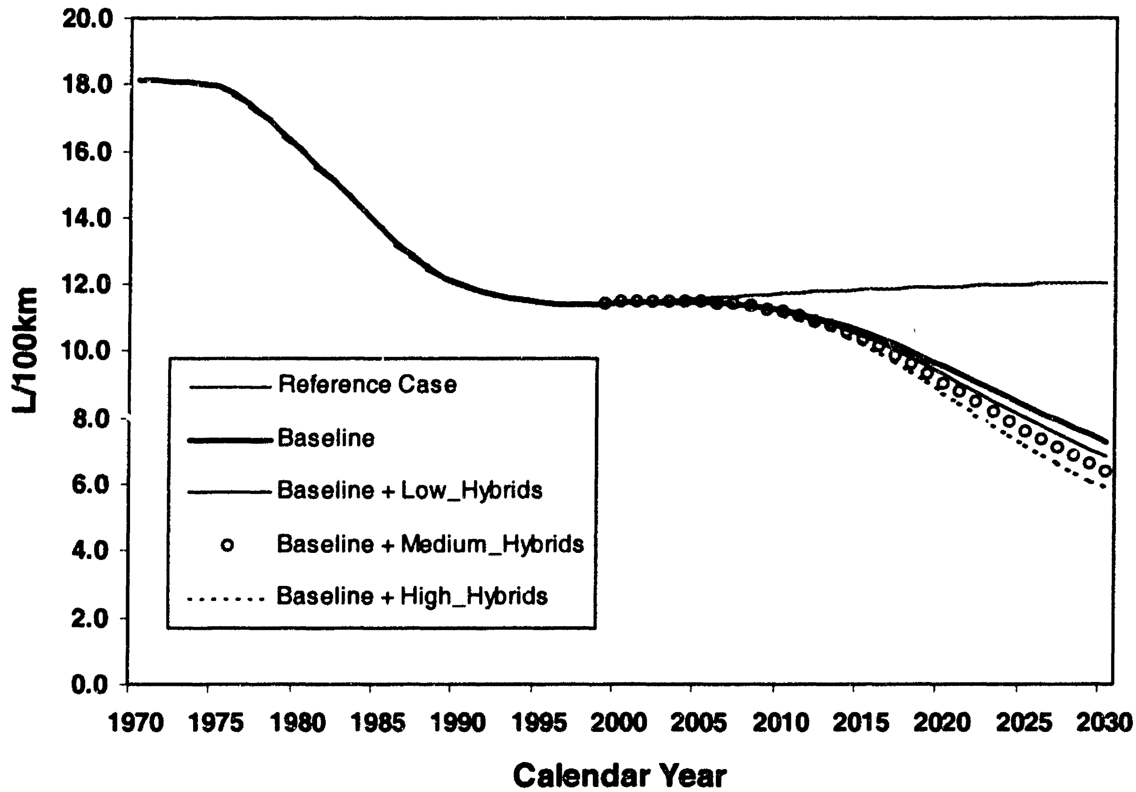

Figure 5-6: Average Light-Duty Fleet Fuel Consumption for Various Technology Scenarios

5.2 Sensitivity to Other Input Parameters

In the previous section, the effects of introduction of fuel saving technologies on the light vehicle fleet energy and fuel use have been evaluated. However, other parameters might have a significant impact and they could constitute potential levers to act upon towards the goal of reducing the U.S. light duty vehicle fleet energy use. The objective of this section is to perform a sensitivity analysis to the other identified parameters affecting fuel use which are: (1) sales mix, (2) new vehicles sales growth rate, and (3) average annual per-vehicle VKT growth rate.

5.2.1 Sensitivity Relative to Sales Mix

In addition to the reference case assumption of 60% market share of light truck in 2030, three alternatives have been introduced. A 50%, 40% and 30% 2030 light duty truck market share were considered. The results are presented in the table below.

Table 5-1: Sensitivity Analysis Relative to Light Truck Share of New Vehicle Sales

Fuel use (Billion liters)	2030 Market Share			
	Reference case (60%)	50%	40%	30%
No Change				
2020	679	-0.7%	-1.3%	-2.0%
2030	774	-1.6%	-3.3%	-4.9%
Baseline				
2020	541	-0.6%	-1.2%	-1.8%
2030	467	-1.5%	-3.1%	-4.6%

The maximum reduction in fleet energy use due to changes in light truck market share is 2% in 2020 and 5% in 2030 for a decrease in the share of light trucks to 30% of new sales in 2030. This reduction is even less important if measured relative to the baseline fuel use level.

This result reflects what Greene and Fan (1995) found in a previous study: the shift from cars to light trucks has a negative effect on fuel economy but the net result was only about one half MPG improvement in the combined fuel economy of passenger cars and light trucks (in 1996) over what it would have been had the size class market shares been frozen at 1975 values. More, in this case, the share is allowed to decrease progressively to the 2030 target market share. If one considers the time required for the changes in composition to permeate throughout the whole light duty vehicle fleet, the effect of reducing the light truck share is smaller than if that share was held constant equal to its target value within the considered timeframe (2000-2030).

The increasing popularity of sport utility vehicle has *de facto* a negative effect on fleet fuel consumption. What this analysis shows is that this effect can be easily offset by even a small level of introduction of fuel efficient technologies.

5.2.2 Sensitivity Relative to New Sales Annual Growth Rate

The reference case assumes a 0.8% annual growth rate for the new light duty vehicle sales. The following analysis has tested a no growth situation as well as scenarios where this average annual growth rate is halved (0.4%) or doubled (1.5%).

Table 5-2: Sensitivity Analysis Relative to New Sales Annual Growth Rate

Fuel use (Billion liters)	Annual Sales Growth rate			
	Reference case (0.8%)	0%	0.4%	1.5%
No Change				
2020	679	-11.4%	-5.9%	11.2%
2030	774	-18.0%	-9.5%	19.1%
Baseline				
2020	541	-10.9%	-5.6%	10.7%
2030	467	-17.4%	-9.1%	18.3%

Keeping the current levels of new light vehicle sales (no growth) lead to fuel savings as big as 11.4% of the reference case in 2020 and 18% in 2030. However, due to the population growth and the increasing motorization rate in the U.S., this situation is unlikely. But it is reasonable to consider a slow down in new light vehicle sales that might be caused by an increase in the cost of ownership for instance. Half the reference case growth rate leads to saving an additional 6% of the corresponding energy use in 2020 and 9.5% in 2030.

5.2.3 Sensitivity Relative to per-Vehicle VKT Annual Growth Rate

In the reference case, the average annual per-vehicle VKT grows at a rate of 0.5% from 2000 to 2030. The effect of a reduction or an increase of that number is studied hereafter.

Table 5-3: Sensitivity Analysis Relative to per-Vehicle VKT Annual Growth Rate

Fuel use (Billion liters)	Annual per-Vehicle VKT Growth Rate			
	Reference case (0.5%)	0%	1%	1.5%
No Change				
2020	679	-8.1%	8.1%	16.3%
2030	774	-11.7%	11.7%	23.4%
Baseline				
2020	541	-8.1%	8.1%	16.3%
2030	467	-11.7%	11.7%	23.4%

The results show that all things being equal, a 0% growth of travel can lead to fuel saving of 8% of the reference case level in 2020 and nearly 12% in 2030. Successful travel reduction strategies can have a significant impact on the fleet energy use.

Unlike technology-based improvements, travel and new sales reduction strategies can take effect in the short term. For that reason, they should be included in fleet energy use reduction initiatives.

5.3 Composite Scenario

Building upon the previous analysis of the technology-based scenarios and the effects of the different input parameters, a composite scenario is developed. Relative to the reference case and the baseline, the composite scenario considers the introduction of advanced ICE-Hybrids under the medium market share assumption (50% target market share), concurrently with the baseline vehicles. In addition, the annual new vehicle sales growth rate is halved (0.4%) while the annual per-vehicle VKT is assumed to remain constant (0% growth). Furthermore, this scenario assumes a decline in the market share of light trucks to 40% in 2030.

Such a composite scenario illustrates the potential impacts a series of measures can have on the fleet fuel consumption and energy use.

Table 5-4: Savings in Light-Duty Vehicle Fleet Fuel Use for Chosen Actions

Fuel Use (Billion liters)	Reference Case	Baseline	Baseline + Medium Hybrids	0.4% Sales Growth	0% VKT Growth	40% Light Truck Share	Composite
2020	679	-20.3%	-24.5%	-24.8%	-26.8%	-21.3%	-35.2%
2030	774	-39.6%	-47.1%	-45.1%	-46.7%	-41.5%	-58.8%
2020		541	-5.2%	-5.6%	-8.1%	-1.2%	-18.7%
2030		467	-12.4%	-9.1%	-11.7%	-3.1%	-31.7%

The composite scenario allows decreasing the 2020 fleet fuel and energy use to the 1997 level (440 billion liters per year), still 12% over the 1990 level, and forecasts an additional 23% decrease in 2030 to reach the 1972 level approximately (320 billion liters per year, 18% below the 1990 level).

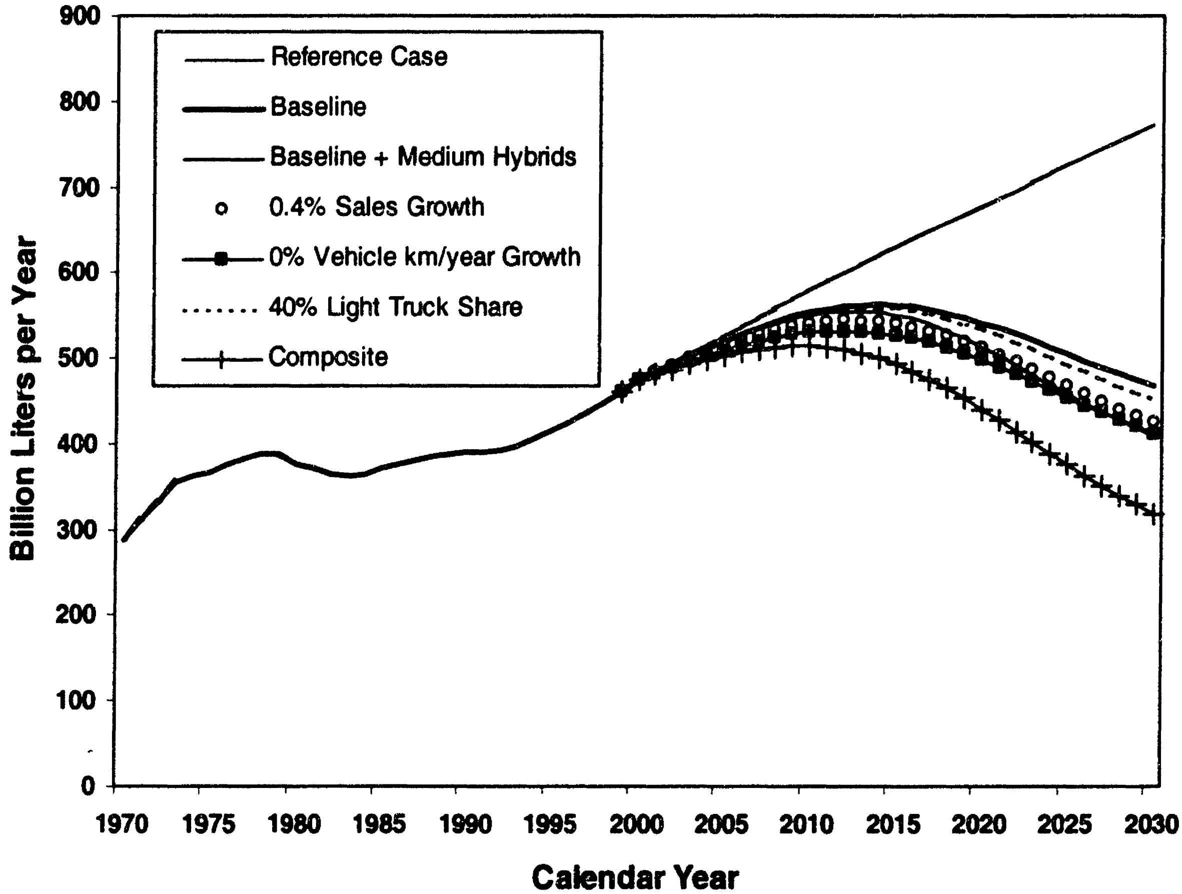

Figure 5-7: Light Duty Fleet Fuel Use for Various Scenarios

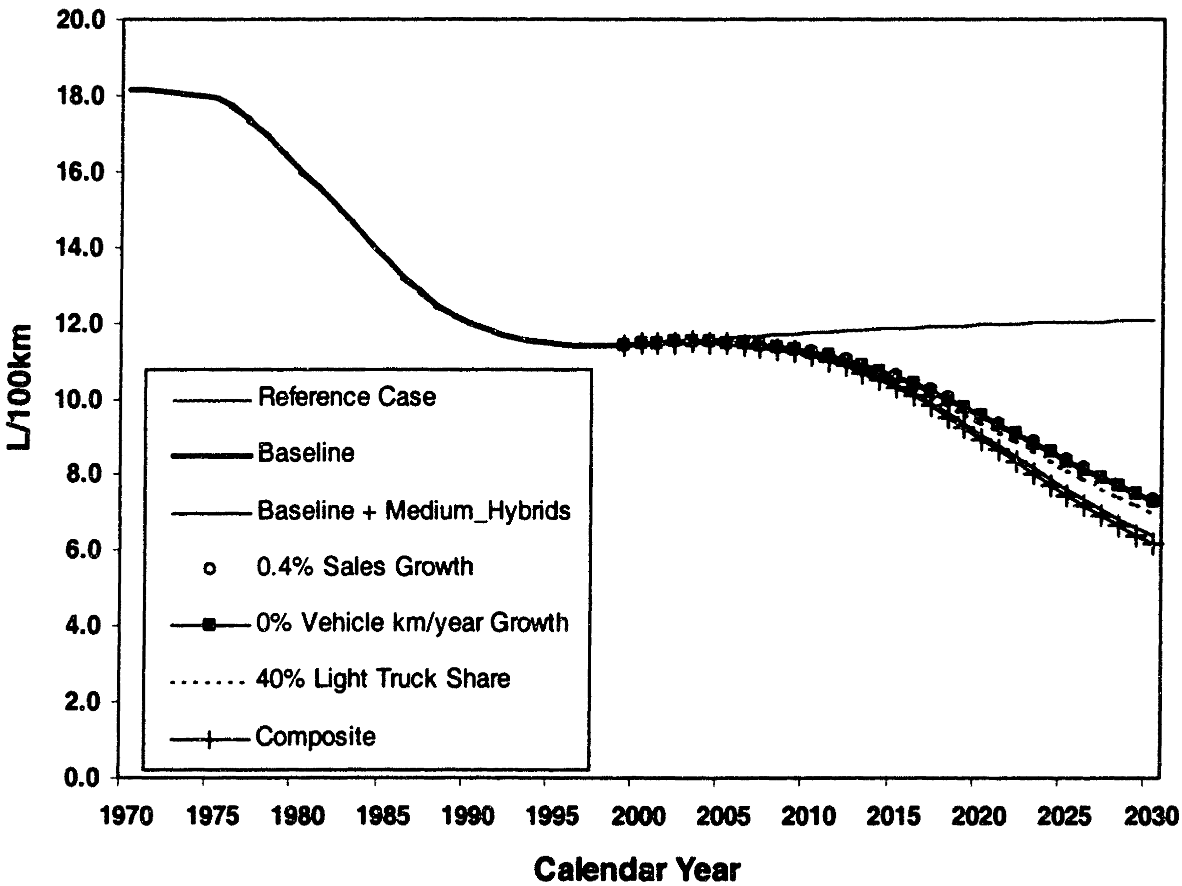

Figure 5-8: Average Light-Duty Fleet Fuel Consumption for Various Scenarios

5.4 Discussion

Several lessons can be derived form the previous analysis. First, the reduction of new vehicle fuel consumption of the evolving baseline provides the most significant savings in fleet energy use over all the other considered measures. These effects on new vehicles take time to permeate through the whole fleet. As a matter of fact, several years will pass before the effects are noticed and the stagnant level of new vehicle fuel consumption of the past decade will transpose the current increasing trend in fleet energy use at least for another 10-year period. This shows the benefits of early action.

An increasing share of sport utility vehicles will have only a modest effect on fleet energy use. Measures like travel reduction and slowing down of the stock increase have a bigger relative impact on fleetwide fuel savings. Considering the baseline scenario as a reference, the effect of the latter measures is comparable in magnitude to the introduction of advanced ICE-Hybrids vehicles in the fleet. Note that the impacts of these different levers are additive and the composite scenario illustrates that considerable reduction in fleet fuel consumption can be achieved with actions on the majority of factors evaluated.

Travel and stock reduction strategies have an immediate effect on fleet fuel consumption. Indeed, as shown on figure 5-7, the total fleet energy use for the composite scenario peaks in 2020, five years earlier than what would be achieved if only technology strategies were considered.

It is important to notice that, with the assumptions of the reference scenario (on sales mix, sales and VKT growth), the model predicts that a minimum annual rate of reduction of new vehicle fuel consumption of 1.3% is needed to offset the effects of stock and VKT growth and stabilize the total light duty vehicle fleet fuel use as shown on the figure below. This number is sensitive to new vehicle sales growth rate and per-vehicle annual VKT growth rate and should not be considered on an absolute basis. The main point is that a continuous decrease in new vehicle fuel consumption is needed to limit the growth of light-duty vehicle fleet fuel and energy use.

However it is also important to keep in mind that the potential barriers to adopt the measures whose effects have been evaluated in this chapter have not been assessed. In fact, only the potential benefits were outlined. Such an assessment will be needed in order to design effective policies.

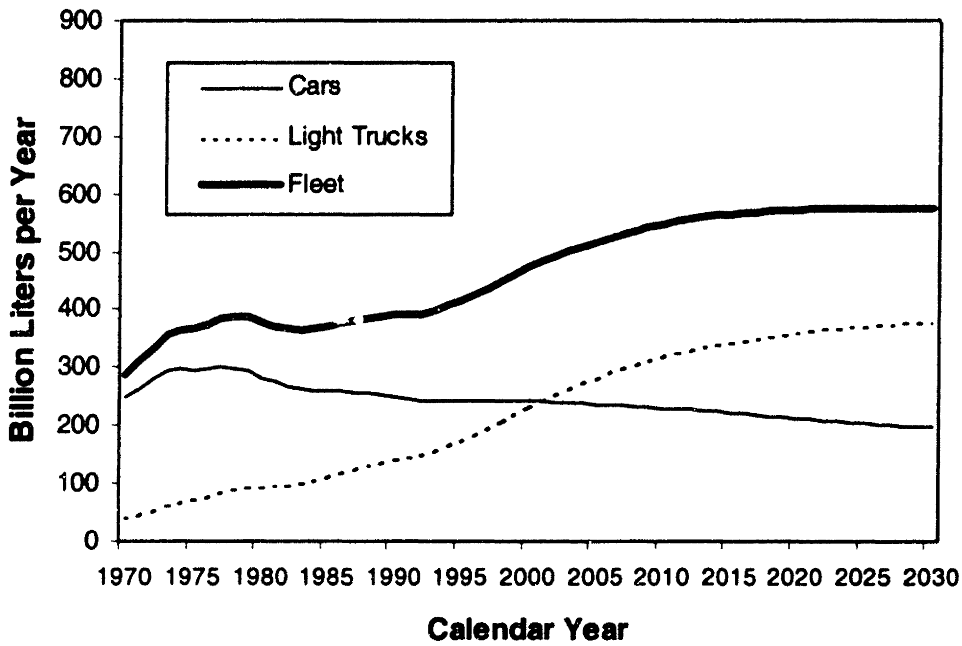

Figure 5-9: Stabilization in light-duty vehicle fleet fuel use due to a steady 1.3% annual decrease in average new vehicle fuel consumption (baseline vehicles only).

Chapter 6: Policy Considerations

A number of options are available to the policy maker in regard to the objective of reducing the light duty vehicle fuel consumption and energy use. Some of these options address the supply side by fostering the development and the introduction of less energy consuming vehicles (through reduced gasoline consumption or alternative fuels with higher energy density) while other options deal with the reduction of travel demand or reducing travel demand for energy and/or carbon intensive means of transportation. Birky *et al.* (2000) classify the available policy instruments into four categories: (1) Regulatory, (2) Research, Development and Demonstration, (3) Fiscal and, (4) Information and Education.

To date, the U.S. has chosen to pursue reduced light-duty fuel use primarily through policies aimed at vehicle fuel economy. The U.S. Government attempts fall into categories (1) and (2) listed above. The first step, starting back in 1975, was to enact fuel economy regulation (CAFE), and recent policies has focused on research, development with the Partnership for a New Generation of Vehicles (PNGV). While the PNGV has made substantial progress, update of the CAFE standards have been actively and successfully resisted by the industry over the past decade and until now.

Given the inefficiencies of the fuel economy market and the risk of a marginal commercial adoption of successful R&D results, and considering the effects of continuing the stagnant conditions of the past decade on the future fleet fuel and energy use, actions will need to be taken by the Federal Government and the other stakeholders if significant petroleum and greenhouse gas emissions reductions are to be achieved.

This chapter elaborates on the existing measures and discusses other policy options available to contribute to the reduction of the fleet energy use and greenhouse gas emissions.

6.1 Regulatory Measures: Improving New Light-Duty Vehicle Fuel Economy

The 1975 Energy Policy and Conservation Act established among other things, mandatory fuel economy standards for passenger cars and light trucks sold in the U.S. Since 1975, domestic new car fuel economy has roughly doubled; the fuel economy of imports has increased by about one-third, and the fuel economy of light trucks has improved by more than 50%.

However, the effectiveness of the Corporate Average Fuel Economy (CAFE) standards themselves has been controversial. Some argue that these improvements would have happened as a consequence of rising oil prices during the 1970s and 1980s. Some studies suggest that the majority of the gains in passenger car fuel economy during the 1970s and 1980s were technical achievements, rather than the consequence of consumers' favoring smaller cars. Between 1976 and 1989, roughly 70% of the improvement in fuel consumption was the result of weight reduction, improvements in transmissions and aerodynamics, wider use of front-wheel drive, and use of fuel injection. The fact that overall passenger car fleet fuel economy has remained comparatively flat during a period of declining real prices for gasoline also suggests that the CAFE regulations have contributed to placing some sort of floor under new-car fuel economy.

General criticisms of raising the CAFE standards have been that, owing to the significant lead times manufacturers need to change model lines and because of the time needed for the vehicle fleet to turn over, increasing CAFE is a slow and inefficient means of achieving reductions in fuel consumption. Further, it is argued that the standards risk interfering with consumer choice and jeopardizing the health of a recovered domestic automotive industry. Some argue that raising the CAFE standards would be an ineffective or marginal way to reduce emissions of carbon dioxide. On one hand, improvements in fuel economy should enable the same vehicle to burn less fuel to travel a given distance. However, to the extent that technologies to improve fuel economy add cost to new vehicles, it has been argued that consumers will tend to retain older, less efficient cars longer. It has also been suggested that there is a correlation between improved fuel economy and an increase in miles driven and vehicle emissions. However, vehicle miles traveled have continued to increase in recent years when fuel economy improved only slightly, suggesting that the broader factor is the overall cost of driving, which is tied as well to the price of gasoline. The relationship between where people live and where they work is also a factor.

Proponents of a CAFE increase have argued that boosting the standards might bring about the introduction of technological improvements that do not compromise features that consumers value, but which would otherwise not be added because these improvements do add to the cost of a new vehicle.

By analyzing the principal claims against the mandate and confronting them with historical evidence, Greene (1997) has explained why the CAFE standards have been a successful energy policy and why this instrument is likely to be a part of any serious effort to achieve sustainable transportation.

There is a proven potential for improvement of new light vehicle fuel consumption by technology innovation. Significant benefits can be achieved in the short term at a relatively modest increase in costs. Whether forcing these improvements will reduce the customer value, have unbearable adverse effects or even threaten the domestic industry is the objective of a recent study by the National Research Council (NRC, 2001), mandated by the federal Government. In any case, the current CAFE standards do not reflect the "maximum feasible" target to be met. Future updates will be needed to sustain a downward trend in new vehicle fuel consumption.

The National Research Council report recognizes that raising CAFÉ standards would reduce future fuel consumption below what it otherwise would be. However, the report stresses that other policies could accomplish the same end at lower cost and provide more flexibility to manufacturers to continually decrease fuel consumption, while allowing them to meet consumer preferences. The proposed alternatives include tradable credits for fuel economy improvements, feebates (taxes on vehicles achieving more than average fuel consumption coupled with rebates on vehicles achieving less than the average fuel consumption), higher fuel taxes (see section 6.3), standards-based vehicle attributes, or some combination of these.

6.2 Research, Development and Demonstration: the Partnership for a New Generation of Vehicles (PNGV)

In late September 1993, President Clinton announced establishment of a government and industry research program, the Partnership for a New Generation of Vehicles (PNGV), that had among its goals development of an environmentally friendly "Supercar" that would as much as triple the fuel efficiency of today's mid-size cars without sacrificing performance, affordability, and safety. The PNGV is an effort to combine the resources and expertise of federal agencies and laboratories with the private sector to reduce U.S. dependence on oil and maintain competitiveness without intervening to alter the market price of fuel.

More precisely, the PNGV is a joint effort of the U.S. Government and the United States Council for Automotive Research (USCAR). The project has three goals:

(1) Significantly improve national competitiveness in manufacturing,

(2) Implement commercially viable innovations from on-going research to improve the technology of conventional vehicles in the near term, and

(3) Develop a vehicle (the “Supercar”) to achieve up to three times the fuel economy of today’s vehicles with equivalent customer purchase price and meeting the customers’ need for quality, performance and utility.

Production prototypes of the Supercar were projected to be ready by 2004. By early 1998, the PNGV completed its selection of technologies judged to hold the most promise for development of the Supercar. Research and development was to be focused on hybrid electric vehicle drive, direct-injection engines, fuel cells, and greater use of lightweight materials. Concept cars embodying ICE hybrid and other fuel economy improving technologies were demonstrated in 2000 on schedule.

Despite the technological advances, there is some uncertainty of producing a prototype that will have low enough cost and high enough consumer appeal to penetrate the motor vehicle market in sufficient volume to substantially reduce motor vehicle greenhouse gas emissions. In addition to that, the automotive industry is largely self-financed and competitive. This suggests that most of the advanced development will be made in-house and therefore the PNGV role will be that of a catalyst and a technology showroom but most of the production-focused efforts are likely to come from the industry.

Given the fact that for the automaker the pay-off for improving fuel economy is small and the risk is large, the incentive to perform research and development for market-driven fuel consumption improvement is also small, except if induced by the threat of future regulation or other policy measures. The PNGV is an attempt to move the relationship between the Federal Government and the auto industry into a more constructive direction.

6.3 Fiscal Measures: Gasoline Taxes

Owing to higher taxation of gasoline in other nations, Americans enjoy one of the lowest prices for gasoline in the world. As a consequence, an increase in crude oil price as was experienced during 1999 and 2000 results in a much greater increase, in percentage terms, in the price of gasoline here than in other nations, where tax adjustments help alleviate to some extent the fluctuations in oil prices.

Raising the price of gasoline has not proven a popular or politically feasible choice for leveraging consumers into more efficient vehicles. Owing to the relative price inelasticity of gasoline demand, many believe that the size of the price increase it would take to curb gasoline consumption to any degree would have a damaging effect on the economy of several times greater magnitude. Indeed, analysis of recent research (Plotkin, Greene, 1997) suggests that an increase in gasoline taxes would be one-third as effective in achieving a reduction in demand as studies of the 1980s projected. Furthermore, the authors argue that fuel economy policies are more effective than fuel taxes. As a matter of fact, from recent estimates, a 10% increase in fuel economy alone produces twice as much reduction in gasoline use and CO_2 emissions as 10% increase in gasoline price.

Price, however, could be used to at least keep some floor under the cost of gasoline to motorists. For example, a decision could be made to see that gasoline would not become less expensive than a certain level in real (inflation adjusted) dollars. The federal tax could be adjusted annually to preserve that level, if necessary, in nominal (unadjusted) dollars. Or, the price of gasoline might be adjusted by equal annual increments to achieve some statutorily established real increase. In subsequent years, under this option, the price could be adjusted to see that changes in the nominal price did not erode the real price. However, given the concerns about the sharp escalation in home heating oil and gasoline prices that began during 1999, the deliberate use of the price mechanism to reduce gasoline consumption seems highly unlikely, for the moment.

6.4 Information and Education

The American society is one that has benefited from the abundance and accessibility of resources. This matter of fact has in turn shaped people's behavior and provides little incentive for saving resulting in a way of life leading to consume increasing quantities of power and other resources. Motorists in the U.S. have favored bigger, more powerful cars, with more amenities and have driven more miles each year on average. Moreover, the U.S. appetite for oil is neither a recent nor a temporary trend. This points out the need and the difficulty of communicating on conservation issues to a society that has no reason to behave likewise. Maximizing everyone's self interest is simply not an option in regard to issues like global warming requiring cohesive behavior. Information and education initiatives are critical to help the consumer's be more environmentally conscious and behave accordingly.

6.5 On the Reduction of VKT

In the past, several forecasts have predicted a slowdown in annual growth of vehicles kilometers of travel. These estimates were justified by increasing vehicle saturation and induced time constraints. In fact, since 1970, total light vehicle fleet vehicle kilometers of travel (VKT) have increased at a rate of over 3% per year on average, faster than both population and GDP. However, this figure has been about 2.5% per year for the past 10 years.

Several factors influencing this trend are identified (Schaper and Patterson, 1998). They are: population and economic activity growth, population shifts toward regions with higher VKT per vehicle, average trip length growth, the cost of driving and the aging of the population, the latter factor being the only one contributing to a decrease in VKT.

Concurrently with the growth of the U.S. population (about 1% per year for 1970-1998 period), the average number of persons per household has been decreasing while the number of vehicles per household increased. In the mean time, the South and West where vehicles travel on average 760 kilometers per year more than in the Northeast and Midwest regions (Schaper and Patterson, 1998) have seen an increase in their share of the population. However, one of the most important effects having contributed to the growth of VKT is the evolution of the average work trip length. This distance has grown by more than a third between 1983 and 1995 (about 3% per year). During the same period, travel time grew 14% and average work trip speed increased by 20% (NPTS, 1995). While the fuel cost of driving a mile has declined to its lowest level today, the total cost of driving a mile have not changed significantly over the past 20 years (Davis, 1999). Finally, aging of the population, the sole factor identified that could play a role in dampening VKT growth, because older people tend to drive less, is offset by the fact that there is a trend for age groups to drive more over time.

Several policy instruments are available to reduce VKT growth: educational programs to influence motorist awareness of the environmental effects, and fiscal measures like VKT-based registration and insurance fees, road and congestion pricing, parking policy and fuel taxes. However, the literature on initiatives aiming at reducing VKT is sparse. Schaper and Patterson, (1998) report that the majority of efforts to reduce VKT are performed by the Department of Transportation. In 1998, DOT was spending billions of dollars on efforts affecting VKT while the Environmental Protection Agency and the Department Of Energy were spending less than $1 million each. Until now there is few or no evidence of a successful implementation of policies to reduce the light duty vehicle fleet VKT.

Chapter 7: Conclusion

Building upon the vehicle technology assessment conducted at MIT ("On the Road in 2020", Weiss *et al.*, 2000), this study has assessed the potential for reducing the U.S. light-duty vehicle fleet fuel consumption and energy use for the next thirty years. The vehicles technologies that were considered were the evolving gasoline-fueled baseline vehicle with steadily decreasing fuel consumption (35% below the 1999 average new car fuel consumption in 2020), and a gasoline internal combustion engine hybrid vehicle with an advanced body design (61% reduction in fuel consumption in 2020).

Using a vehicle fleet turnover model, the impact on the light-duty fleet of various technology penetration scenarios has been assessed. The effects of other factors including the light-duty vehicle stock growth, the increasing per-vehicle annual distance traveled and the sales share of light-duty trucks were evaluated as well. In sum, the reduction of new vehicle fuel consumption achieved on the evolving baseline and advanced ICE-Hybrids vehicles provides the most significant savings in fleet energy use over all the other considered measures. The baseline scenario predicts fuel savings of 20% relative to the reference scenario in 2020. However, because of the time needed for the vehicle fleet to turn over, these effects will be visible only after 10 to 15 years. Furthermore, actions aiming at reducing the stock and the total distance traveled growth rate appear to have significant effects on fleet fuel consumption as well, which are visible in the short term, while an increasing share of light-duty trucks will have only a modest impact. Finally, all things being equal, a steady decline in average new vehicle fuel consumption is needed to offset the growth of the stock and the total distance of travel. With the assumptions of the baseline scenario, a 1.3% annual decrease in average new vehicle fuel consumption allows to stabilize the light-duty vehicle fleet fuel use around 2015 and after. However, this number is sensitive to new vehicle sales growth rate and per-vehicle annual VKT growth rate and should not be considered on an absolute basis. The main point is that a continuous decrease in new vehicle fuel consumption is needed to limit the growth of light-duty vehicle fleet fuel and energy use.

Various policy options were discussed. Given the inefficiencies of the fuel economy market and the risk of a marginal commercial adoption of successful R&D results, and considering the effects of continuing the stagnant conditions of the past decade on the future fleet fuel and energy use, actions will need to be taken by the Federal Government and the other stakeholders if significant petroleum and greenhouse gas emissions reductions are to be achieved. The National Research Council study (NRC, 2001) points out that other policies like tradable credits for fuel economy improvements, feebates, higher fuel taxes or standards-based vehicles attributes could be a lower-cost alternative to the current CAFÉ regulation.

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Appendix: Detailed Output from the Fuel Consumption Model

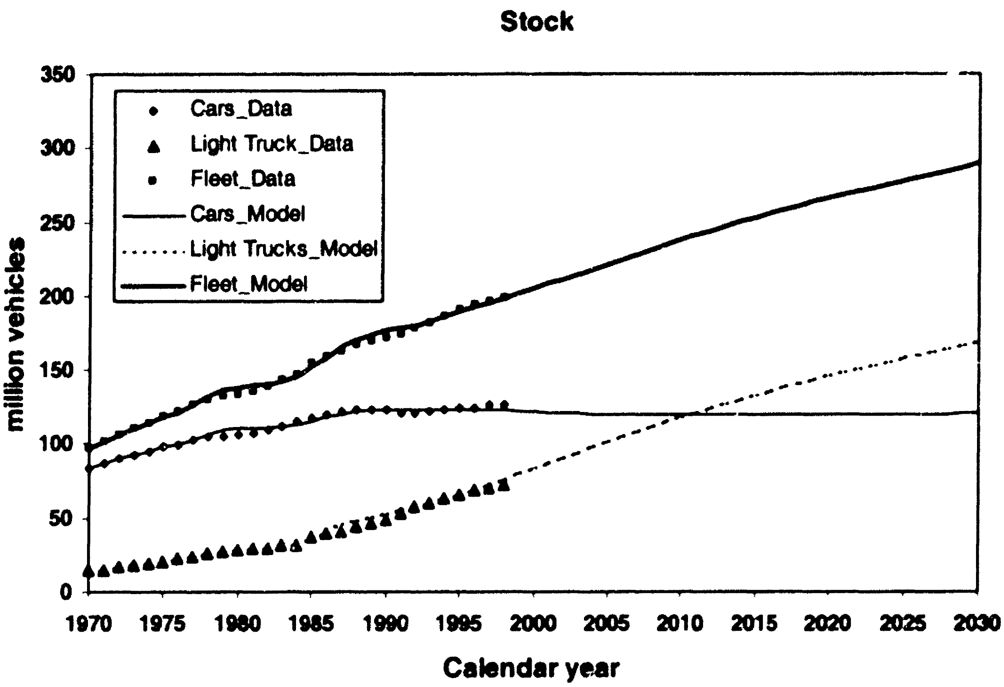

Figure B-1: Projected Stock of Light-Duty Vehicles under the Reference Case

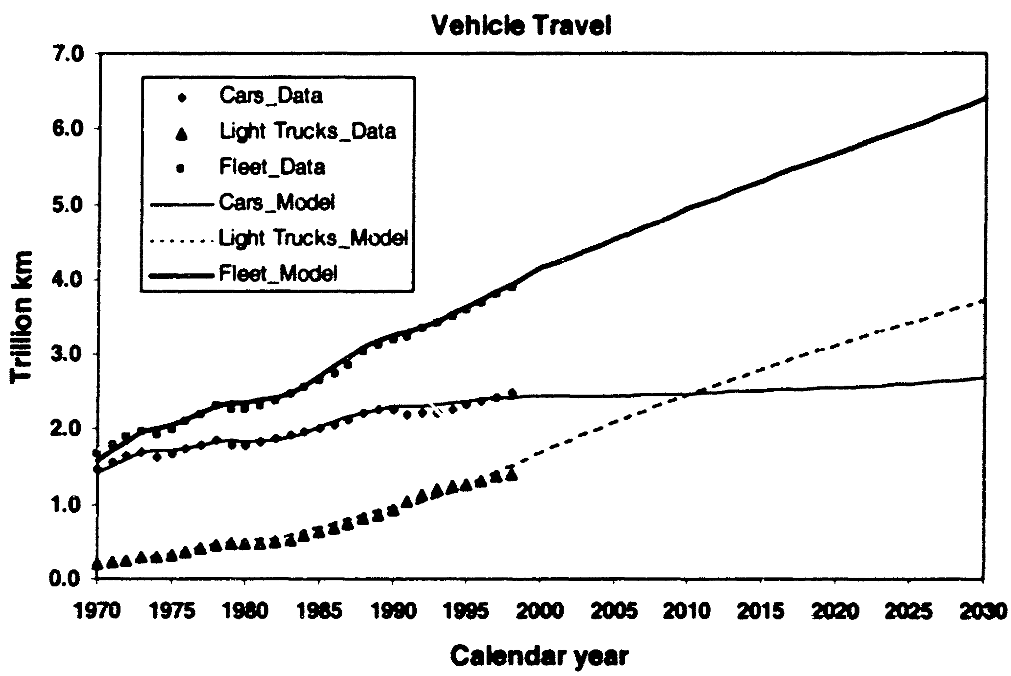

Figure B-2: Projected Travel of Light-Duty Vehicles

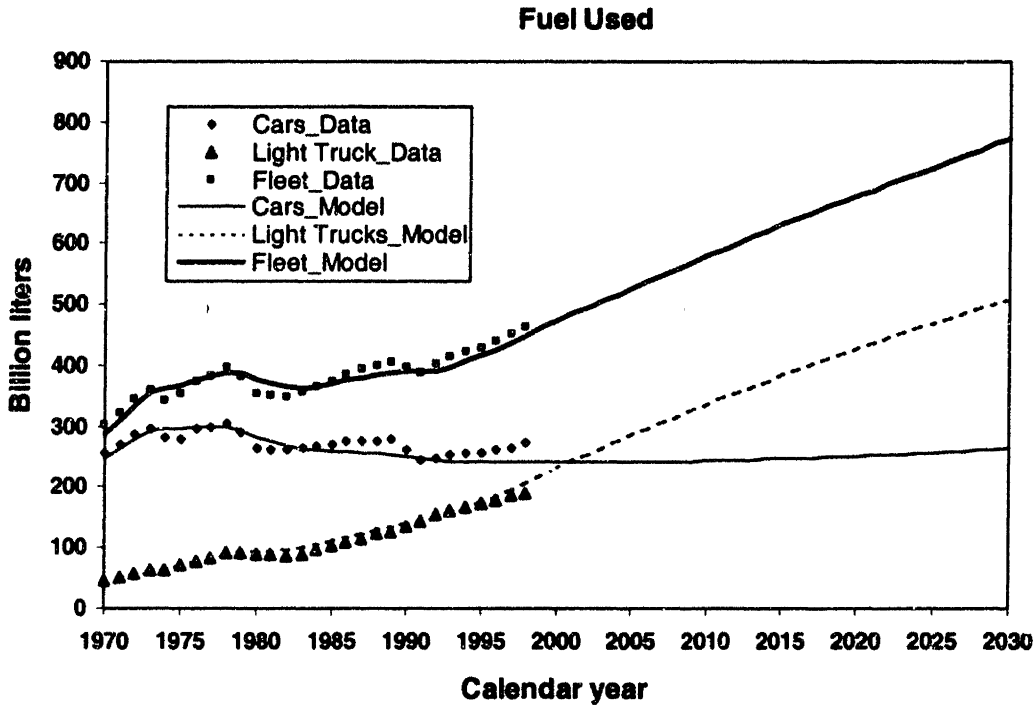

Figure B-3: Projected Fuel Use of Light-Duty Vehicles under the Reference Case

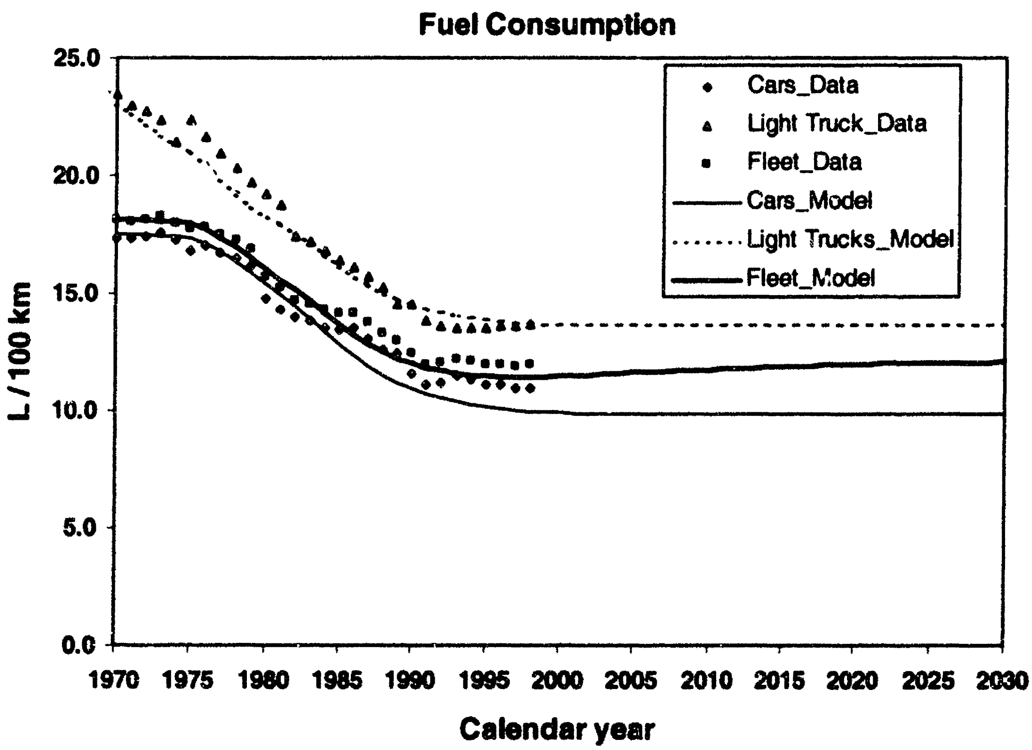

Figure B-4: Projected Average Fuel Consumption of Light-Duty Vehicles under the Reference Case

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