

Reduction of Greenhouse Gas Emissions from the Light-Duty Vehicle Sector:
An Examination of End-Use Policy Options

by

Kara Callahan

A.B., Mathematics
Smith College, 1988

Submitted to the Department of Civil and Environmental Engineering
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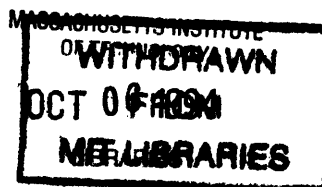
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Signature of Author.....
Department of Civil and Environmental Engineering
July 25, 1994

Certified by.....
Frederick P. Salvucci
Senior Lecturer, Department of Civil and Environmental Engineering;
Center for Transportation Studies
Thesis Supervisor

Certified by.....
Richard de Neufville
Chairman, Technology and Policy Program

Accepted by.....
Joseph M. Sussman
Chairman, Departmental Committee on Graduate Studies



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Abstract

In 1993, President William Clinton proposed a national goal of reducing greenhouse gas emissions to 1990 levels by the year 2000. As the source of a significant amount of greenhouse emissions in the United States, emissions from the light-duty vehicle sector must be reduced if this goal is to be reached. This thesis examines options by which the Clinton objective might be reached for the light-duty vehicle sector. First it establishes the level of greenhouse emissions from this sector in 1990: examining both full life-cycle emission levels and end-use emissions. Using a computer model of the light-duty vehicle sector, a base-case forecast is provided for what emissions levels are expected to be in 2000 barring any intervention. Next a framework for the development of end-use emission mitigation policies is proposed which concentrates on three key elements of emissions production in this sector: vehicle miles traveled, fuel efficiency and vehicle stock. These factors are presented in the context of a system in which these elements and policies interact. Using the computer model and this framework, policy options are examined which focus each of the three primary emission producing factors. Each initiative is evaluated for its technical potential and feasibility for reaching the emission mitigation goal. The discussion of each policy option includes its: greenhouse gas reduction potential; impact on transportation efficiency and effectiveness; economic impact; political and feasibility outlook. The thesis concludes with a discussion of how effective policy might be formulated and makes recommendations for further study.

Thesis Supervisor: Frederick Salvucci

Title: Senior Lecturer in Civil and Environmental Engineering; Center for Transportation Studies

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The final printing and thus the arrival of this thesis coincides with another, even greater arrival, the birth of my third niece, Maria Caitlin Callahan. Maria reminds me why I believe my research is important. Let us not forget how the actions of today will affect the lives of the generations to come. As Mom always said, try to leave things better than you found them. I dedicate my thesis to my new niece and all the children of her generation.

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Chapter One

Introduction

1.1 The Concern Over Greenhouse Gases and Global Climate Change

"We must take the lead in addressing the challenge of global warming that could make our planet and its climate less hospitable and more hostile to human life. Today, I reaffirm my personal, and announce our nation's commitment to reducing our emissions of greenhouse gases to their 1990 levels by the year 2000...This must be a clarion call...for American ingenuity and creativity..."

President Clinton
April 21, 1993

President Clinton's call for dedicated action towards the reduction of greenhouse gas emissions in an effort to stave off global warming and its effects places the concern of many in the scientific and environmental communities on the national agenda. For over twenty five years, the government's primary air quality concern has focused on public health issues associated with air pollution, as embodied in the Clean Air Act of 1970 and the Clean Air Act Amendments of 1990. Without diminishing the importance of this legislation and its goals, attention is now also being given to those emissions that affect the function of the earth's atmosphere and the global climate system.

An over abundance of greenhouse gases from anthropogenic sources has been linked to global warming¹. Examination of air trapped in glacial ice and actual

¹A detailed discussion of the role of greenhouse gases in global warming is provided in Chapter 2.

measurements of atmospheric CO₂² (a primary greenhouse gas) indicates an increase in emissions of over 25 percent since the industrial revolution (Neftel, et al., 1985) with an annual increase of approximately 1.5 ppm per year (Keeling, et al., 1990). This historical data and current work suggest that greenhouse gas levels could double by the middle of the next century, resulting in a global temperature increase of between 1.5 °C and 4.5 °C (Dickinson, 1986). Such an increase would have disastrous effects on ocean levels, ecosystems, precipitation patterns and agricultural seasons and locations. Even if maintained at their current levels, the continuing warming effects of these gases threaten global ecosystems, agriculture and the economy. Efforts to reduce greenhouse gas emissions are therefore imperative.

Developing an effective plan for the reduction of greenhouse gas emissions requires a knowledge of their sources. The major anthropogenic sources of greenhouse gas emissions include the combustion of fossil fuels, deforestation, landfills, coal mining, domestic animals and the use of chlorofluorocarbons (CFCs - an entirely man-made chemical). As Table 1 indicates, from a regional perspective, the United States is largest contributor of anthropogenic greenhouse gases. With only five percent of the world's population, the U.S. contributes over 20 percent of the of the world's warming commitment (OTA, 1991). Of this amount, energy consumption (almost entirely fossil fuel combustion) accounts for 97 percent of the total U.S. contribution (EPA, 1990; DOE, 1992), with the transportation sector responsible for 30 percent of those emissions³. In addition, the transportation sector is responsible for 10 percent of the United State's CFC-12 emissions (EPA, 1990). With such significant contributions from a single sector, it is clear that the transportation sector must be a focus of U.S. policy for greenhouse gas reduction.

²Other greenhouse gases include methane, nitrous oxide, chlorofluorocarbons, nitrogen oxides and carbon monoxide.

³As determined by the author as part of an internal study for the Research and Special Programs Administration of the U.S. DOT (the Volpe Center), 1993.

Table 1-1: Greenhouse Gas Emissions by Country (1987)

Country	Carbon (million tons)		Relative Contribution to Total (1987)
	1960	1987	
United States	791	1,124	20%
Former Soviet Union	396	1,035	18%
China	215	594	11%
Japan	64	251	4%
West Germany	149	182	3%
Poland	55	128	2%
India	33	151	3%
Other	1	9	39%
World Total	2,547	5,599	100%

1.2 Policy Considerations in Context

The evidence for global warming and the need for immediate and definitive action is a position supported by many in the scientific community. However, uncertainties have left some scientists skeptical as to the magnitude or even the existence of any serious problem. An issue whose certainty is in question can often be a weak platform on which to build policy, reach consensus, dedicate resources and implement programs. In the case of global warming, because the impact of emissions generated now will be realized for decades or centuries into the future, should the hypotheses supporting the global warming theory be correct, the risk of not acting quickly will be to the severe detriment of future populations. Given the relative risk, a commitment by the government to develop policy and programs to address this issue is both pertinent and prudent. At the same time, the policy-making must be responsible in addressing the risk factor. Developing policies that have multiple attributes and objectives is essential. For example, policies that reduce petroleum fuel consumption address the global warming issue while also contributing to the energy independence and national security goals. Other policies which reduce the number of vehicles on the road and the amount they are used not only help reduce greenhouse emissions but also contribute to solutions for congestion on our roadways. Just as a diverse portfolio helps reduce the risk for an investor, so do policies with a range of objectives help reduce risk and ensure that public resources and government efforts are not wholly misguided and wasted.

1.2.1 Policies for the Light-Duty Vehicle Sector

As noted above, transportation's role as a major contributor to greenhouse gas emissions dictates its presence in a comprehensive emissions reduction plan. Within this sector, end-use emissions from light-duty vehicles (LDVs - automobiles and light-duty trucks) are responsible for 60 percent of greenhouse gas emissions. When the entire life-cycle (which includes raw material recovery and refining, vehicle manufacture and scrappage) of vehicles are considered, the level of emissions attributed to LDVs further increases. In developing policy for this sector, several factors regarding transportation policy in general and policy specific to the light-duty vehicle sector must be considered. First, policy addressing transportation must recognize that it is not an isolated and singular system, but an integrated set of subsystems consisting of: vehicle systems, infrastructure systems, and energy systems (TMP, 1992). As such, policy for the transportation sector must address and be considered with respect to all of these systems. Second, light-duty vehicles have been the subject of a substantial amount of policy and regulation, especially in the past twenty-five years. Policy regarding LDVs has addressed a variety of concerns from safety, to air quality and energy consumption. This point is not to imply that further regulation is not desirable. The purpose is to suggest that the legislative history of this sector has produced strong groups and coalitions on either side of the issues. The planning of policy affecting the light-duty vehicle sector must consider if not include these groups in its policy making process. While inclusion of the concerned parties does not ensure ultimate support, exclusion of these groups may result in their further polarization and resistance.

In formulating policy options and especially those that involve issues with known long-term implications, time-scale must be considered. President Clinton's call for the reduction of greenhouse gas emissions to 1990 levels by 2000 is an ambitious and worthy goal. While it motivates efforts and focuses attention on the global warming issue, if global warming is to be addressed in a thorough manner, research, policy and implementation plans must look beyond 2000 and before 1990. Though a suitable benchmark for 2000, even if attainable, 1990 greenhouse gas levels will not stabilize the concentrations of greenhouse gases in the atmosphere and will not be sufficient to ward off global warming. More drastic reductions will be necessary if atmospheric greenhouse gas concentrations are to be stabilized (EPA, 1990). Table 1-2 suggest the approximate reductions below 1990 levels that would be required to achieve this goal. As population grows and the world (and especially populous nations such as China and other developing countries) becomes increasingly industrialized, policy must reflect these dynamics. Because climate change is a global problem, without an international effort, even the most

ambitious greenhouse gas mitigation programs will be rendered impotent, if pursued by a single nation, alone. As policies are evaluated for their effectiveness in obtaining goals such as the Clinton charter, their value should not be measured solely on their short-term impact. The options considered must be evaluated in the context of both short and long term effectiveness.

Table 1-2: Emission Reductions Necessary to Stabilize Atmospheric Concentrations of Greenhouse Gases

Gas	Reduction Required
Carbon Dioxide	50 - 80%
Methane	10 - 20 %
Nitrous Oxide	80 - 85%
Chlorofluorocarbons	75 - 100%
Carbon Monoxide	Freeze
Nitrogen Oxide	Freeze

1.2.2 Understanding the Political Landscape

If we assume that the concern over climate change is justified and we know that light duty vehicles are significant contributors to the problem, it is still not assured that policies can be developed and implemented to address the problem. The technical problem of greenhouse emissions and the role of the light duty vehicle exist within a complex social and economic system that is highly influential in the acceptance and success of policies. The goal of policy is to promote desired behavior and affect change. However, even if the ultimate goal is agreed to be worthy, achieving the desired change can be difficult. As Machievelli so astutely notes:

There is nothing more difficult to plan, more doubtful of success, or more dangerous to manage than the creation of a new system. For the initiator has the enmity of all who would profit by the preservation of the old institution and merely lukewarm defenders in those who gain by the new one.

This observation is especially relevant to the creation of greenhouse reduction policies that affect the light duty vehicle sector. In the United States, the passenger vehicle has many strongly positive attributes, despite some of its detracting qualities. The automotive industry is a major player in the economic health of the United States, both domestically and in the international market. Passenger vehicles also provide Americans with an

exceptional amount of unconstrained personal mobility. Because policies which affect these vehicles and the way in which they are used impact the vast majority of the population both directly and indirectly, there is likely to be strong and vocal sentiment surrounding policy that affects their operation.

Past political debate over corporate average fuel economy (CAFE) standards and more recently on gas taxes and in the NAFTA (North American Free Trade Agreement) talks indicate that there is much interest by such parties as labor unions, the auto industry, environmental groups and the general public in proposed policies that affect automobiles and their use. An even more basic concern, then, in establishing effective policy is initiating the political support to propose, present and back policies that involve changes in automobiles and/or people's driving behavior. The need to work within a political context to address greenhouse emission reduction adds a somewhat difficult and at times deceptive element to the technical problem.

To some it may seem clear that a problem such as global climate change - a problem that could drastically change if not destroy humanity - warrants immediate action and commitment. However, due to the social, economic and political implications, garnering support and commitment for action that will address climate change is not simple or guaranteed. There are several elements that complicate the effort to gain this support. First, the vehicle, though a source of detrimental emissions is also the source of much good, as indicated above. Making the case for supporting emission mitigation even more difficult is the uncertainty surrounding climate change. In developing and seeking support of greenhouse emission reduction policies, the political bodies and the public who might be sought to sponsor the reduction policies are faced with supporting changes to something that provides very strong benefits, while at the same time there remains a fair amount of uncertainty as to the severity of the problem or even its existence. When considered from this perspective it is perhaps more obvious why even potential defenders of these policies might feel "lukewarm" in their support, as Machievelli would say.

1.3 Thesis Outline

This thesis will investigate both short and long term policy options for the reduction of greenhouse gases from the light-duty vehicle sector. Both the process of analyzing and implementing policy will be addressed. A select number of policies will be examined for both their technical potential and their social and economic feasibility. Using a computer model, the selected short-term options will be evaluated for their quantitative effectiveness. Each policy's technical potential will be measured by the amount of emissions reduction it

is forecast to achieve by 2000 and 2010. Then the policies will be reviewed in a more qualitative sense. The qualitative analysis will investigate the political, social and economic implications and impact associated with each policy option.

Chapter 2 provides an overview of the greenhouse effect and global warming. Sources of greenhouse emissions will be discussed and the relative contribution of the United States to this global problem will be presented. The contribution of the transportation sector and specifically that of the light-duty vehicle (LDV) sector will then be discussed. Within the LDV sector, the most significant components affecting emissions will be presented within a life-cycle context - from the point that raw materials such as iron ore are extracted from the ground; through the fabrication and assembly processes; to driving and everyday use; and finally, to the disposal of the vehicles. Factors involving the end-use emissions from a vehicle - those emissions that are released while driving - will be focused upon and discussed as targets for policy measures in the greenhouse gas reduction plan.

Chapter 3 provides a detailed description of the model used in this evaluation. The purpose of the model and its limitations are presented. Suggestions for enhancements to the model are put forth. The chapter closes with a discussion regarding the use of models in policy making.

Chapter 4 presents the policy options considered and a structure for their evaluation is presented. For each policy, both its quantitative and qualitative aspects are considered. Each option is evaluated for its contribution to greenhouse gas emission reduction, transportation efficiency and effectiveness and economic impact. Factors affecting the policies' implementation are also examined. For each measure, the parties who will be most directly affected by the policy or who will have the largest say in the support and passage of the given policy are identified. The obstacles that face the implementation of each policy are then discussed and review of the over-all likely feasibility is provided. If you are limited on time and read no other chapter, read this one.

Chapter 5 opens with a summary of the thesis. Because this thesis does not provide a comprehensive analysis of all policy options, alternatives - including some long-term options - to these policies are also presented and discussed. The chapter attempts to synthesize the information presented and discussed to this point in the thesis by making recommendations for implementation strategies. The chapter and the thesis conclude with suggestions for further study.

Chapter Two

Greenhouse Gas Emissions and the Light-Duty Vehicle Sector

2.1 The Greenhouse Effect and Global Warming

The greenhouse effect is a very necessary and normal process in our global climate system. It is this process that keeps the earth from becoming a cold and uninhabitable planet. A particular group of gases (the “greenhouse gases”) in the earth’s atmosphere effectively absorb and “trap” the radiative heat from the sun, thus warming the earth and its atmosphere. More accurately, of the solar radiation that reaches the earth, only thirty percent is lost as it is reflected back into space by the atmosphere and the earth. The remainder of the radiation is absorbed by the atmosphere, land, ice, oceans and biomass of the earth; which in turn, emit the long-wave radiation that is absorbed and trapped by the greenhouse gases, allowing the earth to be warmed. This process is the greenhouse effect (see Figure 2-1). The particular gases central to this process, the “greenhouse gases”, include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), ozone (O_3), nitrogen oxides (NO_x) and carbon monoxide (CO). Of these, water vapor and carbon dioxide are the most significant, however, the concentration of water vapor is not greatly influenced by human activity. Also, two of the gases - nitrogen oxides and carbon monoxide are considered indirect contributors, because they react chemically to increase ozone (from NO_x) and methane (from CO), which are greenhouse gases.

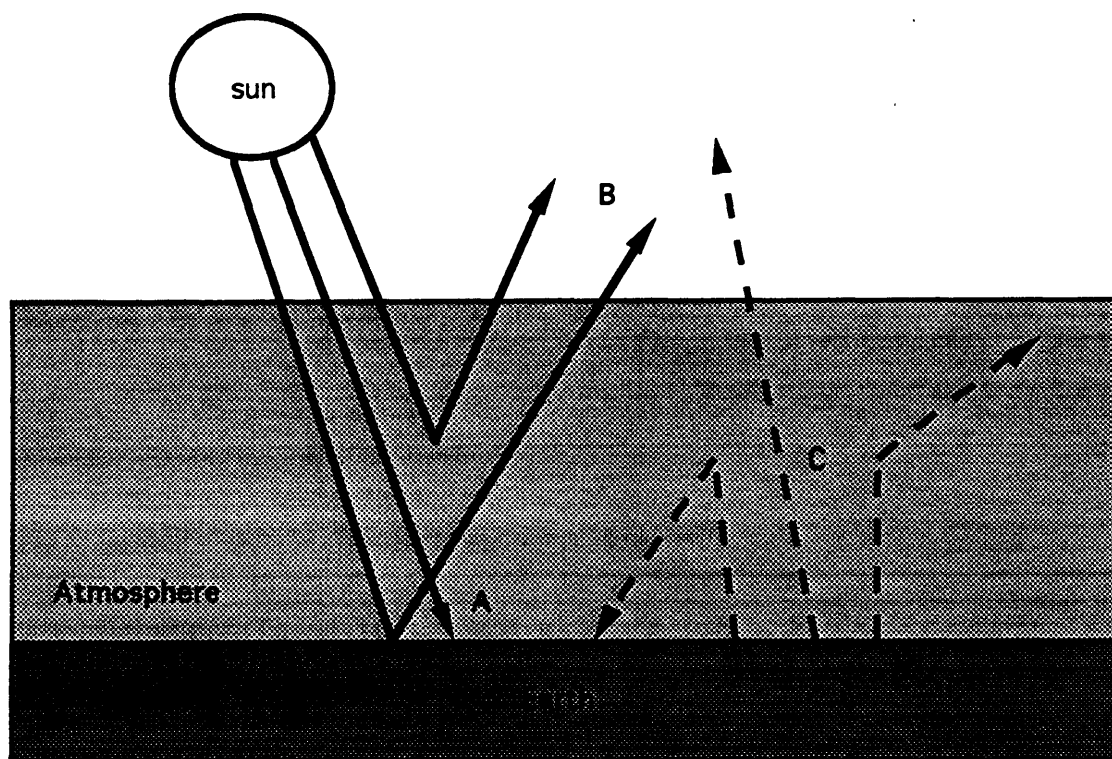


Figure 2-1: The Greenhouse Gas Effect -

When solar radiation reaches the earth, some is absorbed (A), while some is reflected into the atmosphere (B). The earth, in turn, emits long wave radiation into the atmosphere, some of which is trapped by greenhouse gases, warming the planet (C).

The earth's ecosystems are normally in balance with the atmosphere, providing natural sources and sinks for the greenhouse gases (Table 2-1). However, human activity and especially activity in the past century, has both increased the number and intensity of the sources and decreased the effectiveness of the sinks. Approximately 80 percent of the increase in greenhouse emissions over the past century is due to a rise in the contribution of sources (primarily through the combustion of fossil fuels) while only 20 percent of the emissions increase is due to loss of sinks (primarily through deforestation) (Houghton, 1992). This imbalance elevates the strength of the greenhouse effect, which over the long-term creates a trend of global warming. A major study on climate change performed by the Intergovernmental Panel on Climate Change (IPCC) holds that the global mean surface air temperature has increased by about 0.45 °C over the last century, with the five globally averaged warmest years occurring in the 1980s, and estimates that the global mean temperature will increase by about 0.3 °C per decade in the future (IPCC, 1990). This rate

of temperature change is potentially disastrous as it could be too fast for ecosystems and humans to adapt.

2.1.1 Measuring the Gases

Several gases are active agents in the greenhouse effect. However, each gas is found in different concentrations in the atmosphere (Figure 2-2) and each gas has unique properties that make it a greater or lesser factor in the global warming process. The three gaseous properties that most directly influence the warming effect are:

- o atmospheric concentration - defined as the volumetric amount of gas in the atmosphere, usually measured in parts per million;
- o radiative absorption - the ability of gas to partially absorb long-wave terrestrial radiation emitted by the Earth and re-emit it; and
- o atmospheric residence - the amount of time a gas remains in the atmosphere. Greenhouse gases have lifetimes ranging from years to centuries. A gas' residence or lifetime is determined by its chemical properties and the sources and sinks of the gas in the oceans, atmosphere and biosphere.

A gas' contribution to global warming can be measured based on changes in the relative atmospheric concentrations a gas. Radiative forcing is a change imposed on a climate system that modifies its radiative balance.¹ A gas' particular characteristics, including the absorptive strength of the gas within the infrared spectrum, its decay profile (or residence time in the atmosphere) and the relative concentration of all gases in the atmosphere determine its relative impact on radiative forcing. A summary table of the major characteristics of each gas is provided in Table 2-2.

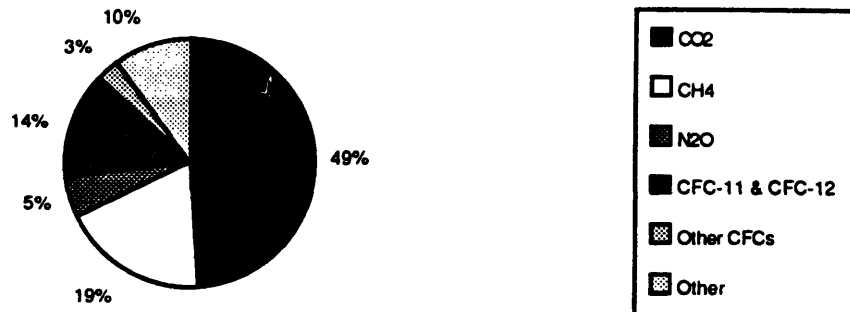
¹ The radiative balance is determined by how much of the solar radiation is absorbed or reflected by the earth and its atmosphere and at what point in the process.

Table 2-1: Greenhouse Gases: Sources and Sinks

Gas	Sources	Sinks
CO ₂	Fossil fuel combustion Deforestation [†]	Ocean Vegetation (photosynthesis)
CH ₄	Fossil fuel Landfills Biomass burning Natural wetlands Rice paddies Animals - ruminants Termites Oceans and freshwater lakes Methane hydrate destabilization	Reaction with OH radicals Dry soils
N ₂ O	Oil and coal combustion Nylon and nitric acid production Deforestation Biomass burning Contaminated aquifers Soils Oceans Grasslands	Photolysis Reaction with oxygen
CFCs	<u>CFC-11</u> : Rigid and flexible foam Aerosol propellant <u>CFC-12</u> : Refrigerant Rigid and flexible foam Aerosol propellant <u>CFC-113</u> : Electronics solvent <u>HCFC-22</u> : Refrigerant Production of teflon polymers	Photolysis (for CFCs without hydrogen) Reaction with OH radicals in the atmosphere (for CFCs containing hydrogen)
CO	Technological sources Biomass burning CH ₄ oxidation Plants Oceans Oxidation of hydrocarbons	Soils Photochemistry Flux into stratosphere
NO _x	Fossil fuel combustion Biomass burning Lightning Oxidation of ammonia Soils	Wet deposition Dry deposition
O ₃	Anthropogenic emissions of NO _x and HC in troposphere due to fuel combustion CFCs in stratosphere	Reactions with other chemicals

Source: Adapted from EPA, 1990. *Policy Options for Stabilizing Global Climate*. (Washington, D.C.: Office of Policy Planning and Evaluation, December, 1990).

[†]The effects of forest removal and degradation are long-term as the time element for the reversal (regrowth) of these actions is on the order of 50 to 70 years or more. The semi-permanent loss of the forest as a sink essentially redefines the problem of global warming, displacing the effects of one solution source for over half a century.



Source: EPA (1990)

Figure 2-2: Greenhouse Gas Atmospheric Concentrations

Table 2-2: Greenhouse Gas Characteristics and Global Warming Potentials

Gas	Concentration (1988)	Chemical Properties	Lifetime (years)	Global Warming Potential (GWP)
CO ₂	351 ppm	Inert	120	1
CH ₄	1670 ppb	Reactive	8 - 12	21
N ₂ O	307 ppb	Inert	120 - 160	290
CFCs	CFC-11: 226 ppt CFC-12: 392 ppt CFC-113: 30 ppt HCFC-22: 80 ppt	Reactive	CFC-11: 60 CFC-12: 120 CFC-113: 90 HCFC-22: 15	CFC-11: 3,700 CFC-12: 7,600 CFC-113: 4,000 HCFC-22: 1,500

Source: Adapted from EPA, 1990. *Policy Options for Stabilizing Global Climate*. (Washington, DC: Office of Policy Planning and Evaluation, December, 1990) and OTA, 1991. *Changing by Degrees* (Washington DC, February 1991).

For policy making and other general considerations of greenhouse gases it is useful to have a standard methodology by which to compare the relative contributions of each gas. Two common methodologies are based on 1) concentrations (volume based) and 2) emissions (mass-based). A volumetric index compares the radiative forcing effects of estimated changes in atmospheric concentrations of a gas over a given time interval such as a decade. An emissions index measures the radiative forcing effects of mass-based emissions for a single year, over a given time frame. The mass-based methodology was developed by the IPCC and is widely used today. The specific metric defined by this methodology is the Global Warming Potential (GWP). In its 1990 study, the IPCC defined GWP as the time integrated contribution to radiative forcing from the instantaneous release of 1 kilogram of a trace gas relative to that from 1 kilogram of carbon dioxide. The global warming potentials for each of the major greenhouse gases are listed in Table 2-2.

Another convention used to simplify the evaluation of the gases effects is to consider all gases in terms of their carbon equivalent content. Using carbon equivalence (C_e), the relative warming effectiveness gases is more easily compared and the total effectiveness of gases emitted from a single source or evaluated in a certain area is additive. Carbon equivalence is based on the carbon content of CO₂. Using the Global Warming Potential Index (GWP Index) for a given gas, its equivalent CO₂ level is calculated:

$$\text{CO}_2(\text{equivalent}) = (\text{grams})_{\text{gas}} \times (\text{GWP Index})_{\text{gas}}$$

Using this figure, the mass based carbon equivalent is then calculated by multiplying it by the molecular weight of carbon (12) and then dividing this figure by the molecular weight of CO₂ (44).

$$C_e = \text{CO}_2(\text{equivalent}) \times \frac{12}{44}$$

But because 12 divided by 44 is equivalent to 1/3.67, the CO₂ equivalent for the gas can simply be divided by 3.67 to find the grams of carbon equivalence.

$$C_e = \text{CO}_2(\text{equivalent})/3.67$$

In this thesis, greenhouse gas impacts are measured in carbon equivalence.

2.2 Human Activity and Global Warming

2.2.1 Contributions by Region

The anthropogenic contributions to greenhouse gas emissions varies by geographic region as well as by activity. The industrialized nations are, and have historically been the greatest contributors to the problem (see Figure 2-3), with the United States, former Soviet Union and the Western Europe contributing 41% of the total emissions. Of that amount, the United States contributes half. Though the industrialized nations are by volume the greatest contributors, the countries with the highest growth in greenhouse gas emissions are the developing nations. Since 1960, the emissions growth rate for the United States has been 54%, while for nations such as India and Nigeria, the growth has been six or more times that (Masters, 1991). Though in the near-term the actual volumetric commitment of these nations may be insignificant, this extreme rate of growth can have serious implications for the future. With a population growth rate that is the highest of any region (Table 2-3) combined with the increasing adoption of the harmful activities and behavior of industrialized nations, the relative contribution of developing nations to radiative forcing could increase significantly in the near future. This prospect places even greater onus on industrialized nations to mitigate their contribution to global warming. This effort by industrialized nations' must reach beyond their borders. Many raw materials and, increasingly, product manufacture comes from developing nations. Therefore, the demands placed on developing nations by those that are industrialized will also impact global emission levels. Changes in behavior and technology by industrialized nations which take into account the both their demand on developing nations and the potential for emulation, help ensure that the benefits of the emission reduction efforts will be carried far beyond their borders.

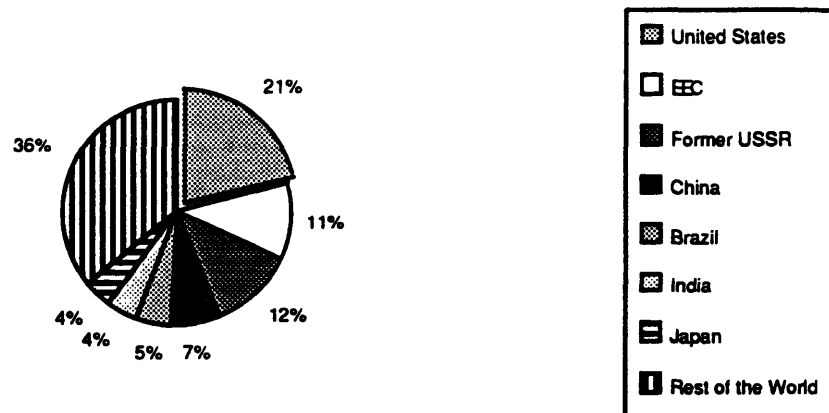


Figure 2-3: Regional Contribution to Radiative Forcing (EPA 1990)

Table 2-3: Annual Population Growth Rate by Region

Region	Annual Population Growth Rate (1980 - 1985)
North America	0.9%
Europe	0.3%
East Asia	1.22%
Oceania	1.51%
Caribbean	1.53%
Southeast Asia	2.05%
Southern Asia	2.14%
Latin America	2.34%
Western Asia	2.79%
Africa	2.92%
<i>World Average</i>	<i>1.67%</i>

Source: Adapted from WRI and IIED, 1987

2.2.2 Contributions by Activity

As Table 2-1 indicates, the sources of anthropogenic emissions are many and range from deforestation to agriculture (especially rice paddies and livestock) to fuel consumption. Of these activities, the combustion of fossil fuels (petroleum products, natural gas and coal) is the most significant contributor to radiative forcing and is the source of 70 percent of the carbon dioxide emitted to the atmosphere annually from anthropogenic sources (EPA, 1990). Other significant non-energy sources of greenhouse gases are the

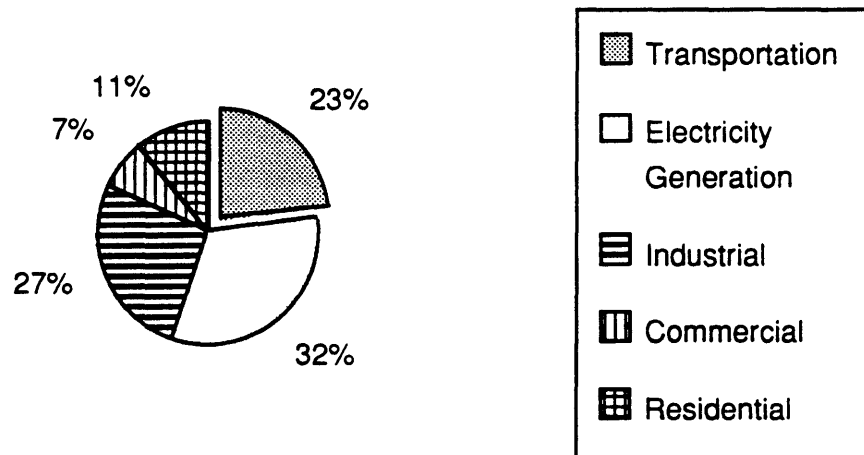
production and use of chlorofluorocarbons², land-use (deforestation³ - contributing 20 percent of the CO₂ emitted annually; destruction of wetlands, biomass burning, etc.), animal husbandry, rice cultivation and use of nitrogenous fertilizer.

2.2.3 Contribution by the United States

The United States is the world leader in contribution to the global warming commitment. With five percent of the world's population, the United States accounts for about 20 percent of the world's warming commitment. U.S. CO₂ emissions (in 1990, 20 percent of the global total) originate almost exclusively from fossil fuel combustion. Not surprisingly, the United States is the largest consumer of fossil fuel, accounting for 24 percent of the world consumption (OTA, 1991). Americans rely on fossil fuels in almost every aspect of their daily lives. It is helpful in policy making to categorize fuel use by sector so that appropriate measures and programs can be established to effectively address the emissions from common processes. A commonly used categorization breaks out electricity generation, transportation, industry, commercial and residential sectors. Using this grouping, electricity generation is the largest fuel consumer, followed closely by the transportation sector (Figure 2-4a). Correspondingly, these sectors are the two largest contributors to carbon emissions (a measure of radiative forcing) (Figure 2-4b).

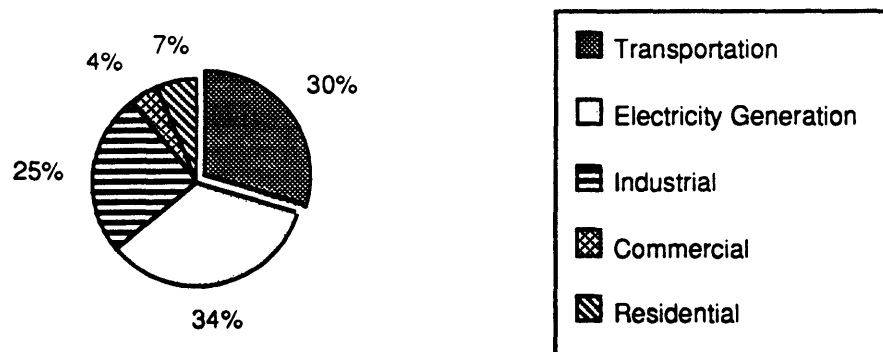
² in September of 1987, 47 nations reached an agreement known as the Montreal Protocol to control the production and use of chlorofluorocarbons (CFCs). In 1990, a stronger version of the Montreal Protocol was established. In the United States, the Clean Air Amendments of 1990 placed even more stringent regulations on CFCs.

³ Deforestation is increasing at a rate of 1.3 percent annually. If unchecked, at this rate over all contribution to global warming from deforestation could increase to 25 percent within a decade.



Source: VNTSC, 1993.

Figure 2-4a: Fuel Use by Sector (1990)



Source: VNTSC, 1993.

Figure 2-4b: Carbon Equivalent Emissions by Sector 1990

2.3 Contribution of the Transportation Sector

As a primary contributor to the nation's global warming commitment, if the United States is to reduce its greenhouse gas emissions, efforts must be directed at the transportation sector. Approximately 80 percent of the carbon emissions from transportation originates from fuel use. The remainder come from CFCs used in vehicle fabrication and in-vehicle air conditioning. It is not merely the fact that transportation sector is an energy intensive sector that makes it such a large contributor, but because the fuel it consumes is almost entirely emissions laden and fossil based. Of 21.65 quads⁴ (DOT, 1993) consumed by the transportation sector in 1990, all but 0.018 quads (0.083%) was from a fossil source (DOT, 1992). Depending upon the fuel type and efficiency of the combustion process, carbon emissions vary. For each fuel there exists a carbon coefficient (measured in million metric tons of carbon per Btu; see Table 2-4), which represents the carbon equivalent amount of greenhouse gas emissions released by that fuel during combustion (Marland and Pippin, 1990). The carbon equivalent emission for each fuel is calculated by simply multiplying the appropriate coefficient with the Btus of the fuel consumed.

Unlike the electricity generation sector where there exist non-emission sources of power (nuclear, hydro-electric, solar and wind), the options for transportation are limited. In the future electricity and hydrogen may be fuel options for automobiles, but it is likely that jet fuel, fuels for ships as well as trains will remain fossil based. Even for the automobiles, it will take time once these fuels are introduced, to be represented by any significant number in the fleet. To address its contribution to global warming, the transportation sector must therefore look to options in addition to fuel based alternatives. For these reasons, transportation is a focus of policy-maker's attention when addressing greenhouse gas mitigation.

2.3.1 Contribution by Mode

The transportation sector can be further broken down to determine use and greenhouse gas emissions by mode. This segmentation reveals passenger vehicles (automobiles and light-duty trucks) as the single greatest contributor to carbon emissions of any mode; claiming a startling 50 percent of the responsibility (see Table 2-5 and Figures 2-5a and 2-5b). This fact is not so remarkable, however, it simply reflects Americans' attitude towards personal transportation and dependence upon the automobile.

⁴ 1 quad = 1 quadrillion (1×10^{15}) British thermal units (Btus)

Table 2-4: Carbon Coefficients of Transportation Fuels

Fuel	Carbon Coefficient (MMT/quad)
Gasoline	19.42
Diesel	19.97
Natural Gas	14.54
LPG	17.09
Alcohol	17.60
Jet Fuel	19.46
Residual Fuel	21.66

Source: Marland and Pippin, 1990.

Table 2-5: Fuel Use and Carbon Emissions by Mode

Mode	Fuel Use (quads)	Carbon Equivalent Emissions
Automobile	8.93	173.49
LDT	2.20	42.65
Commercial Truck	1.77	34.30
Heavy Duty Truck	3.66	72.60
Air	2.41	46.90
Marine	0.37	7.78
Off-Road Engines	1.81	35.97
Total	21.14	413.70

Source: VNTSC, 1993

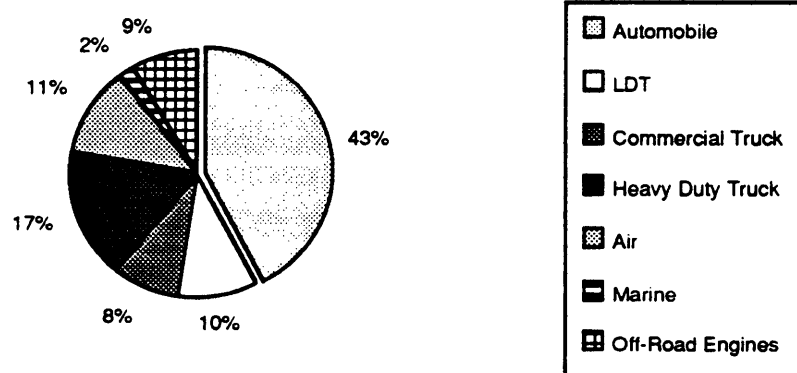


Figure 2-5a: Fuel Use by Mode

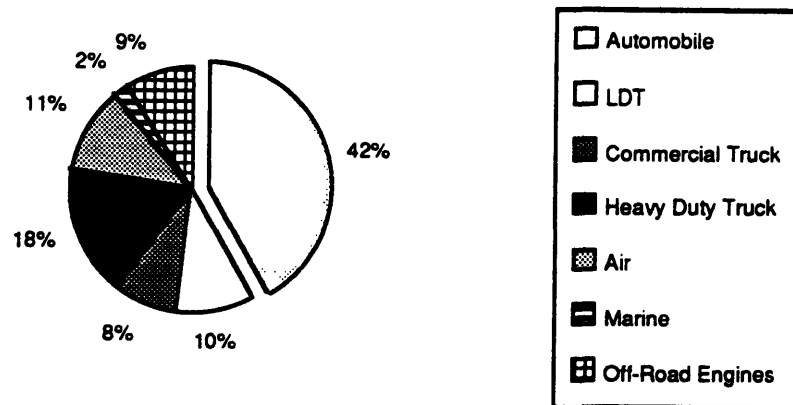


Figure 2-5b: Carbon Emissions by Mode (1990)

2.4 Factors in Passenger Vehicle Emissions

Just as categorizing source sectors and sub-sectors helps better direct remedies to the emissions problem, further refining the source of emissions allows for measures to be even better directed. The previous section indicated that passenger vehicles is the single largest source of greenhouse gas emissions in the transportation sector, based on fuel use. This fact provides reasonable justification for focusing research and policy on this sector for greenhouse emission reductions. However, combustion of fuel is not the only source of emissions from this mode (or other mode). When assessing and addressing emissions from this sector it is important to not only consider the “end-use” emissions from fuel use but those emissions produced over the entire life of a vehicle, from production, to use to ultimate scrappage. This life-cycle assessment of emissions is necessary to better evaluate emission reduction policies. For example, if a policy dramatically reduces tail-pipe emissions but only through manufacturing processes that increase greenhouse emissions so as to more than off-set the tail-pipe savings, it may not be worthwhile to pursue.

This review of the factors affecting greenhouse emissions will be divided into factors in pre- and post- vehicle use and factors in end-use emissions. Pre- and post vehicle use factors include greenhouse emissions released during the retrieval and production of materials used in vehicles, the manufacture of vehicles and those produced as part of the disposal processes. The emissions from end-use can be traced to a few major

factors: size and characteristics⁵ of the vehicle fleet, vehicle miles traveled (VMT), fuel efficiency and driving conditions such as congestion and type of driving (highway versus city).

2.4.1 Factors in Pre- and Post- Vehicle Use Emissions

This analysis will be divided distinctly into an examination of the pre- and post- use factors.

Pre-Use Emissions

To evaluate the level of pre-use emissions, three categories of sources were established. They include:

- **Processes** - This refers to the production and fabrication processes that release gaseous effluents, such as emissions that are released during the steel fabrication process;
- **Energy** - Each process, from raw material extraction to vehicle assembly requires energy and with energy come the emissions associated with its generation (assuming that combustion generation processes are used); and
- **Transport** - In the pre-use period intermediate products and even the final product must be transported from original source to and between the locations for the production processes. In this analysis it was assumed that fossil fuels were used in transport of the goods and therefore emissions from the fuel use had to be accounted for.

Though a vehicle is constructed of several materials, steel is by far the most significant material, constituting 55% of an average passenger vehicle, by weight (Ward's, 1993)^{6,7}. Because of this, the emissions derived from the processing of steel and manufacture of vehicles were used as a proxy for process emissions from all materials combined. The reported emission level is thus an underestimation of the actual emissions associated with vehicles in the pre-use stage. However, this figure (the total reported pre-use emissions) provides a good order-of-magnitude approximation for the emission level and is therefore useful for general comparisons and analyses. For this evaluation, emissions from each pre-use subsegment are reported in carbon equivalent grams per vehicle. In addition, the total pre-use figure is reported in million metric tons of carbon equivalent for the entire

⁵ Characteristics of the stock include the total size of the fleet, the percentage that is cars versus light duty trucks and the age concentrations in the fleet.

⁶ For this study 1993 figures were used based on the average for American made vehicles, weighing 3,149.5 lbs.

⁷ Iron based products constitute 68% of an average vehicle's body weight.

stock of both import and domestic vehicles sold in the United States on an annual basis. A flow chart of the vehicle pre-use period is provided in Figure 2-6. The associated emissions are listed next to each process and transport segment.

Work by Hahn (1994) suggests the process that produces the greatest amount of emissions in the pre-use period is the blast-furnace refinement process (Refinement and Fabrication in Figure 2-7), producing a total of 717,246 g/vehicle of carbon equivalent⁸.

The energy requirements of pre-use vehicle processes and production are significant. Energy is required for each of the processes both in the raw material recovery and refinement processes and in the manufacture of vehicles (see Figure 2-6). Hahn (1994) indicates that the most energy intensive processes (on a per-vehicle basis) are the pre-assembly processes - raw material recovery, the refining and fabrication. If we assume that all the energy consumed by these processes is generated with fossil based fuels, the total greenhouse commitment associated with energy consumption in pre-use processes is 283,283 grams of carbon equivalent per vehicle.

Finally, there are emissions associated with transportation in the pre-use processes. In an effort to develop some initial figures, U.S. fabrication of steel and manufacture of automobiles was considered. It was assumed that foreign manufacturers will have similar transportation requirements, however this is most likely an underestimation. Countries that do not have native iron resources will have to transport either the raw material or steel products a greater distance to reach the assembly plant. Also, because foreign manufacturers must ship their vehicles from the home port to the United States and then from the U.S. port to the retail distributors, it should be obvious that foreign built vehicles will always carry much higher emission levels from transportation.

The analysis of transportation related emissions is divided into two parts, pre-assembly and post-assembly. The pre-assembly transportation estimates are calculated for the United States, but are assumed to be the same for foreign automakers. For pre-assembly transportation, intermediate products must be transferred from the mining site to the steel production site and from the steel production site to the automobile fabrication site. For this work, it was assumed that the iron product is transported from the mining site in northern Minnesota⁹ by rail (65 miles) and then by water (550 miles) over the Lake Superior to the steel fabrication site in Michigan. From steel fabrication to automobile parts production and assembly plants the distance is estimated to be 350 miles by rail¹⁰. The

⁸ based on 785 kg of steel used in an average vehicle weighing 1,431 kg

⁹ Northern Minnesota holds the largest commercial deposits of iron ore in the United States.

¹⁰ Following the scenario for steel fabrication, 350 miles represents an average distance from which the majority of U.S. plants are located.

emissions for each segment of the pre-assembly journey is summarized in Table 2-6 and the total carbon equivalent emissions per vehicle for the pre-assembly transportation segment is 18,945 grams.

The post assembly transport involves transporting the fully assembled vehicle to its retail distribution point. Transportation requirements differ significantly between foreign manufactured and North American manufactured vehicles. Vehicles built overseas travel greater distances, as they go from assembly plant to home port, home port to U.S. port and U.S. port to retail sales point. Surface transport of vehicles from their assembly site to their home port is assumed to be by rail over a total distance of 230 miles¹¹. Overseas transport assumes crossing the Atlantic or Pacific by car carrying freight ships traveling approximately 3,750 miles if traveling from a European port, and 5,150 if traveling from an Asian port. For domestic vehicles, transport of the assembled vehicle to its retail sales point is assumed to be by diesel fueled tractor trailer carrying 7 vehicles over a distance of 398 miles¹². Total post-assembly emissions from transport is assumed to be 31,263 per vehicle (see Table 2-6, above). Total pre-use transportation emissions are then 50,209 grams of carbon equivalent per vehicle.

The aggregate of pre-use vehicle emissions is 1,089,833 grams of carbon equivalent per vehicle. A summary is provided Table 2-7. For the entire fleet of vehicles sold in the United States in a single year, 11.7 MMT of carbon equivalent can be attributed to the pre-use period¹³.

Post-Use Emissions

Post-use processes include the dismantling, shredding and recycling of used vehicles. As with the pre-use processes emissions can be traced to three primary sources: process emissions, energy generation emissions and transportation emissions. Hahn (1994) estimates that the aggregate per vehicle post-use emissions is 1,305 grams in carbon equivalents. This translates to 1.04×10^{-2} MMT of carbon equivalent emissions per year when summed over the entire stock of vehicles scrapped annually.

¹¹ This is the average distance that freight is hauled by full truck load in the United States and therefore represents only a proxy for surface transport from assembly site to port.

¹² Truck journey based on the average length trip for freight transported by truck in the United States as reported by ENO Transportation Foundation, Inc.

¹³ 1993 sales figures for cars and light-duty trucks sold in the United States were used

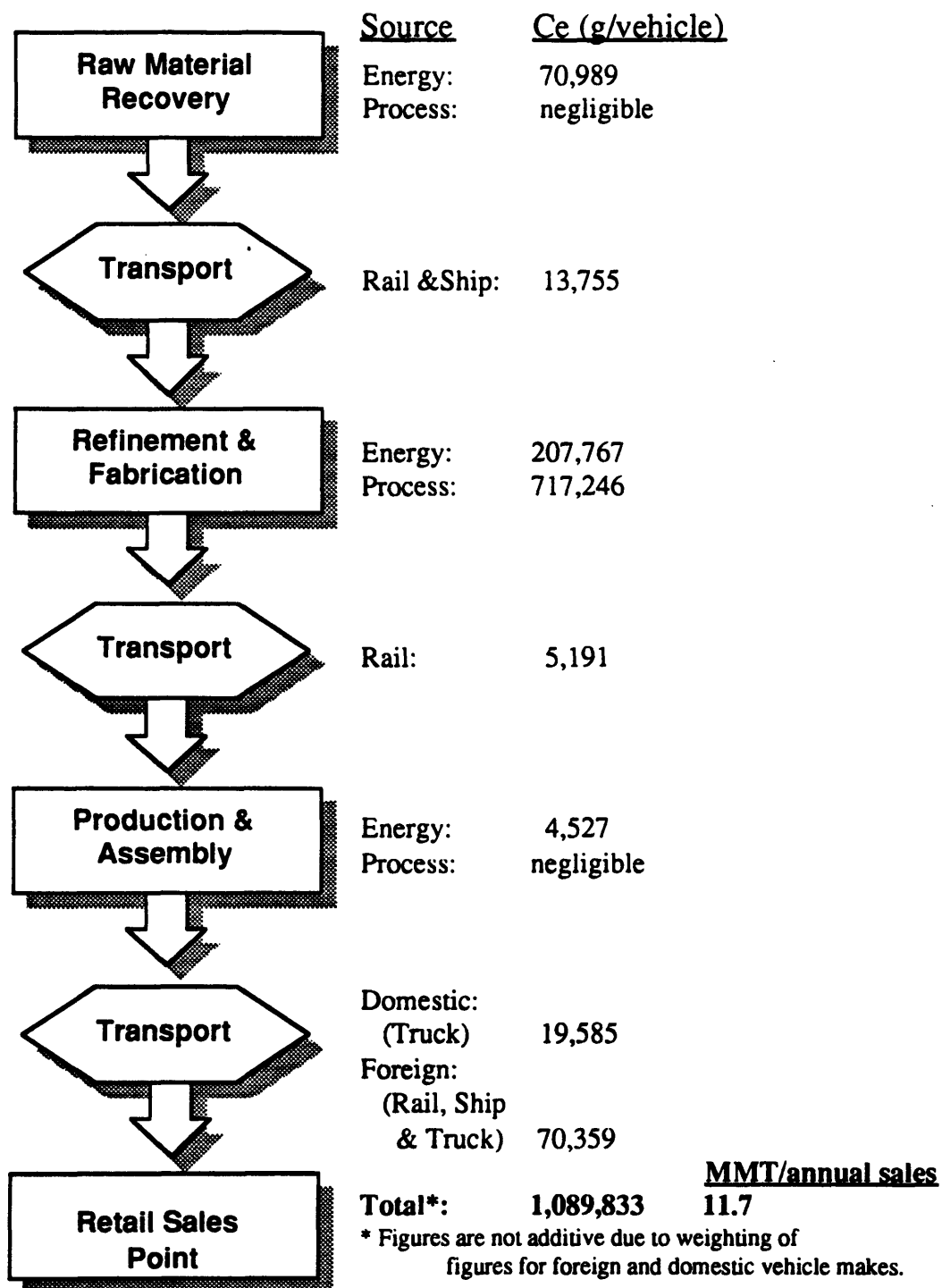


Figure 2-6: Vehicle Pre-Use Period Emissions

Table 2-6: Pre-Use Emissions from Transportation

Route & Mode	Raw Figures Ce Emissions (g/vehicle)	Weighted Figures Ce Emissions (g/vehicle)
<u>PRE- ASSEMBLY</u>		
Extraction - Fabrication		
Rail & Coastal Vessel	13,755	13,755
Fabrication - Assembly		
Rail	<u>5,191</u>	<u>5,191</u>
Pre-assembly subtotal	18,945	18,495
<u>POST ASSEMBLY</u>		
<i>Domestic</i>		
Assembly - Retail		
Truck	<u>19,585</u>	<u>15,081</u>
<i>Total Domestic</i>	<i>38,531</i>	
<i>Import</i>		
Assembly - Port		
Rail	3,411	785
Port - Port (car carrier)		
European	7,968	1,833
Asian	39,395	9,061
Port - Retail		
Truck	<u>19,585</u>	4,505
<i>Total Import</i>	<i>89,305</i>	
Post-assembly subtotal (Domestic & Import)	70,359	31,263
GRAND TOTAL (Domestic & Import)		50,209

Table 2-7: Greenhouse Emissions Associated with a Vehicle's Pre-Use Period

Source	Carbon Equivalent Emissions
Processes	717,245
Energy	283,282
Transportation	<u>89,305</u>
TOTAL g/vehicle	1,089,833
New Vehicle Sales	10,757,879
TOTAL MMT/new sales	11.7

Factors in Pre-and Post Use Emissions

The primary purpose of the pre- and post-use emissions analysis is to provide some perspective on the full cycle emission impacts of end-use emissions reduction policies. The division of the pre- and post-use processes into process, energy generation and transportation sources allows us to better determine the extent of a policy's impact. Based on the analysis above, an average vehicle purchased in 1993, with a rated fuel efficiency of 28.3 miles per gallon, that is driven 12,000 miles per year over a life of 8 years would emit a total of 10.03 metric tons of carbon equivalent throughout its life-cycle (Table 2-8)¹⁴. With total pre-use emissions equaling 11 percent of the total life-cycle emissions, it is a significant contributor, while post-use emissions are relatively insignificant when compared to the other portions of the life-cycle. Knowing these relative contributory levels provides insight into where policy should be focused. Also, when considering policies in general, the effect of a particular initiative on reducing the total life-cycle figure, will depend upon how that policy affects each portion of the vehicle's life-cycle. For example, requiring higher efficiency vehicles may induce automakers to use aluminum in place of some steel. While this will produce a lighter weight and more fuel efficient car, the pre-use impact will be significant and negative. The pre-use process and post-use processes associated with aluminum emit more greenhouse gases than those associated with steel. It is therefore necessary that the fuel savings resulting from the use of aluminum be enough to off-set this difference. To ensure this, the fuel efficiency standards must be set sufficiently high. To accommodate the additional emissions from the replacement of some steel parts with

¹⁴ Fuel efficiency figure based on average for new vehicles sold in 1993 as reported by the MVMA. Vehicle life figure was the average life for a vehicle in 1992, as reported by Ward's Automotive Yearbook.

aluminum (1.34 metric tons of Ce), fuel efficiency standards would need to be raised to a minimum of 33 miles per gallon. Thus, reductions from end-use emissions would only begin to be realized if these vehicles could achieve more than the 33 mpg efficiency level.

Table 2-8: Life-cycle Carbon Equivalent Emissions of a 1993 Model Year Vehicle¹⁵

Time Period	Ce Emissions (metric tons / vehicle)
Pre-Use	1.09
End-Use	9.21
Post-Use	1.31×10^{-3}
Total	10.30

Though beyond the scope of this thesis, which focuses on end-use policies for the reduction of greenhouse emissions, a comprehensive plan for the reduction of greenhouse emissions from the light-duty vehicle sector would address emissions from the entire life-cycle of light-duty vehicles - from ore raw material recovery to vehicle disposal and recycling. The analysis presented above, suggests several areas where emissions levels might be improved. More efficient or less polluting fuel combustion processes in both pre-use and post-use could be effective. More generally, reducing emissions from power generation by using non polluting or less polluting sources would be another effective step. Finally, improvements in emissions from the transportation elements of the pre- and post-use processes through alternative fuels, more efficient modes and a more efficient network would also help meet the greenhouse emission reduction objective.

2.4.2 Factors in End-Use Emission

Because of the linear relationship between fuel use and greenhouse emissions, the factors that affect fuel use are the same as those that impact greenhouse emissions. A simple equation reveals the most essential factors affecting fuel use:

¹⁵ Assumes the vehicle is kept in service for 8 years with annual mileage of 12,000 miles, and a rated fuel efficiency of 28.3 mpg.

$$\text{Fuel Use} = \text{NOV} * \text{VMT/V} * \text{VE}$$

Where:

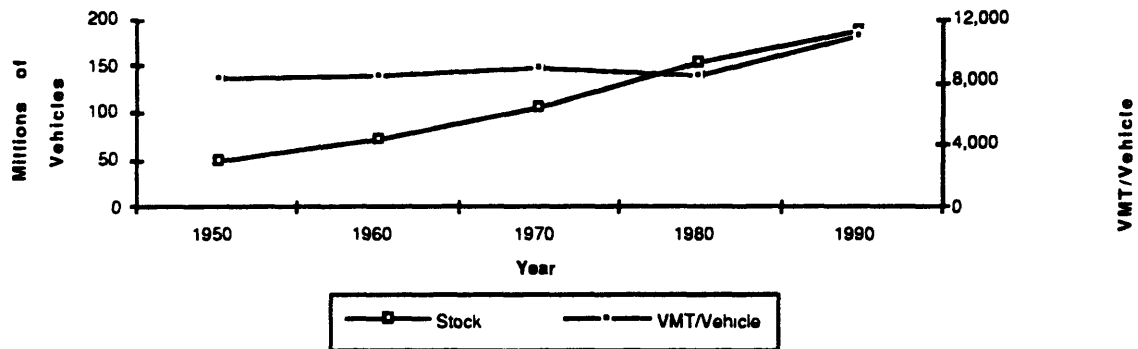
NOV = Number of Vehicles in Fleet
VMT/V = Vehicle Miles Traveled per Vehicle
VE = Average Vehicle On-Road Efficiency

Another important factor not discretely captured in this formula is driving conditions. Driving conditions is both a function and a result of these factors but is deemed important enough to address as a major influence in emissions levels to be considered in its own right. Defining the major factors of fuel-use and therefore end-use emissions, provides a basis for the consideration of policy measures. Policies can be considered in accordance with their effect on each of these factors. All policies must address at least one of the major factors and several will impact two or more. An effective plan for reducing greenhouse emissions should include policies that together impact several of these factors. A greenhouse emission reduction plan which focuses narrowly on only one particular factor will almost assuredly fail or, at most, be so weak as to be essentially ineffective. Because there is a great deal of uncertainty as to the effectiveness of any particular measure, a multi-objective approach reduces the risk of relying on one strategy over the others.

Fleet Size and Characteristics

The size and of the passenger vehicle fleet is perhaps the most obvious of the factors contributing to fuel use and greenhouse emissions - so long as there are cars on the road (which are traditionally fueled) there will be greenhouse emissions. It might be suggested that growth in the fleet size does not necessarily increase the total vehicle miles traveled and therefore fuel use. The argument follows that as more cars enter the fleet, the vehicle miles traveled *per vehicle* will be less and thus the *total* vehicle miles traveled (and the total fuel use) will not significantly change. However, historical trends show that this is not the case. In fact as more cars have entered the fleet, VMT per vehicle has actually increased (Figure 2-7).

Aside from the direct affects on fuel use from increased fleet size, there are other, indirect effects. A larger fleet that experiences higher usage contributes to problems such as the growth of congestion (to be discussed in a later section). Also, if we assume that a significant part of the growth is due to new entries into the car ownership sector, transportation planners may focus more on services to personal vehicles and drivers than on other public modes of transportation.



Source: U.S. DOT, 1992.

Figure 2-7: Historical Growth in Vehicle Fleet and VMT Per Vehicle

In addition to the actual number of vehicles in the fleet, the general characteristics of the fleet will impact the rate at which it consumes fuel. Characteristics of the fleet include the age mix of the vehicles, the mix between passenger cars and light duty trucks and the level of maintenance that these vehicles receive. A low retirement rate for vehicles tends to increase the amount of fuel the fleet consumes, as older vehicles tend to be much less efficient than newer ones. The mix between passenger vehicles and light-duty trucks has become a timely and serious concern. The recent trend in new vehicle purchases has been away from the passenger car and towards LDTs (Figure 2-8). Because LDTs have not been subject to the same level efficiency standards as the passenger car, this shift in the fleet mix has significantly impacted the efficiency and thus, the amount of fuel consumed by the fleet. Finally, the level at which vehicles are maintained will affect fuel use and emissions. Vehicles that are well maintained will be more efficient and less polluting.

Vehicle Miles Traveled

The annual vehicle-miles traveled by passenger vehicle far outnumber those logged by any other mode. In 1990, passenger vehicles accounted for 91 percent of the domestic vehicle-miles traveled (Figures 2-9) (DOT, 1992)¹⁶. This substantial form of transportation has been growing in use, both on a per-car basis and as a whole. Historically, both per-vehicle and total VMT has show large and consistent growth (Figures 2-10a and 2-10b). From

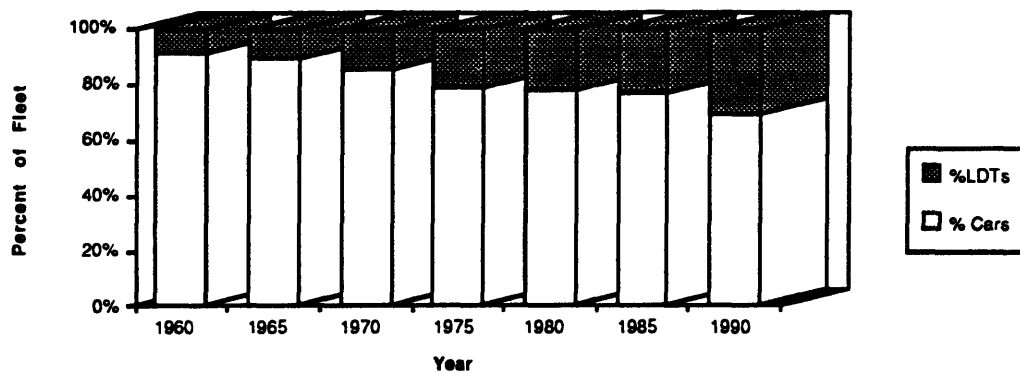
¹⁶ Excluding water travel and international air flights

1980 to 1990, per-vehicle VMT increased 30 percent while total vehicle miles traveled increased over 40 percent (DOT, 1992).

A survey of the current literature reveals a fair and somewhat varied range of factors that are believed to most strongly influence VMT. Fuel price and vehicle efficiency are commonly cited as major influences. But other factors, such as land-use, can have a major impact on VMT in the long-term. Though there may be arguments over the most pertinent factors influencing VMT, there is no question that with all other factors remaining the same, increasing VMT increases carbon emissions.

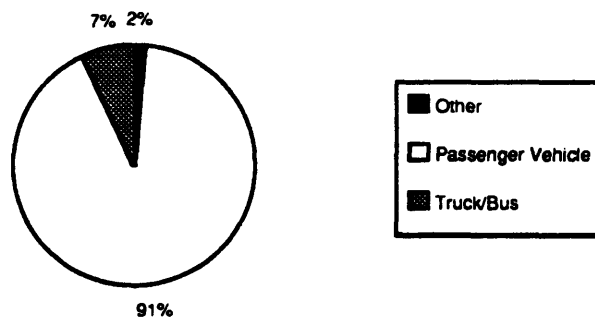
Fuel Efficiency

A factor that directly affects the amount of fuel a vehicle consumes is its fuel efficiency. In 1975, Corporate Average Fuel Economy (CAFE) standards for automobiles and light duty trucks were set through legislation. This legislation mandates that every manufacturer's fleet maintain an average fuel efficiency level that meets or exceeds the CAFE standard. This legislation mandates that every manufacturer's fleet maintain an average fuel efficiency level that meets or exceeds the CAFE standard. Since CAFE standards went into effect in 1978 fleet efficiency of new vehicles has risen 42 percent (SRI, 1991). Currently CAFE standards for passenger vehicles is set at 27.5 mpg. Light-duty trucks (LDTs) were subject to similar but lower standards. CAFE standards for LDTs were established in 1982 and since that time fleet fuel economy has increase 16 percent. The current CAFE standard for LDTs is 24.5 mpg. The effect of CAFE standards on the fleet fuel efficiency has been dramatic (Figure 2-11) but as older cars are replaced by the newer efficient cars, unless standards are raised, it is likely that the fleet efficiency will soon level off at the set standard.



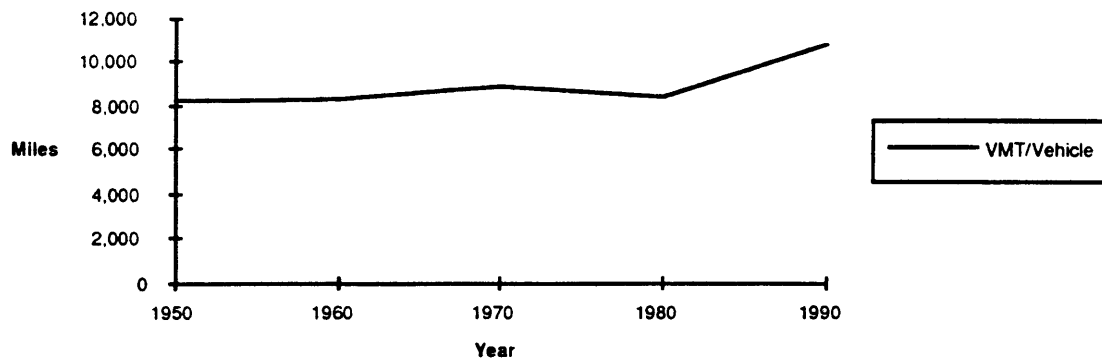
Source: U.S. DOT, 1993.

Figure 2-8: New Vehicle Sales Mix -
The current trend is towards the light-duty truck



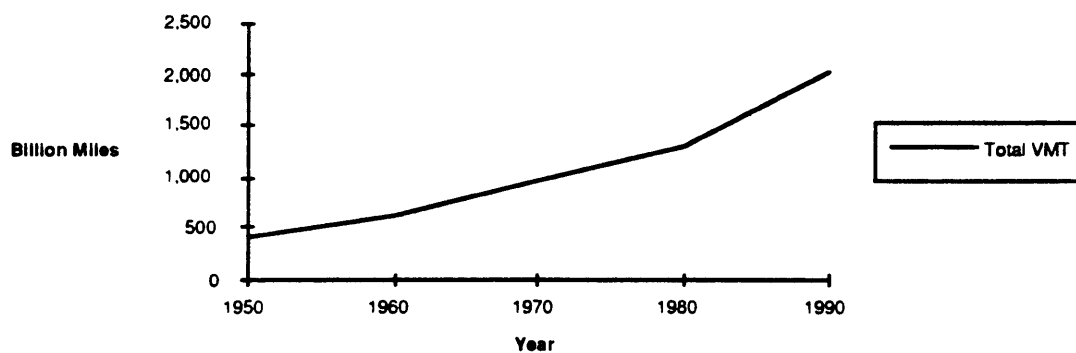
Source: U.S. DOT, 1992.

Figure 2-9: Domestic Vehicle-Miles Traveled by Mode



Source: U.S. DOT, 1992.

Figure 2-10a: Trends in Passenger Car Vehicle Miles Traveled Per Vehicle



Source: U.S. DOT, 1993.

Figure 2-10b: Trends in Total Vehicle Miles Traveled

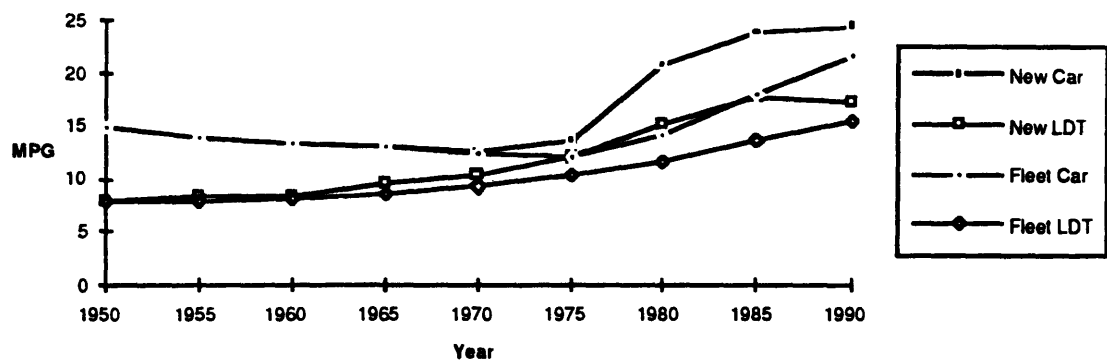
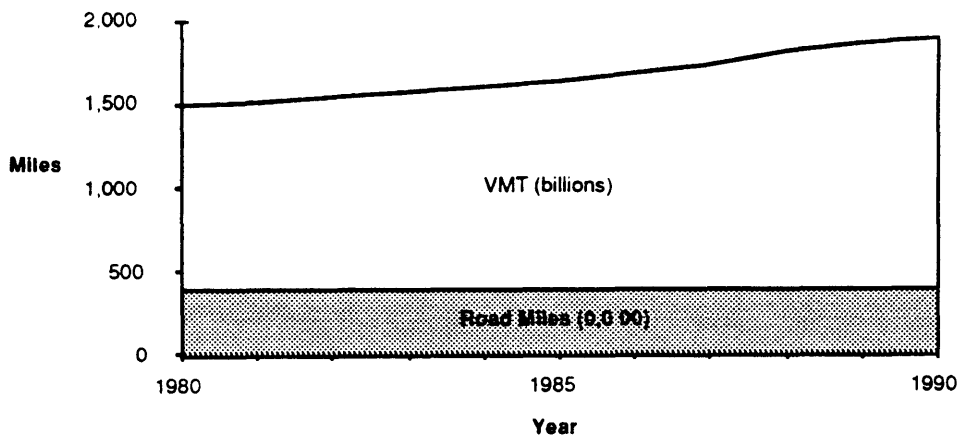


Figure 2-11: Fleet Average Fuel Efficiency (1950 - 1990)

Driving Conditions

The conditions under which a vehicle is operated can significantly influence the amount of fuel consumed and the carbon emissions released. The speed of the vehicle and the number of starts and stops, for example, impact the amount of fuel used. Passenger vehicles generally run most efficiently at speeds between 35 and 45 mph. Speeds that are 20 mph higher or lower can reduce the efficiency by 30 or more percent. Vehicles operated in city settings or on congested roads where they repeat a cycle of acceleration and braking, consume more fuel than when operated on an uncongested highway where they can maintain consistent speeds. Congestion alone is responsible for the waste of 3 percent of all the gasoline consumed in the United States (Hanks and Lomax, 1990). And wasted fuel means unnecessary emissions. Historical trends suggest that congestion will persist. While miles of roads have stayed relatively constant in the past few decades, vehicle miles traveled has increased significantly (Figure 2-12).



Source: U.S. DOT, 1993

Figure 2-12: Vehicle Miles Traveled and Road Miles

2.5 Targets for Reduction

Based on carbon emissions, fuel use and use for travel, the passenger vehicle segment of the transportation sector is the most vital target for greenhouse gas mitigation measures. Without such measures, the trends in fuel use will likely continue, causing further damage and making future goals to minimize emissions and control global warming that much more difficult to attain. If carbon emissions from the passenger vehicle sector are to be reduced, reductions will have to be made in fuel use. Each of the factors mentioned in the previous section - size of vehicle fleet, vehicle miles traveled, fuel efficiency and driving conditions - will need to be addressed. That these are not independent factors in the sector's use of fuel, but, rather interdependent factors, makes the prospect of effective policy development challenging. Though there are many unknowns in this process, it is certain that no single approach or measure will prevail as the dominant solution. It is also certain that technology alone can not satisfactorily address the emissions problem in passenger vehicles. New technologies make vehicles more efficient, reduce tailpipe emissions and/or allow for alternative (lower emission) fuels to be used in our vehicles. However, unless driving behavior is changed, policies will have avoided a root cause to the fuel use/emissions problem. While technological changes can address the emissions per mile from vehicles, only changes in behavior will change the fleet size, driving conditions (congestion, number of trips, etc.) and the actual miles traveled.

The remainder of this thesis will look towards the future by developing a base case forecast for how we could expect the greenhouse gas emission problem to increase in the absence of any mitigation measures and then considering policy alternatives and their effects on carbon emissions. To aid in this analysis a computer model was developed and is described in detail in the following chapter. The remainder of the thesis discusses policy options and makes recommendations towards lessening the passenger vehicles' contribution to global warming.

Chapter Three

The Evaluative Model

3.1 Policy Objectives and Evaluation

When considering policies to address the global warming issue, it is useful first to establish a general time horizon by which these policies can be categorized. Some policies will be appropriate and effective in the short-term but may be neither in the long-term. Conversely, other policies may be ineffective given a short time horizon while in the long term they may be the most prudent of approaches. When evaluating policy options it is important to consider them within the appropriate time context and to compare policies of the same time horizon. A comparison of a short-term option with a long-term option is not an effective evaluation method and is perhaps only relevant as a demonstration of the impact of time differences.

As discussed in section 2.4 of the previous chapter, when evaluating greenhouse gas reduction policies, it is not only helpful to consider the time context but also the general objective of each policy. A long list of policy options provide various means of attaining these objectives. Most short-term policies can be categorized as either fuel efficiency measures or VMT reduction measures, though some may be cross functional. Mid- and long-term policies have a time advantage that allows for technological advances and implementation, adding direct tailpipe emissions reduction¹ and reduction in fleet size as a third and fourth objective. Table 3-1 provides an overview of potential policies, their categorical objective and a brief description of the means by which they would reach their objective.

¹ Reduction of direct tail-pipe emissions refers to the actual reduction of greenhouse and other harmful emissions from the exhaust (through use of new technologies and/or low emitting fuels), all other factors (such as fuel use) remaining the same.

Table 3-1: Summary of Policy Measures -

Measure	Means			
	Increase Efficiency	Decrease VMT	Decrease Fleet	Decrease Tail-pipe Emissions
Fuel Tax	+	+		
Pay at Pump Insurance	+	+		
Congestion Pricing		+		
Non Pricing Transportation Control Measures		+		
Increase Transit Subsidies/ Investment		+	+	
New Vehicle Feebate/Rebate	+			
Scrappage of Older Cars	+		+	
Raise CAFE Standards	+			
Eliminate Employer Subsidized Parking		+		
Full Cost Road Pricing		+		
Vehicle Emissions Taxes	+			+
Fuel Efficient Oil, Tires and Air Conditioning	+			
High Speed Rail		+		
Alternative Fuel Vehicles				+
Land Use Planning		+	+	

3.1.1 Purpose of the Model

With the policy options and objectives defined, it is then necessary to devise a methodology with which to evaluate the options. The evaluation of greenhouse gas reduction policies involves a very clear quantitative component - the determination of expected emission reductions. A policy which theoretically has the highest emission reduction level is not necessarily the most viable option either politically or technologically. However, assessing the potential for emissions reduction does provide some metric by which to compare the policies at one level and determine which policies do not warrant further investigation due to little or possibly even negative reduction potential. The problem of assessing the purely quantitative aspects of a policy lends itself well to an evaluative computer model. Such a model can provide a standard means by which greenhouse gas reduction potential can be estimated for each policy. The model used in this policy analysis was designed for the evaluation of short-term policies as it can only assess changes in VMT and fuel efficiency. The output of this model is restricted to estimates of greenhouse gas emission reduction (measured in carbon equivalent levels) relative to the 1990 levels and to the base case scenario described later in this chapter.

The policies that indicated sufficient potential for emissions reduction were then evaluated for transportation effectiveness, economic impact and implementation feasibility. Detailed description of the analysis is provided in the following chapter.

3.2 Model Description

In 1993, the Volpe National Transportation Systems Center (VNTSC) developed a spreadsheet model of CO₂ emissions from cars and light duty trucks (LDTs) based on the Department of Energy (DOE) IDEAS model light duty vehicle sector. The model was initially created in the summer of 1993 to aid in the analysis of policy proposals for the reduction of greenhouse gas emissions from the light duty vehicle sector in response to President Clinton's initiative to create a Climate Change Action Plan. The IDEAS model and other data were used to estimate a series of regression equations that are used to predict new automobile and light duty truck (LDT) purchases, the fuel economy of new vehicles, and average utilization of cars and LDTs. These regression equations were then combined with the stock aging portion of the model to forecast the size and age structure of the vehicle fleet, fuel consumption, and greenhouse gas emissions from light duty vehicles. The model assumes that the vast majority of the fleet is gasoline powered and therefore

does not consider the effect of alternative fuels. All prices are in 1990 dollars, fuel use is in gallons and emissions are in million metric tons (MMT) of carbon equivalent (Ce).

3.2.1 Model Structure

The model consists of four primary sectors: car stock, vehicle usage, fuel efficiency and the summary sector. Each sector of the model is directly influenced by a set of assumptions for five exogenous variables. In each sector, separate calculations are performed for passenger cars and light duty trucks. Using information from each of the three other sectors, the summary sector calculates fuel consumption and greenhouse gas emissions from the entire fleet as well as from passenger cars and light duty trucks, individually. A schematic diagram of the model is provided in Figure 3-1. The car stock sector uses forecasts of new vehicle sales derived from regression estimates, the annual sales data and a survival rate equation to forecast fleet size by model year. The vehicle usage sector calculates average fleet VMT by using regression model forecasts of VMT per vehicle and applying the percent increase to the model year specific usage rate, as forecast by a usage decline equation. Finally, the fuel efficiency sector estimates the average fleet on road fuel economy using a forecast of new vehicle fuel efficiency and the deterioration rate of fuel efficiency with age. The model also accounts for Corporate Average Fuel Economy (CAFE) standards in the fuel efficiency forecasts. Each model sector is described in detail below.

Assumptions

There are five exogenous variables that are key elements in the calculations for this model: Population, GNP, the Price of Gas, Average Price of Cars and Average Price of LDTs. Historical data and current forecasts are used to determine a baseline annual growth rate for each variable from which future levels of each are calculated, although these future assumptions may be set at any values desired by the analyst. These values may be changed by the user to test different scenarios.

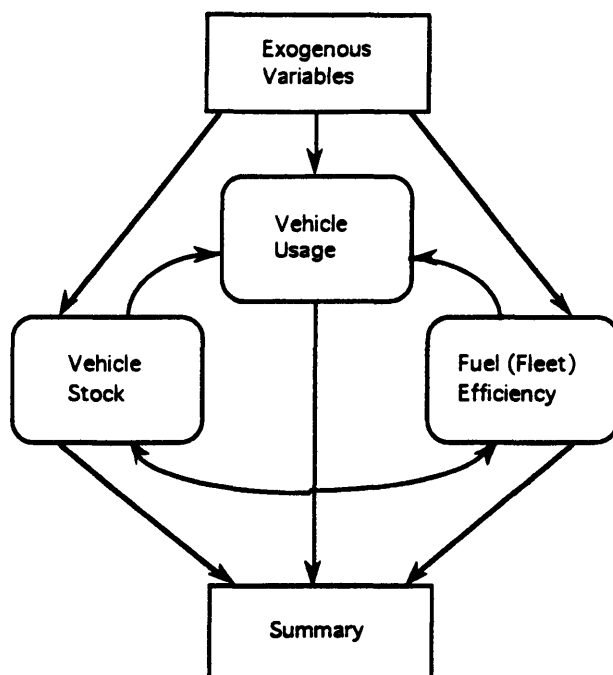


Figure 3-1: General Model Structure

These variables are used to develop the input data used by other model sectors, through equations that forecast new vehicle sales, vehicle stock, vehicle usage (VMT) and fuel efficiency. The final output (fuel consumption and C_e emissions) is calculated from this endogenously generated input.

3.2.2 Model Sector Descriptions²

Car Stock

The vehicle stock sector consists of equations fit to historical data that are used to forecast new vehicle sales; and a set of retirement or scrappage rates that are used to determine the number of each model year's vehicles that remain in service during each successive year. The historical data used to develop forecasting equations come from the IDEAS model and ranges from 1960-1990. The original sources were the Motor Vehicle Manufacturers Association (MVMA) for years 1960-1975 (cars) and 1960-1979 (LDTs) and the EPA for the remaining years through 1990 (for both cars and LDTs). The model forecasts new auto and LDT sales as a function of fuel prices, vehicle prices and income. The forecasting equation (derived through regression fit to the historical data) for new vehicle sales is:

²* The model and statistical information for equations is provided in Appendix A

$$\text{NCS} = 1,513,598 * (\text{PrGas})_t^{-0.37} * (\text{GNP/Pop})_t^{0.91} * (\text{PrVeh})_t^{-0.59}$$

$$\text{adj. } r^2 = 0.81; n = 41$$

Where:

NCS = New Car Sales

PrGas = Retail price of gasoline per gallon in 1990 US dollars (forecasted as described in *Assumptions*, above)

GNP/Pop = Real GNP per capita in 1990 US dollars, (see *Assumptions*, above)

PrVeh = Price index for new passenger automobiles in 1990 US dollars

The subscript "t" indicates that each variable is measured for a calendar year.

The corresponding equation for new light-duty truck sales is:

$$\text{NLDT} = 1,924,160 * (\text{PrGas})_t^{-1.34} * (\text{GNP/Pop})_t^{0.8} * (\text{PrVeh})_t^{-1.24}$$

$$\text{adj. } r^2 = 0.89; n = 13$$

Where:

NLDT = New Light Duty Truck Sales

All other variables are as defined previously.

This equation implies that LDT sales are four times as sensitive to the price of gas as car sales. This result suggests that people will vary their LDT purchases in a manner inversely related to the price of gasoline.

The remaining element of the car stock sector determines the stock of each model year's vehicles remaining in service during each calendar year. Using a stock survival equation derived from the DOE IDEAS model, the remaining stock is calculated as follows:

$$\text{RemSt}_m = (1/(1+(\text{Age}_m/\text{AVL}_m)^\alpha)) * \text{NCS}_m$$

Where

"m" subscript indicates that the figure varies by model year

Age = Calendar Year - Model Year

RemSt = Remaining vehicle stock

NCS	= New Car Sales (calculated above)
AVL	= Average Life of Vehicle
α	= the slope of the survival rate function;

The expression in the parentheses represents the fraction of each model year's new vehicle sales that remain in service at each year of their age. Historical survival rates follow an inverse "S" shaped curve, as illustrated in Figure 3-2. Average life is defined as the number of years at which fifty percent of the vehicles in that model year have been scrapped. Alpha represents the "steepness" of the survival rate function: a very small value for α would mean that half of the vehicles sold in any model year are retired very quickly, while the remaining half of the vehicles last indefinitely. A very large value for α would suggest that half of the vehicles last the average life before any of them are scrapped, while the remaining half are retired shortly thereafter.

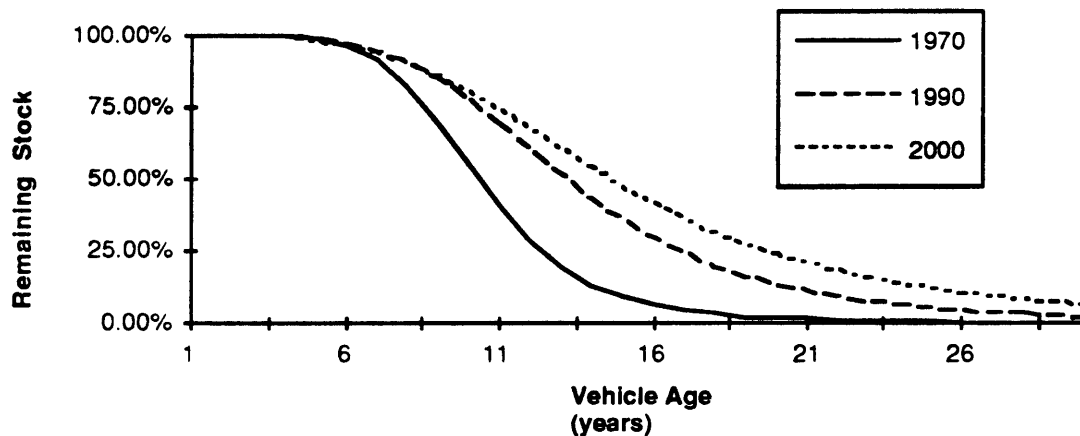


Figure 3-2: Passenger Car Survival Rates -
Model years 1970, 1990 and 2000 (projected).

Historically, the average life of automobiles has increased in an almost perfect linear manner since 1950, beginning in 1950 at 7.43 years and increasing annually by about 0.14 years. As average life has increased, α has decreased in a linear manner over the same period. Figure 3-3 represents this relationship graphically.

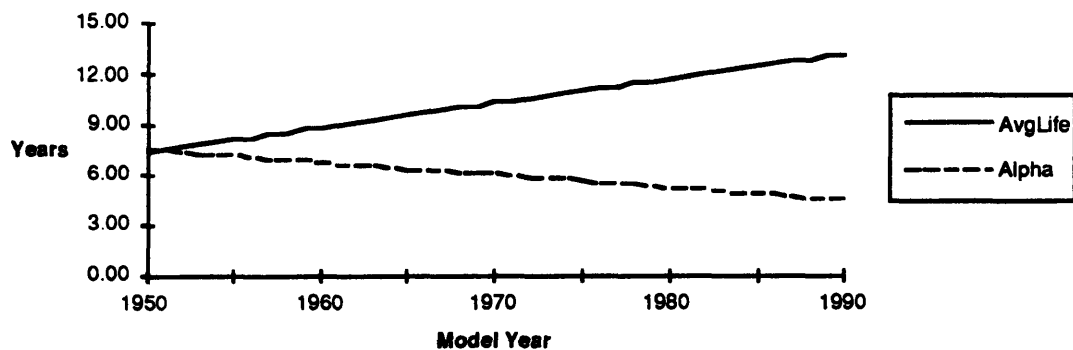


Figure 3-3: Historical Trend of Passenger Car Average Life

In the model, α is calculated from an equation derived by EEA from R.L. Polk data on the stock of vehicles of each model year registered in each subsequent calendar year. For passenger vehicles:

$$\alpha = 11.577 + (-5.382 * AVL)$$

Survival rates, average life and α for LDTs are different than those for passenger cars. Each of these variables changes to a much smaller degree over time. As Figure 3-4 shows, there has been only a slight increase in LDT survival rates since 1970, and this trend is not expected to change. Historically, average life for LDTs increased slightly through 1980, but has been flat ever since. In this model, average life in 1950 is assumed to be 12.60, reaching 14.50 years by 1980, at which level it remains. Alpha has remained relatively constant at 4.20 over the entire period 1950 - 1990 (see Figure 3-5) and is assumed to remain so through 2010.

In the final step of this sector, the model aggregates the forecast of each year's new vehicle sales with the model year-by-model year estimates of the remaining stock to determine a figure for the total size of the vehicle fleet during each future year.

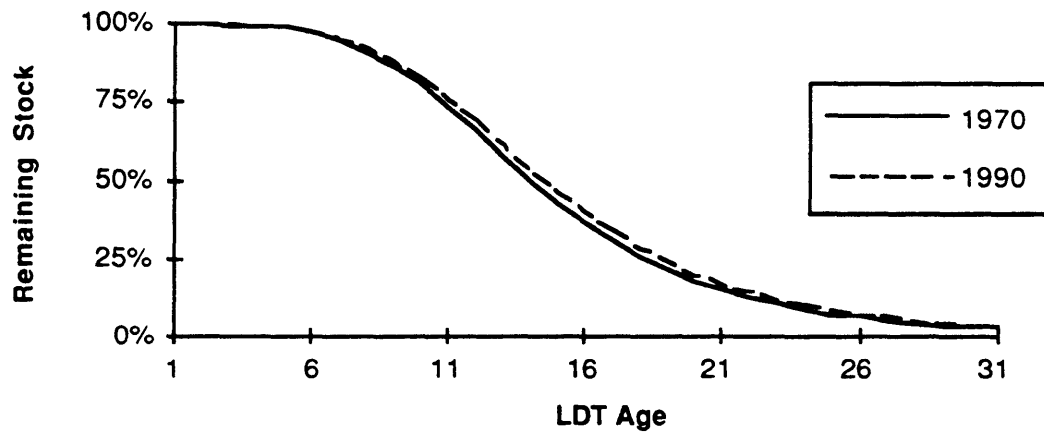


Figure 3-4: Survival Rates for Light Duty Trucks

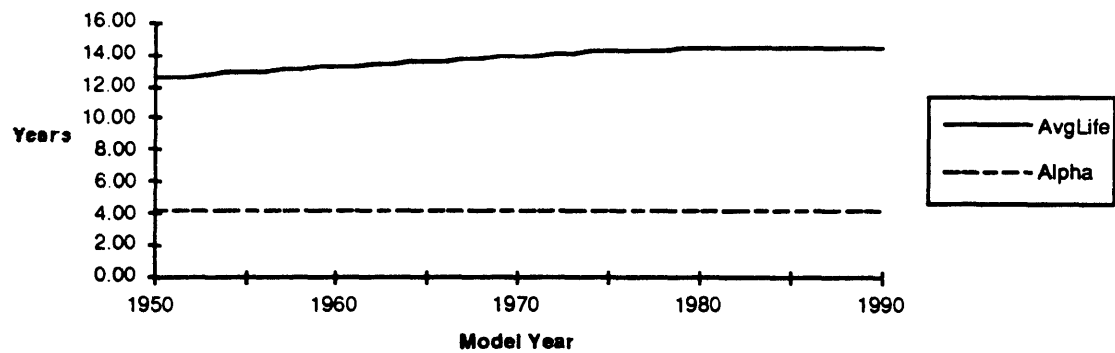


Figure 3-5: Average Life and Alpha for LDTs

Vehicle Usage

Vehicle usage is measured by annual vehicle miles traveled (VMT) per vehicle. As with the Car Stock sector, the Vehicle Usage sector contains two components: forecasts of average annual utilization of vehicles during each year, derived from equations fit to historical data; and assumptions about how the average usage of vehicles changes with increasing age. Data taken from the National Personal Transportation Survey (NPTS) for the years 1969, 1977, 1983 and 1990 were used to calculate new vehicle usage from 1960 to 1990. From these data points figures for the intermediate years were extrapolated linearly. For the years 1960 through 1969, VMT was assumed to be constant at 16,100 miles per year. From 1983 through 1989, VMT was assumed to remain constant at 17,000. In 1990, VMT was adjusted to 16,900 miles per vehicle to reflect actual NPTS data. The model forecasts fleet average VMT using a regression fit to historical data from 1950 - 1990. In this equation, VMT is calculated as a function of price of fuel, GNP/Population and the number of Vehicles per capita in the stock.

The equation used to forecast average annual VMT per automobile:

$$AAVMT = 1,394 * (PrGasPerMi.)_t^{-0.16} * (GNP/Pop)_t^{0.46} * (VST/Pop)_{m,t}^{-0.38}.$$

$$adj. r^2 = 0.91; n = 41$$

Where:

AAVMT = Average Annual VMT

PrGas = Price of gasoline at the pump, which is forecasted based on annual percentage growth assumptions (see *Assumptions*, above). [1990 US dollars]

GNP/Pop = Real GNP per unit population, (see *Assumptions*, above) [1990 US dollars/capita]

VST/Pop = Vehicle Stock per Unit Population

The annual utilization of each model year's vehicles is assumed to decline as they age according to an equation derived from information contained in the IDEAS model VMT subsector. In each calendar year, the usage decline is calculated for each model year. The percent change in new vehicle VMT from the previous year is then applied to the declined VMT levels of the older stock to determine vehicle usage over the entire fleet. The result is a shift in the usage curve, where the magnitude and direction of the shift is determined by

the percent change in new vehicle VMT. Figure 3-6 illustrates this behavior. The equation used in the Volpe model calculates the decreased VMT by model year for each calendar year.

$$DVMT = \Delta (AAVMT)_m * (GRVMT) * \text{EXP}(-0.0521 * \text{Age})_{m,t}$$

Where:

- DVMT = Declined level of VMT (from initial "new car" value)
- $\Delta AAVMT$ = Average Annual VMT, calculation described above
- GRVMT = Vehicle Growth Rate = The annual rate of change in average VMT for new vehicles
- Age = Vehicle Age = Calendar Year - Model Year

The calculations are done in a parallel manner for light duty trucks and are:

$$NLVMT = 3,361 * (\text{PrGasPerMi.})_t^{-0.28} (\text{GNP/Pop})_t^{0.21} * (\text{VST/Pop})_{m,t}^{0.18}.$$

$$\text{adj. } r^2 = 0.94; n = 40$$

Where:

NLVMT = New Light Duty Truck VMT

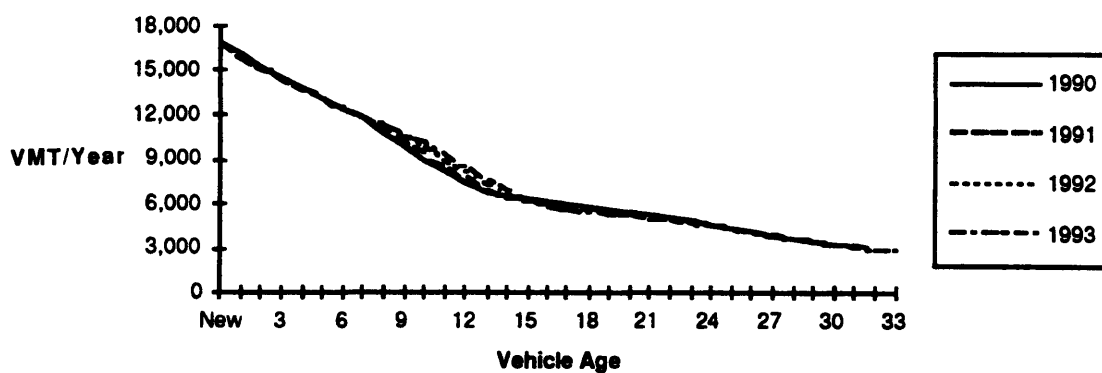


Figure 3-6: VMT Decline Rate

Fuel Efficiency

The fuel efficiency sector is structured in a way similar to the car stock and the vehicle usage sectors: forecasts of the fuel efficiency of new vehicles, for model years beyond 1990, are developed from historical data and the deterioration in fuel efficiency segment (how engine efficiency degrades with the age of a vehicle) is used to estimate the efficiency of vehicles from each model year that remain in service during each subsequent calendar year. The historical data, collected by EEA for IDEAS, come from two sources: the early data (1960 - 1994) were collected from the Transportation Energy Data Book, Edition 1. For the later data (1975 to 1990), on-road figures were derived from EPA standards by discounting the standards by approximately 15 per cent.

New vehicle fuel efficiency is calculated as a function of fuel price, per capita GNP and historical efficiency levels. A regression on historical data was performed to derive the following forecasting equations for the fuel economy of autos and light-duty trucks:

$$\text{NCMPG} = 1.595 * \text{MPG}_{m,(t-1)}^{0.848} * \text{PrGas}_t^{0.09} * (\text{GNP/Pop})_t$$

$$\text{adj. } r^2 = 0.96; n = 13$$

Where:

$$\text{NCMPG} = \text{New Car MPG}$$

PrGas, GNP and Population are exogenous variables dependent upon user input (see *Assumptions*, above)

$$\text{NLMPG} = 1.041 * \text{MPG}_{m,(t-1)}^{0.97} * \text{PrGas}_t^{0.14} * (\text{GNP/Pop})_t$$

$$\text{adj. } r^2 = 0.93; n = 13$$

Where:

$$\text{NLMPG} = \text{New LDT MPG}$$

For LDTs, the model was estimated for 1978 to 1990, since prior to the early 1970s the composition of the new LDT fleet was considerably different. The phenomenon of substitution of LDTs for passenger cars only became widespread in the late 1970s and 1980s.

If the user wishes to test a policy of increased CAFE standards, the model will substitute the user-specified values for those compiled from the equation. To approximate actual on-road fuel economy associated with the specified CAFE levels (which are

measured under carefully controlled test conditions), the projected CAFE standards are decreased by 15%.

Fuel Consumption & Greenhouse Gas Output (Summary)

The two primary outputs of summary sector of the model are forecasted fuel consumption and greenhouse gas emissions. There is a linear relationship between fuel consumption and carbon emissions, so changes in fuel consumption have the same relative effect on carbon emissions. The calculation for fuel consumption is straightforward and incorporates the results from the other sectors:

$$\begin{array}{l} \text{Fleet} \\ \text{Fuel} \\ \text{Consumption} \\ \text{in year } t \end{array} = \sum (\text{VMT}_m / \text{MPG}_m) * \text{Vehicles}_m$$

Carbon equivalent emissions (Ce) were calculated using conversion factors developed by Duleep and used by DOE in its *Annual Energy Outlook*:

$$\text{Ce} = \text{FuelUse} * \text{CCF} / 6.007\text{E-}4$$

Where:

$$\begin{array}{ll} \text{Fuel Use} = & \text{Fleet Fuel Consumption (as calculated above)} \\ \text{CCF} = & \text{Carbon equivalent Conversion Factor} = 19.7 \text{ MMT/Quad} \end{array}$$

the last number is a unit conversion factor from quads of thermal energy to gallons of fuel.

3.2.3 Base Case Model Run

As a point of comparison for other policy options, using the model, a base case scenario was comprised. Table 3-2 lists the assumptions for the growth rates.

Table 3-2: Assumptions and Justifications for Base Case Scenario

Variable	Growth Rate	Justification
Population	0.7%	Census midrange growth estimate
Real GDP*	2.0%	DOE midrange growth estimate
Price of Gas*†	0 %	Historical growth 1950 - 1990 = -0.4%
Price of Cars*	1.5%	Somewhat competitive market
Price of Trucks*	1.5%	Somewhat competitive market

* Growth rate above general price inflation ("real" growth).

† Survey data were used for the price of gas in 1991, since the price was atypically high in 1990 because of the Persian Gulf conflict.

Base Case Output

Under the base case scenario, the size of the fleet is projected to grow by 21% between 1990 and 2000 and then another 9.4% by 2010. The number of miles traveled is forecast to increase 24% by 2000 and another 9% by 2010. Both of these trends lead to additional fuel consumption.

Fleet fuel efficiency is forecast to increase slightly by 2000 as the more fuel-efficient vehicles sold in the 1980s cycle through the fleet. New vehicle fuel efficiency is expected to drop because of rising incomes and flat real gas prices. Between 2000 and 2010 overall fleet fuel efficiency decreases as declining new vehicle fuel efficiency becomes the dominant effect. The net result of these three effects -- increasing vehicle ownership, increasing utilization and decreasing fuel efficiency -- is a 15% increase in both fuel consumption and CO₂ emissions over 1990 levels by 2000 (reaching 301 MMT of carbon equivalent emitted) and a further 7% increase by 2010 (323 MMT of carbon equivalent). Outcomes of the model's forecast under this scenario are provided in Table 3-3.

Table 3-3: Summary of Base Case Outcome

	1990	2000	2010	1990-2000 % change	2000-2010 % change
Cars					
Sales (000)	9,301	10,676	10,344	14.8	-3.11
Stock (millions)	121.6	142.1	160.8	16.9	13.2
VMT (millions)	1,484,029	1,772,155	1,996,119	18.0	12.6
New MPG (road)	24.3	24.0	23.9	-2.52	-0.41
Fleet MPG (road)	21.2	23.1	22.9	7.11	-0.75
Carbon Emissions (MMT Ce/yr)	170.4	187.2	212.4	10.2	13.5
LDT					
Sales	3,823	3,985	3,670	3.15	-7.91
Stock	48.73	62.51	63.10	30.0	0.93
VMT	555,080	806,740	807,177	40.5	0.05
New MPG	17.2	18.7	18.7	8.55	0
Fleet MPG	15.5	17.2	17.6	12.3	2.72
Carbon Emissions	87.2	114.4	111.5	25.1	-2.59
Total					
Sales	13,124	14,661	14,014	4.24	-4.41
Stock	170.3	204.6	223.9	20.6	9.43
VMT	2,039,109	2,578,895	2,803,296	15.9	8.70
Carbon Emissions	257.6	301.6	62.58	15.4	7.39

3.3 Limitations of the Model

Though models are helpful tools in policy analysis all models are inherently flawed. Models are meant to represent or *simulate* the very complex systems of the world around us. By necessity models are simplifications of these systems and therefore can not exactly replicate them. The model used in this analysis is an econometric model. These models function on the premise that the relationships between parameters in the system as represented in historical data will remain the same in the future. Econometric models therefore are not capable of representing the changing dynamics of a system. In the short-term, when relationships will tend to be very similar to the recent past, the impact of the fixed relationship assumption may be negligible. However, as the time frame extends further into the future, the structural relationships may shift, resulting in gross errors. For this reason, the model used in this analysis does not extend beyond 2010 and the crucial figures for the quantitative analysis are observed for the year 2000.

Because econometric models rely heavily upon historic data, the quality of this data can greatly influence the model's forecasts. The sources of the data and the methodology

used when the data was originally collected and logged (direct observation, derived data calculated from composite observations, etc.) will affect the model's outcomes. Interpolations and estimates made to fill missing data points can also distort the model. In the construction of this model, efforts were made to use data that was as consistent, complete and reliable as possible. A particular data problem point in the model is that for VMT. VMT is a derived piece of information. VMT is usually calculated from information on fuel sales and vehicle efficiency using the equation:

$$\text{VMT(mi)} = \text{On-road fleet efficiency (mi/gal)} * \text{gallons of fuel sold (gal)};$$

Where on-road fleet efficiency is also derived.

Because VMT is calculated based on observed data (fuel) as well as other derived data (fuel efficiency) it is more vulnerable to error than purely empirical data. Verifying and, if necessary, improving the VMT data and subsequent forecasts is the focus of continued work for this model.

3.4 The Use of Models in Policy Making

Models are increasingly being used in the policy making process. The development and availability of user-friendly software for modeling along with the appeal of producing “hard numbers” with which to defend one's theories has made computer models ever more prevalent in business and government decision making processes. Though there are virtues to the use of a quantitative evaluative tool, too much emphasis can be placed on a model and the value of its outcomes. As explained above, even the most complex and comprehensive model is a simplification of an even more complex real-world system. With a multitude of modeling techniques from optimization to econometrics to system dynamics modeling and more available to the modeler and policy-maker, each has its strengths and weaknesses. Furthermore, a technique that may be appropriate for one type of analysis may be inappropriate for another. As computer models are more frequently employed in the policy-making process, it becomes necessary to not only evaluate the policy options suggested by the model, but the methodology and the model itself. In addition to the methodology used, models often reflect the bias of the developer. The choice of parameters, equations and exogenous variables as well as their sources will influence the model's outcome. The bias of the developer is perhaps more dangerous in the outcome of a model because of the image of objectivity associated with quantitative assessments.

The information and insights that models provide can be of great value. However, this information must be considered in context and should not be used as the sole source of evaluation. Equally important is the qualitative analysis of a policy. Understanding the political and social impact of an alternative is as crucial to a policy's success as its quantitative potential.

Chapter Four

Policy Options and Effectiveness

4.1 An Approach to Policy Making

The difficulty in addressing the greenhouse emissions problem for the light-duty vehicle sector is not determining the *technical* problem or its solution. The sources of the emissions and good approximations of their contributions to global warming have been identified (see Chapter 2). For the light-duty vehicle sector, fuel use and CFC production must be reduced to mitigate global warming. Determining the appropriate level of reduction, whether that goal is feasible and defining the means by which the goals can be achieved is the current challenge. Ideally, emissions from the light-duty vehicle sector would be reduced to the point where their effects would be inconsequential to global warming. However, given current technology and conditions, this would require substantial change in our driving behavior. The problem is not simply reducing greenhouse emissions from the light-duty vehicle sector, but doing so in a way that maintains a sufficient level of mobility while avoiding detrimental impacts on the economy.

This chapter seeks to synthesize the quantitative and qualitative aspects of proposed solutions. Using the model described in Chapter 3, the three major factors of end-use emissions - vehicle miles traveled, vehicle efficiency and vehicle stock - the technical potential of selected policy options were evaluated. Those that were judged to have sufficient technical potential were further evaluated for feasibility of implementation which took into account the social, political and economic impacts. These are discussed in Chapter 5.

4.1.1 Emission Control as a System

In Chapter 2 (section 2.4), several factors were identified as the major influences to fuel consumption and therefore greenhouse emissions. They are VMT per vehicle, size of vehicle stock and vehicle fuel efficiency. When developing policy - the means by which emissions goals will be met - the policy's impact on all of these factors must be accounted for simultaneously. It must be recognized that the methods employed through policies do not act in isolation but are dependent upon the interaction of a number of factors. For example, a policy that improves vehicle efficiency will reduce the amount of gasoline fuel consumed, assuming all other factors remain the same. This, in turn, will reduce the operating costs of the more efficient vehicles. Because it is now less expensive to drive, the number and/or lengths of trips will increase, thereby increasing the amount of gas consumed (this effect is known as "backlash"), which will increase the level of emissions. This illustrates how the implementation of one action can trigger a number of subsequent actions and reactions that may either enhance or diminish the intended effects of the policy. The series of actions and reactions occur due to the structure and functioning of the *system* that underlies the actions. The underlying system in which a policy operates will determine its ultimate success.

Understanding a system can enable a policy-maker to better determine what the direct and ancillary effects of a given policy may be. The system which underlies driver behavior and the effects of emission policies for the light-duty vehicle sector is illustrated in Figure 4-1. This model represents the behavior of a driver and vehicle only after a car has been purchased.

The model presented in Figure 4-1 consists of elements and arrows showing the relationships between the elements. The small plus and minus signs on the head of the arrows between the elements indicate the directional effect the preceding element has on the subsequent one. For example, as the price of gas increases so does the cost to drive, hence there is a small plus sign at the tip of the connecting arrow. Conversely, as the cost to drive increases, the distance driven decreases, and so a minus sign is found at the tip of this arrow. In addition, hatch marks across an arrow indicate a time delay between the one element and another. For example, there is a time delay between the time when new, more efficient vehicles are introduced in the market and that time when the efficiency of the fleet is significantly affected.

The elements and arrows join to form feedback loops. The interaction of the system's elements can be explained through these feedback loops. A feedback loop indicates how a series of actions affects each other and how the entire series acts as a

whole. The reader will note the plus and minus signs encircled with directional arrows (a number next to one of these indicates a major loop). These indicate the location and “polarity” of the feedback loops. The positive, or reinforcing loops (represented by the plus sign inside a circle) indicate growth or build up. The negative or balancing loops (represented by the minus sign in a circle), indicate an evening out or a balancing of the system. In the long run we could expect to find some balance between the emissions producing and the policy reducing components. The actual outcome depends on several factors including:

- 1) Only essential variables were included - this system is simplified and required the aggregation of some variables. Therefore not all effects of the variables that were in some way excluded (either through aggregation or omission) have been captured.
- 2) The system is assessed based on the dominance of loops. If the more dominant loops are primarily reinforcing it will be a system of unchecked growth. Strong negative feedback loops will result in a balancing effect on the system.

In this system, two of the three primary components (fleet size and VMT) of emissions production are not likely to be controlled directly by policy. Efficiency is the one element that can be more easily regulated directly. The challenge to policy makers then, is to develop policies that have the greatest potential for affecting the influencing factors (such as price of fuel) of the primary components in the intended manner. The arrows extending from the “Policies to reduce emissions” element in the model indicate the mechanisms used by the policies discussed in this thesis to affect the primary components of fuel use and emissions. Specifically, the policies to reduce emissions include: increasing fuel efficiency (direct); increasing fuel price (indirect mechanism for reducing VMT and increasing efficiency); increasing the price of vehicles (indirect mechanism for reducing vehicle stock) and increasing operating and maintenance costs (indirect mechanism for reducing vehicle stock). The single, but important, exception is the “emission control technology” element. Though policies (such as subsidies for research and development in this area) could be implemented to encourage the development of technology this option is not examined in this thesis. It is assumed that the creation of other policies will generate the impetus in the market to support this development.

In this system there are nine major feedback loops. They are:

Emission Producing Loops (Reinforcing)

1. Fleet Efficiency $\rightarrow^{(-)}$ Fuel Consumed $\rightarrow^{(-)}$ Price of Fuel $\rightarrow^{(+)}$ Operating and Maintenance Costs $\rightarrow^{(+)}$ Desired Efficiency $\rightarrow^{(+)}$ Efficiency of Vehicle $\rightarrow^{(+)}$ Fleet Efficiency (positive)

2. Vehicle Miles Traveled (VMT) $\rightarrow^{(+)}$ Fuel Consumed $\rightarrow^{(-)}$ Price of Fuel $\rightarrow^{(+)}$ Operating and Maintenance Costs $\rightarrow^{(-)}$ VMT/Vehicle $\rightarrow^{(+)}$ VMT (positive)
3. Vehicle Stock $\rightarrow^{(+)}$ Fuel Consumed $\rightarrow^{(-)}$ Price of Fuel $\rightarrow^{(+)}$ Operating and Maintenance Costs $\rightarrow^{(-)}$ Return on Investment $\rightarrow^{(-)}$ Scrappage Rate $\rightarrow^{(-)}$ Vehicle Stock (positive)
4. Vehicle Stock $\rightarrow^{(-)}$ Licensed Driver to Vehicle Ratio $\rightarrow^{(+)}$ Vehicle Sales $\rightarrow^{(+)}$ Vehicle Stock (negative)¹

Emission Control Loops (Balancing)

5. Emissions $\rightarrow^{(+)}$ Policies to Reduce Emissions $\rightarrow^{(+)}$ Efficiency of Vehicle $\rightarrow^{(+)}$ (delay) Fleet Efficiency $\rightarrow^{(-)}$ Fuel Consumed $\rightarrow^{(+)}$ Emissions (negative)
6. Emissions $\rightarrow^{(+)}$ Policies to Reduce Emissions $\rightarrow^{(+)}$ Price of Fuel $\rightarrow^{(+)}$ Operating and Maintenance Costs $\rightarrow^{(-)}$ Return on Investment $\rightarrow^{(-)}$ Scrappage Rate $\rightarrow^{(-)}$ Vehicle Stock $\rightarrow^{(+)}$ Fuel Consumed $\rightarrow^{(+)}$ Emissions (negative)
7. Emissions $\rightarrow^{(+)}$ Policies to Reduce Emissions $\rightarrow^{(+)}$ Price of Vehicles $\rightarrow^{(-)}$ Vehicle Sales $\rightarrow^{(-)}$ Vehicle Stock $\rightarrow^{(+)}$ Fuel consumed $\rightarrow^{(+)}$ Emissions (negative)
8. Emissions $\rightarrow^{(+)}$ Policies to Reduce Emissions $\rightarrow^{(+)}$ Operating and Maintenance Costs $\rightarrow^{(-)}$ Return on Investment $\rightarrow^{(-)}$ Scrappage Rate $\rightarrow^{(-)}$ Vehicle Stock $\rightarrow^{(+)}$ Total VMT $\rightarrow^{(+)}$ Fuel consumed $\rightarrow^{(+)}$ Emissions (negative)
9. Emissions $\rightarrow^{(+)}$ Policies to Reduce Emissions $\rightarrow^{(+)}$ Emission Control Technologies $\rightarrow^{(-)}$ Emissions (negative)

The challenge is to choose and implement policies which interact within this system of feedback loops to affect behavior in the desired manner - so that greenhouse emissions are reduced at best, and at least not increased. While the actual magnitude of a policy's effect may be speculative (though the purpose of computer models such as the one in this thesis is to provide a forecast with some level of confidence), understanding the underlying components of a system and how suggested policies will affect behavior can determine whether the policies are generally appropriate. In other words, as policy is developed, it should strive to be "directionally correct". Thus, while a pure technical assessment of a policy's emissions reduction potential may be high, behavioral elements in the over all system may alter the expected technical outcome, ultimately resulting in an outcome that may not be desirable. With this in mind, we will proceed to examine in greater depth, policies for both their technical potential and "system" effectiveness.

¹ This assumes that there is a saturation point for vehicle stock

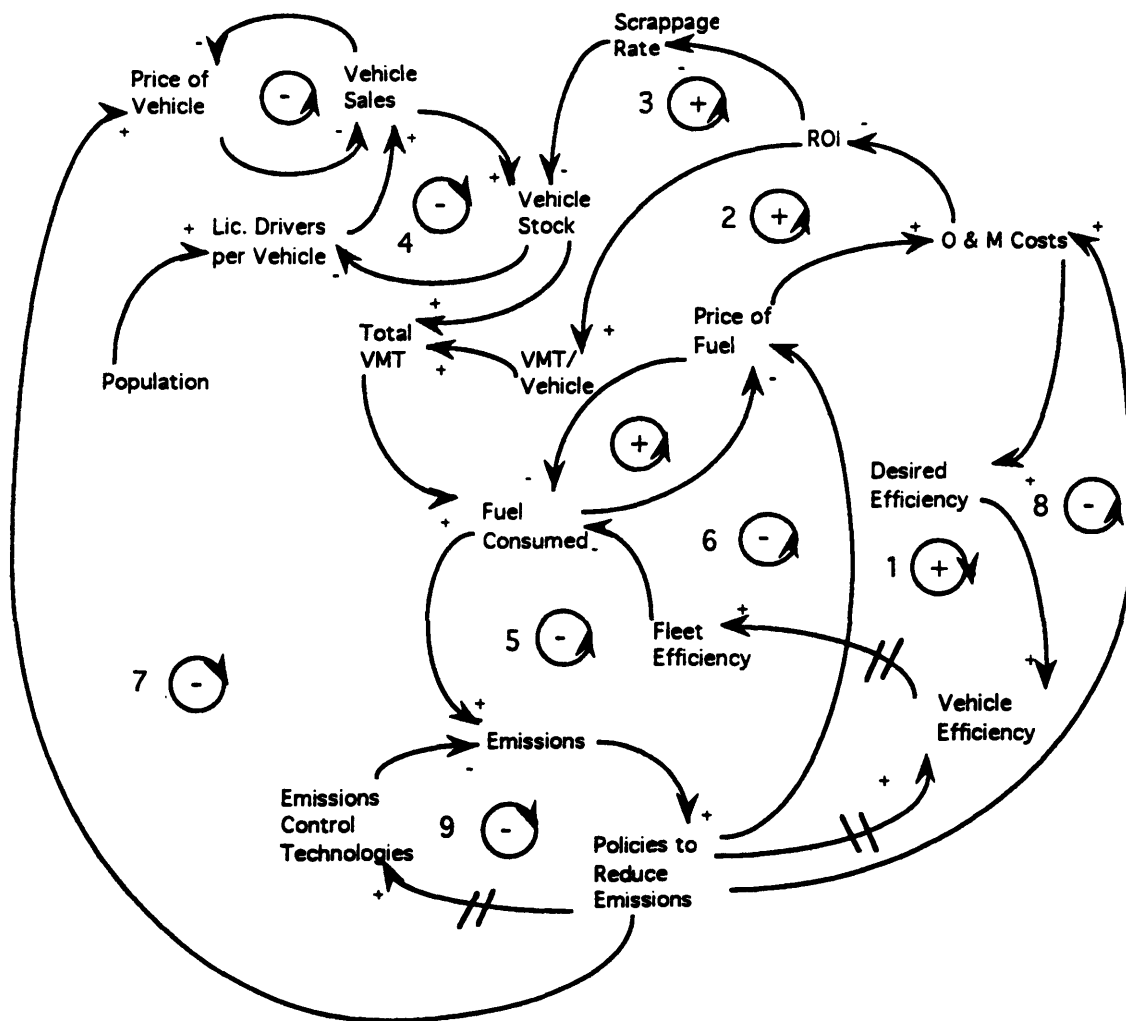


Figure 4-1: Feedback Diagram of Vehicle Use, Fuel Use, Emissions and Control Policies

4.1.2 Setting the Boundaries

Before considering specific policy options, the boundaries of different policy approaches were established to help provide a framework in which the policy options could be better evaluated. Boundaries in this sense, refer to the extremes of various policy approaches that would be necessary to obtain a given goal. The goal in this case is (as stated by President Clinton) to reduce greenhouse gas emissions [from the light-duty vehicle sector] to 1990 levels by the year 2000. The approaches, and thus the boundaries, are the three essential factors in fuel use and in vehicle end-use greenhouse emission production - vehicle miles traveled, vehicle stock and fuel efficiency.

To establish the boundaries, each factor was first considered in isolation. It was assumed that the two factors not being analyzed would remain at the level established in the

base case scenario for the years 2000 and 2005 - annual VMT/vehicle of 12,533 and 12,771 miles for cars and 12,909 and 12,814 miles for LDTs; fuel efficiency (new vehicle) of 27.5 mpg for cars and 21.5 mpg for LDTs; fleet size of 142 million for cars and 62 million for LDTs. Given the remaining factor, the magnitude necessary to maintain the 1990 emissions level was determined. It was determined that if the other two factors were to remain at their projected base case levels, each factor acting alone would have to be of the following magnitude:

- Efficiency - assuming higher efficiency standards could be implemented by 1998, new car efficiency would have to increase by 56 percent to 43 mpg and new truck efficiency would need to increase by 123 percent to 48 mpg.
- VMT/vehicle - VMT/vehicle would need to be reduced by 9 percent (to 11,343 miles) from the current level for cars and 21 percent (to 10,198 miles) for LDTs.
- Stock - The fleet size could grow at only one third the projected rate to 128 million for cars and to about one fifth the projected rate to about 50 million for LDTs. The fact that the fleet size can grow at all is due to the replacement of older vehicles with new vehicles that maintain the CAFE standards, thereby increasing the fleet efficiency.

Thus, we have created the extreme cases for each factor. It is likely that in reality, reaching anyone of these goals or boundaries is not feasible; either because of technical, political or social barriers. These figures are still useful as they provide some perspective on the magnitude of the both the problem and potential solutions. It should be noted that while they are useful as guidelines, due to the interactions of the factors on each other as described in the previous section, these figures should not be considered absolute and rigid goals.

Given that individually, attaining any of the three extremes is not likely given the current political atmosphere, it is practical to consider how these factors in combination could fulfill the emissions reduction goal. A solution space can be constructed of the three essential factors (Figure 4-2). Given a three-dimensional space, each axis (x, y, z) represents a factor (e.g. VMT/vehicle, efficiency, vehicle stock) and is measured in percent change from 1990 levels of that factor. The solution space represents the range of combinations of changes in the factors that is necessary to reach the established emission reduction goal. For example, a 50 percent increase in VMT with no change in efficiency standards would require a 32 percent reduction in stock from the base case. This solution space gives us some insight into the complements and trade-offs that are involved in combining possible approaches to reach the greenhouse gas emissions goal. In a political context, this solution space illustrates not simply how policies *can* be combined to reach a given goal but the actual *necessity* of compensating a lesser than optimal effort in one

dimension with a greater effort in one or both of the other dimensions, so that the ultimate goal is not compromised. However, as stated before, this solution space model should only be used as a framework for initial consideration of actions and not as an exact assessment.

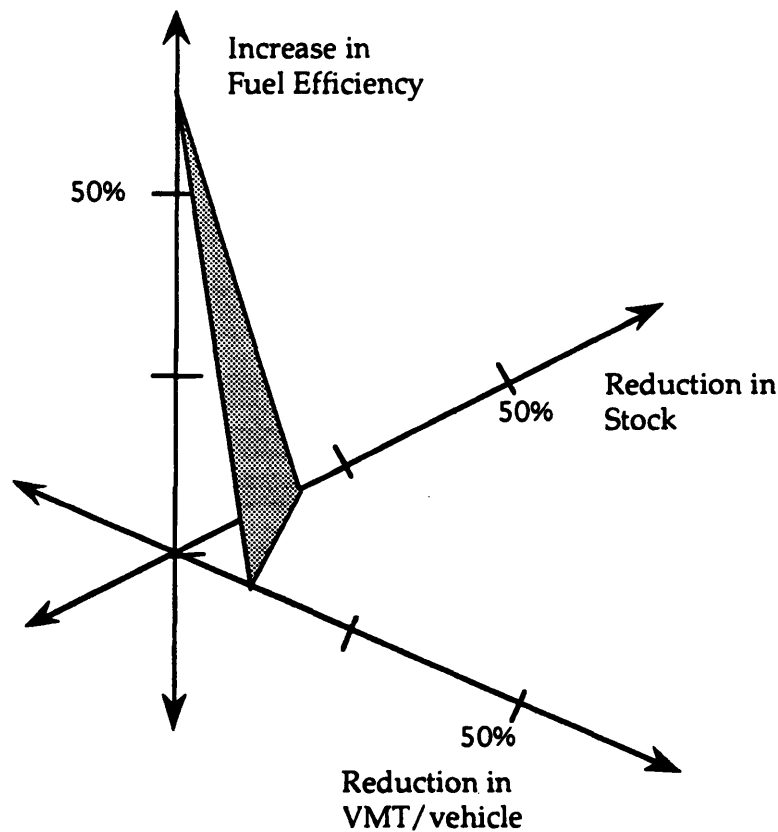


Figure 4-2: Solution Space for Emissions Reduction

4.1.3 The Technical Assessment and Implementation Potential

With a framework that provides guidance as to the outcomes we would expect a suggested policy (or group of policies) to attain, more specific options can be considered. The approach to policy development taken in this thesis is one of technical assessment and evaluation of implementation potential. First, a technical assessment is performed. Technical assessment in this context refers to the more quantitative attributes of the policy options. Technical potential is defined by three elements: greenhouse gas reduction potential, economic impact and transportation effectiveness. Greenhouse gas reduction potential is defined as the likely amount of annual emissions reductions from an established

baseline that can be achieved in the policy's target time period (i.e. short or long term). Economic impact attempts to assess the effects of a given option on the market. This includes the direct cost of implementation but may also consider ancillary costs or benefits. Finally, the impact of each policy on the transportation system will be examined.

The implementation potential for each policy includes consideration of which parties will be involved in the potential success or defeat of the suggested policy and the practical feasibility of the option. Interested parties are defined as those groups most directly impacted by the policy option. Understanding the parties involved gives insight into a policy's strengths, weaknesses and potential barriers (political, social, economic, etc.) to implementation. The feasibility of an option considers both the technical and practical aspects of its implementation as well as its political viability and social impact.

4.2 Short-term End-Use Policy Options

The technical potentials of the short-term policy options were evaluated at two time marks - the years 2000 and 2010. The first date was chosen so that an assessment could be made of the policies' contribution towards President Clinton's goal to reduce greenhouse gas emissions to 1990 levels by the year 2000. The second date was chosen in an attempt to estimate what further impact these measures might have in the foreseeable future. Due to the uncertainty of forecasts, a longer-term date was not practical.

Emission reduction measures can be categorized under five general techniques or approaches defined as:

- 1) increasing fleet efficiency (raise cafe standard, feebate/rebate for new vehicles, scrappage of older vehicles, fuel efficient oil, tires, etc.);
- 2) increasing fuel price (fuel tax, pay at pump insurance);
- 3) increasing the initial cost of a vehicle (vehicle taxes, registration fees);
- 4) increasing the cost of vehicle use (other than raising fuel cost - congestion pricing, eliminate employer paid parking, full cost road pricing, vehicle emissions taxes);
- 5) providing alternatives to traditional motor vehicle travel (non pricing control measures, increase subsidy to transit, high speed rail, emission control technology).

The model used in this study was designed to evaluate options that can be categorized under 1, 2, or 3, above. Because this is a focused rather than a comprehensive evaluation of policy options, only policies that were evaluated using the model will be discussed in depth. In addition, the model is not designed to consider measures categorized under 4 and 5. These measures tend to site specific based on the characteristics of a region and are

difficult to evaluate on a national level. One should not conclude that these factors preclude these measures from serious consideration. Such measures are important and will be addressed as part of the alternative policies discussed in Chapter 5.

The following sections will examine selected policies that fall within categories 1, 2, and 3 and are entitled accordingly. With emission reduction boundaries established in the previous section, the following sections will look towards policies that have been suggested in recent legislative history and in the literature to determine their relative effectiveness for greenhouse gas mitigation.

4.2.1 Increase Fleet Efficiency

Raise CAFE Standards

Corporate Average Fuel Economy (CAFE) standards is the established means by which fuel economy is regulated. Increases in this standard from its current level of 27.5 mpg for cars and 21.5 mpg for LDTs have been proposed for inclusion in the National Energy Security Act, and as means for compliance to air quality problems on both the regional and federal levels with formal bills introduced both in the House and the Senate in 1991. Because this is an established mechanism and one that is considered for a variety of policy objectives, it is worthwhile to consider its potential as a contributor to greenhouse gas mitigation.

The bills most seriously considered by the legislature in 1991 promoted a uniform percentage increase in fuel economy as opposed to setting an efficiency minimum, for all manufacturers. Based on a chosen model year, each manufacturer would be expected to increase their fleet fuel economy by the established fixed percentage. Bills were proposed in both the Senate and the House and ranged in suggested levels of increase between 7.5 percent and 20 percent by the 1996 model year (m.y.) and 20 percent and 60 percent by the 2001 model year (Naggar, 1992)². With these figures establishing the high and low marks for the projected policy, a mid-level increase of 14 percent by m.y. 1999 and 40 percent by m.y. 2001 was used for this analysis. This translates to 31 mpg by m.y. 1999 39 mpg by m.y. 2001 for cars and 25 mpg by m.y. 1999 and 30 mpg by m.y. 2001 for LDTs. These levels are considered the maximum feasible and cost-effective levels for U.S. automakers (SRI, 1991). However, these levels are far below the projected boundary for fuel efficiency determined in section 4.1.2 of 43 mpg for cars and 48 mpg for LDTs with an implementation date of calendar year 1998.

² The lower figures are from the Johnston bill (S.1220) while the higher figures are from the Boxer Bill (H.R. 446).

Greenhouse Gas Reduction Potential

This scenario would result in an increase in carbon equivalent emissions of 27.1 MMT (or 16 percent) over the 1990 levels for the year 2000. This represents a decrease in emissions from the base case of 13.2 MMT or a 33 percent decrease from the base case, which still leaves the emissions far higher than the established reduction goal.

Transportation Efficiency and Effectiveness

Without any significant increase in gasoline prices, greater fuel efficiency in vehicles is likely to increase the amount that people drive as a result of the lower marginal cost of driving. This behavior is termed the “rebound effect” and has been estimated at approximately 28% for this scenario (Kolko, et.al., 1991). When the rebound effect is accounted for, estimated savings from the increased standards remain high, at 10.8 MMT reduction in carbon equivalents from the base case or an emissions increase of 29.5 MMT in carbon equivalents from 1990 levels. This suggests that the increased CAFE standards are still quite effective.

What is perhaps of more concern, is how the increased VMT resulting from the rebound effect will affect congestion. In an already constricted system additional growth in the amount of driving could severely compound the congestion problem (and all of its ancillary problems). This impact on transportation efficiency should be anticipated and addressed so that the economic, social and environmental impacts from the increased VMT can be mitigated.

Another transportation concern of the increased fuel efficiency standards is that of vehicle safety. Detractors from the higher standards claim that the lighter weight and construction changes necessary to meet these standards will compromise the vehicles’ safety. Research by the National Research Council suggest that the actual societal risk from increased efficiency is ambiguous. The danger most often identified is the damage to smaller and lighter (“dangerous”) vehicles when struck by larger, heavier (“safe”) vehicles. There are two points to be made in this regard. First, while small cars pose a greater individual danger than large cars when struck, the societal danger of small cars is less because they tend to create less damage to other cars, pedestrians, roads, etc. than heavier vehicles. And second, as the fleet size and weight shifts to smaller and lighter vehicles it can be expected that the combination of vehicles involved in crashes will shift accordingly. That is, since there will be more smaller and lighter cars on the road it is more likely that similar size and weight cars will be involved in crashes and it will not always be big car against small car.

The issue which makes the safety concern difficult to address is this struggle between the societal and individual perspective. When efficiency standards are

implemented and the vehicle fleet shifts to smaller vehicles as noted above, statistically, society will be safer. However individuals unable to perceive this broader, societal perspective, will feel an even greater need to protect themselves by purchasing larger and heavier vehicles. Because higher efficiency standards do not prohibit the manufacture and sale of the larger vehicles, these will remain available to individuals wishing “more protection”, perpetuating the safety problem of large against small vehicle. Instead, or perhaps in addition to the efficiency standard, a mandate for smaller vehicles might be necessary to resolve the safety issue in light of the societal versus individual benefit struggle.

Economic Impact

Improved fuel economy can be expected to affect the economy in several ways - primarily by altering the demand for petroleum and by influencing and altering vehicle manufacturing, production and sales. With a smaller than estimated growth in gasoline consumption, the petroleum industry will be directly impacted. The decrease in fuel consumption is considered by most to be an important step in increasing the United States' energy (and national) security by decreasing the dependence on foreign oil. While classical economics suggests that the lower fuel consumption should increase fuel prices, due to the highly competitive international petroleum market, the shift in gasoline demand will most likely be translated into lower prices at the pump. While beneficial to consumers, oil company profits will be directly and negatively impacted unless volume of sales can be increased.

Building a more fuel efficient vehicle and especially on a short timeline will impose costs on the automakers and consumers. Manufacturers will (in most cases) need to scrap some plans, develop new vehicle designs and retool facilities for the production of these vehicles. The cost of these changes and the technologies to improve fuel efficiency in vehicles could add between \$500 (if currently available technologies are used) and \$2,750 (including development costs - if technologies that are still under development are used) to the price of a vehicle (SRI, 1991). Such an increase will affect people's decisions to retain older vehicles and/or purchase new ones. This increase will make the purchase of new vehicles prohibitive for some consumers, thus negatively impacting automobile manufacturers. In addition, if new car purchases are significantly slowed due to the higher prices, the original estimation of greenhouse emission reductions may be over-stated, as older vehicles will remain on the road longer before being replaced by the more efficient ones.

Interested Parties

As the discussion above indicates, automakers, lawmakers, safety experts, environmentalists, oil companies and consumers are most interested in the outcome of the proposal to raise CAFE standards. Because CAFE is established and proposal's for its increase have been made several times in the past, the opinions and coalitions supporting and detracting from this proposal are strong. While its proponents are adamant as evidenced by the number of times increases in CAFE have come into serious consideration, its opponents repeatedly and effectively block its progress in the legislative process. While the added concern over global warming may play in its favor, a struggle for establishing a higher standard can be expected. In overcoming this struggle innovative means must be employed that appease the concerns of opposing parties. One possible solution might be for government (the proponent) to provide financial incentives for automakers (the opponent) to retool factories for the production of high efficiency vehicles. Such an approach helps meet the goal of the policy supporter while addressing the concern of those in opposition.

Feasibility

Technically, the suggested fuel efficiency standards are attainable given current technology (SRI, 1991). Attaining these levels according to the proposed time-line is of greater difficulty. Automobile design, planning and production typically runs on a four year cycle, though the lead time is decreasing. Implementing higher standards by m.y. 1998 presses manufacturers to adapt quickly to the changes. Manufacturers claim that this short lead time is costly both in its economics and in vehicle quality. When the likely delays of the legislative process are considered, the prospect of meeting the proposed time-line becomes even less likely. The probable delays associated with implementing this policy undermine the potential for meeting the projected year 2000 emissions reduction goal. However, as global warming is a cumulative and long-term problem, while the time delays are to some extent detrimental, the delays do not justify abandoning this approach.

4.2.2 Raise Fuel Price

Fuel Tax/Pay at Pump Insurance

The objective of higher fuel prices is to decrease VMT and increase fuel efficiency. As with CAFE standards, a gasoline tax is an established and often proposed measure for addressing a variety of imbalances in the system. Though most often proposed as a straight tax, there are other possible mechanisms, such as pay at the pump insurance, through which fuel prices could be raised that may carry additional benefits. In order to

affect all vehicle use, prices would be raised on all fuels used by highway vehicles, principally motor gasoline and diesel fuel. The taxes could vary based on the carbon content of the particular fuel. In this way, the price increase would be proportional to the fuel's relative contribution to greenhouse emissions.

Higher fuel prices would reduce consumption of the taxed fuels through three means:

- 1) improvement over time in the fuel efficiency of the entire fleet as newer, more efficient vehicles replace the less efficient and typically older vehicles;
- 2) reduction in the average utilization of vehicles using taxed fuels;
- 3) shift to vehicles using fuels that are less heavily taxed.

Only the second of these responses would have immediate impact, the first and the third responses would require a period of 5 - 10 years to have an impact as they are dependent upon the cycling time of vehicle purchase, ownership and scrappage. Reductions in carbon emissions would be directly proportional to the resulting reductions in fuel consumption, as well as the carbon content of the taxed fuels.

If a tax is chosen as the means by which fuel prices would be increased, Congressional action would be required to raise federal fuel taxes from their current levels (the current federal levy on motor gasoline stands at 14.1 cents per gallon) and would also need to remove current tax exemptions or reductions for certain highway fuels, such as gasohol. However, straight fuel taxes are a politically unpopular mechanism. Historically fuel tax proposals have met with opposition and when legislated, have often been compromised to levels far below their proposed and suggested effective levels. The use of the collection of funds creates yet another obstacle. It is difficult to gain support for a tax if people do not see application and results from the money collected. The economic argument of pricing items to affect behavior is not likely to be sufficient to gain the public's support. In fact, if a tax were passed, the allocation of the collected revenue would be a serious issue. Even a relatively small tax (in regard to emission mitigation) of 10 cents would result in revenues on the order of 1.2 trillion dollars annually. The determination of the use of these funds would undoubtedly be precarious and politically charged.

One option that carries the same characteristic of increasing fuel prices as does a tax, is "pay at the pump" insurance. This type of automobile insurance reform that would shift cost of basic premium to a surcharge paid at the gasoline pump. The remainder of the premium, which would vary based on driver risk and specific coverage options, could be paid on an individual basis directly to the insurance company, much as the entire premium is now paid.

State annual auto insurance premiums average \$686, with the highest-cost states at approximately \$1,000. Using the national average figures of 12,200 VMT/vehicle and 21.5 mpg, an equivalent gas tax would be in the range of \$1.00 to \$1.75 if all costs are transferred. If the base premium is assumed to be about a third of this cost, a per gallon charge for insurance at the pump would be about \$0.30.

Pay at the pump insurance would need to be adopted on a national level. If left as an option for each state to implement, only geographically isolated states, (Hawaii, California) will adopt pay at the pump because of border problems. Because only base premiums would be collected at the pump, a national program should not pose a problem for setting rates. Differences by region and even by insurance company could be accommodated by the individual premiums paid in addition to the pay at the pump costs.

Greenhouse Gas Reduction Potential

The most recent struggle to pass a gasoline tax resulted in the implementation of a 4.3 cent/gallon tax, down from the originally proposed 10 cents/gallon. The impact of this relatively small increase is expected to reduce gasoline consumption by passenger automobiles and light trucks from the projected level by just less than 2.5 percent by the year 2000. Most of this reduction (about three quarters) will occur as a result of improvements in the fuel efficiency of the year 2000 automobile and light truck fleets. This corresponds to a reduction of 6.3 MMT Ce from the year 2000 emissions baseline, which would reverse 13 percent of the projected baseline growth in automobile and light truck carbon emissions between 1990 and 2000.

A more substantial increase in the fuel price of 30 cents per gallon would have a much more dramatic effect on fuel consumption and emissions reduction. Implemented by the year 1995 as either a tax or through pay at the pump insurance, this increase would result in a decrease in carbon equivalent emissions of 37 MMT below the projected base case, or an increase in carbon equivalents of 3.3 MMT above 1990 levels. The timely implementation of these larger gas tax increases could off-set nearly all of projected 1990 - 2000 growth in carbon emissions by passenger vehicles. The actual source of the reduced fuel consumption (and therefore emissions) is from a decrease in the projected growth of the vehicle stock, a decrease in projected usage and an increase in vehicle efficiency; with the majority of the savings resulting from increased vehicle efficiency.

Transportation Efficiency and Effectiveness

Expected outcomes of higher fuel prices are a smaller vehicle stock, more efficient vehicles, and lower utilization. While on the surface, this might suggest a more efficient system, it is not without notable expense. The introduction of higher fuel costs through taxes will increase (and potentially substantially) the operating costs for a vehicle. Depending upon

the size of the tax, lower income drivers could be priced off the road (evidenced in the smaller stock and lower utilization), thus impairing their mobility. Unless the mobility problem were addressed, this approach would actually make the system less effective.

Though affecting the same object (fuel price) as a tax, pay at the pump insurance has a much different impact on the transportation system. Instead of adding costs to driving, pay at the pump insurance shifts costs from annual lump sum premiums paid for insurance to variable premiums based on the amount one drives. Because the annual premium paid directly to the insurance company would fall, drivers may hold the misconception that their annual cost for insurance is substantially less. This perception of lower annual costs for ownership would lead to an increase in vehicle registrations. Work by the U.S. Department of Transportation suggests that this increase would be 1 percent if all insurance costs were collected at the pump. The analysis is as follows: The average annual fixed cost in 1992 of operating a personal vehicle was \$1,750, when costs for depreciation were omitted (MVMA). Of this amount, insurance makes up 42 percent. The elasticity of car ownership per capita with respect to annual costs is about 0.05. Therefore, a 42 percent decrease in annual costs would lead to a 2.1 percent increase in per capita vehicle ownership. Approximately half of this increase in ownership would be dampened by increased VMT per vehicle³. Therefore, the automobile stock would rise by 1 percent if all insurance costs are collected at the gas pump, and by 0.3 percent if just less than a third of the costs are collected at the pump, as assumed in this case.

Economic Impact

The economic costs associated with higher fuel taxes include those associated with lost fuel sales in the petroleum industry, costs for the design and production of more fuel-efficient vehicles, any welfare losses due to lower comfort and performance in the vehicle and costs associated with foregone travel due to the higher cost of vehicle utilization. However, the increase in automobile and light truck fleet (not new car) fuel economy estimated to produce the results described above for a 30 cent/gallon gasoline tax is about 3 mpg, which appear achievable at modest increased vehicle costs or with minimal degradation of comfort and performance. At the same time, the 1990 National Personal Transportation Survey (NPTS) reports that nearly 27 percent of all VMT driven in personal passenger vehicles is for "social and recreational" purposes, suggesting that 12% reduction in combined auto and light truck VMT underlying the estimated impacts of the 30 cent/gallon tax increase might be achieved at reasonable cost. However, it is more likely that those drivers able to afford a significant amount of recreational travel are not the same as those who will forego travel

³Though VMT will increase, the rate of increase will be less than half of what could be expected without a fuel increase.

due to high fuel costs. It is more likely that lower income people will avoid sometimes essential travel due to the higher fuel taxes. This could mean such things as not seeking work if the distance (and therefore cost) for daily commuting is too great.

In the case of pay at the pump insurance, the economic impacts are different, due to the shift in cost rather than a pure price increase. Pay at the pump insurance will ensure that all drivers are insured to some minimum extent, thereby removing the burden of supporting the uninsured drivers from those who are. The overall social cost of insurance should therefore be lower. Other impacts and economic costs on fuel consumption and driving will be similar to those incurred through a gasoline tax. However, because the total cost of operating a vehicle will not be greatly affected, decisions for travel will be made on a per trip basis thus the impact on essential trips should be less and utilization savings should appear more in the discretionary/recreational uses. As with a fuel tax vehicle sales would be expected to decrease by an estimated 13 percent of what they would have been in 2000 because of the higher cost of driving. This could reduce auto industry profits.

Interested parties

Given a fuel tax, among the most vocal interest groups would be oil companies, consumers, automobile manufacturers, legislators, the trucking industry and environmentalists. A fuel tax would also attract parties interested in the disbursement and use of the collected revenue. Though the proposition of a significant tax invites debate, a debate of equal intensity would most likely center on the revenue issue.

Pay at the pump insurance would attract these groups as well as insurance companies. Because the money collected would already be dedicated for a specific purpose, this mechanism would also address the revenue disbursement concern. This mechanism for increasing fuel price would actually shift the position of some of the interest groups, however. For example, consumers who may have been strongly against a fuel tax may be more receptive to the pay at the pump insurance option since it could potentially lower the overall cost of insurance and therefore operating costs of vehicles.

Feasibility

Unlike increased fuel efficiency which is dependent upon a certain level of technology to be implemented, fuel price increases face no technical barriers. The political and social barriers are instead, formidable. While a pay at the pump mechanism may be more politically appealing than a tax, because drivers are actually purchasing something with the increased fee, this proposal faces other logistical barriers. Purchasing insurance at the pump would obviously require the cooperation of the insurance industry. Defining a rate structure that would be amenable to a large variety of companies across the nation would pose some difficulty. Whether a tax or other means is used to raise the fuel price, there will

remain the problem of determining an appropriate and effective price level. If the increase is too large, it will be difficult to gain support for the proposal. If it is too small, the effectiveness as a greenhouse emissions mitigator will be compromised.

4.2.3 Raise Initial Vehicle Cost

Graduated Registration Fees

The increase in vehicle stock is a concern for a number of reasons. As more cars are added to the fleet, fuel consumption increases, as one might logically guess. This effect is compounded by the fact that historically, as vehicle stock has grown, so too has the number of miles each of those vehicles travels. Since 1980, vehicle miles traveled has increased 36 percent from 1.1 trillion miles to 1.5 trillion. At the same time, the vehicle fleet has grown 21 percent from 155 million vehicles to 191 million. This has led to a 15 percent increase in VMT per vehicle. Thus, not only does the entire fleet place greater burden on the system as it grows, but each vehicle in that fleet as well. It is therefore desirable to discourage further growth of the vehicle stock or to at least reduce the rate of its growth.

Raising the initial vehicle cost is one suggested means for reducing the growth of the vehicle fleet. The objective is to reduce the number of new car sales in an effort to control the size of the vehicle stock. Though simply raising vehicle prices through a tax may seem to achieve the desired effect, there are other means that are more equitable and less arbitrary than such an approach. An indiscriminate tax could have the undesired effect of preventing people who can not afford a car from purchasing one while allowing those wealthy enough to purchase several non-essential or purely recreational vehicles to do so. Increasing vehicle price (and in this case, lifetime cost) can be achieved in a more equitable manner through graduated registration fees.

Graduated registration fees would be designed to penalize owners of multiple vehicles. A fee system could be established based on the number of vehicles per household. In 1990, the average household consisted of 2.63 persons and on average there were also 1.8 licensed drivers per household. While 71 percent of the households owned one or two vehicles (a seemingly appropriate amount) 19.5 percent owned three or more. Assuming that two vehicles per household accommodates the average household, graduated registration fee would target the minority who own three or more vehicles. The registration fees could be structured as follows: the fee to register the first vehicle would be the same or nearly the same as the current standard for the state. The fee to register the second vehicle for a household would be nominally higher only to signal the vehicle

owners as to the impact of additional vehicles on road, but not necessarily to be prohibitive. Registration fees for the third or greater vehicle in a household would be substantially more, perhaps as high as \$500. This fee is clearly meant to discourage the purchase. Such a fee structure would not prohibit those who need vehicles for essential mobility from purchasing them but would impact people who own "non-essential" vehicles. The difficulty here is setting an appropriate fee. Those households who own three or more cars most likely have a high level of expendable income. Therefore, a fee that would affect their purchasing behavior may need to be extraordinarily high. As with any tax, the determination of how revenues accrued from the fees collected would be allocated and used could also prove difficult.

Greenhouse Gas Reduction Potential

A scenario such as the one described above - a registration fee of \$500 dollars per vehicle on 19.5 percent of the new vehicles would unfortunately have only a small effect on the greenhouse emissions. Because it would be applied to only one fifth of the vehicles, many of which are owned by fairly wealthy people, reductions in vehicle stock would be expected to decrease by less than 1 percent by the year 2000, assuming the fees were implemented by 1995. This would result in a decrease of only 4.7 MMT of carbon equivalent from the base case. Doubling this, to a fee of \$1,000 per vehicle above the two per household limit would result in a reduction of the stock by 4 percent and a decrease in emissions of 12 MMT from the base case for the year 2000. Though this mechanism may not be particularly effective in reducing the vehicle emissions, it may be a worthwhile measure as it sends a message of low tolerance for non essential vehicles and may prevent the growth of the multiple vehicle owning sector of the population.

Unlike a tax that increases only the initial price of a vehicle, a registration fee discourages new purchases as well as continued ownership of extra vehicles, because a registration fee is paid periodically throughout the vehicle's life. This approach addresses the fleet size problem from both the decision to purchase a vehicle through to the decisions to keep or scrap a vehicle.

Given the rather weak impact of a graduated registration fee, an alternative policy which addresses the fuel consumed by vehicles might be appropriate. While the registration fees address excess vehicles, a tax based on the fuel efficiency of a vehicle (a "gas guzzler tax") would target excess fuel consumed. As opposed to current taxes which charge the owner at the point of purchase, a more effective approach would be to level an annual tax on these high consumption vehicles. Annual fees signal the owners as to the continued impact of the inefficiency and high consumption rate of their vehicles.

Transportation Efficiency and Effectiveness

Prior to 1990, there were, on average fewer cars per household than licensed drivers per household (see Figure 4-3). As of 1990, the number of vehicles per household actually surpassed the number of licensed drivers per household by a very small margin (Hu and Young, 1993). This fact could imply that the ratio of vehicles to licensed drivers has reached a saturation point and that continued growth of the vehicle stock relative to the number of drivers will be small. This would mean that the additional VMT per vehicle may also level off as each driver will have sufficient access to a vehicle and therefore any additional vehicles will not significantly increase the number or length of trips. While this seems plausible, there is no empirical evidence to suggest that this relationship's limit is somewhere close to unity. It is conceivable that the number of vehicles could far surpass the number of licensed drivers.

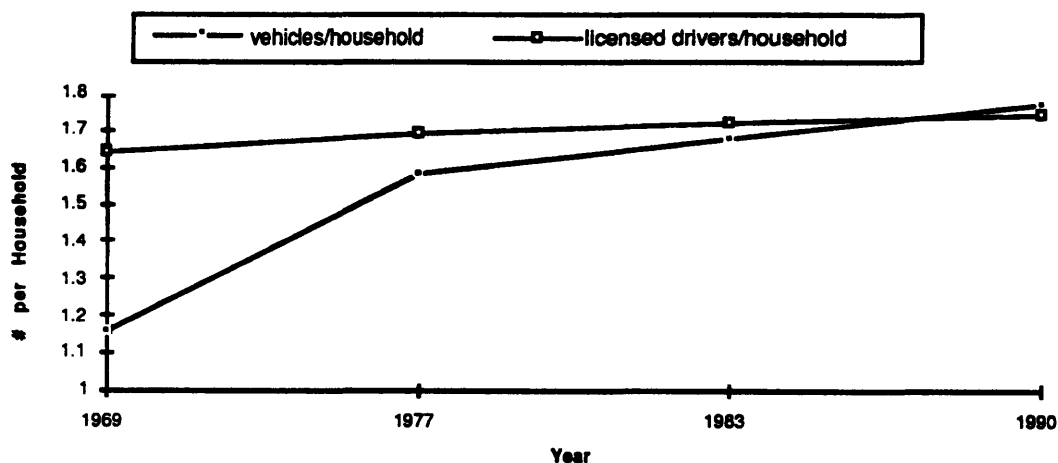


Figure 4-3: Vehicles per Household and Licensed Drivers per Household

If the assumption holds that size of the fleet is inversely proportional to the efficiency with which that fleet is used, then controlling the growth of the vehicle fleet is an appropriate measure. Assuming that fleet fuel efficiency increases or remains the same, limiting the growth of the vehicle stock will almost assuredly reduce the amount of greenhouse emissions produced. A smaller fleet will also have a positive impact on such goals as congestion reduction. This approach could be expected to have an relatively large initial impact in reducing stock growth and after a while have the effect of maintaining a certain level of growth. This is because when graduated fees are initially implemented people's first reaction will be to get rid of vehicles that they deem as extra and perhaps not

purchase new vehicles without retiring an older (and hopefully a less efficient) one as to avoid the severe registration fees. After a short time, people will have “unloaded” the extra vehicles and the system will fall into a maintenance level, where there is neither a significant drop in the growth rate as there was initially but where there is also not a significant increase in the growth rate.

What is important for planners to recognize is that this method is not targeted at reducing the absolute growth. The vehicle stock is still expected to increase but not as quickly as without this registration fee structure. Eventually, the problem associated with a larger vehicle stock will need to be addressed, though the regular fee mechanism may delay the time at which these problems become critical. Also, controlling the stock through this means only indirectly affects people’s driving behavior. This approach does not ask people to consider how and why they drive nor by what mode they chose to drive. Without addressing people’s driving behavior inefficiencies in the system will only be masked temporarily.

Economic Impact

The auto industry is most obviously impacted from a move to control fleet size. Under the low and high scenarios described above, annual sales are expected to drop between 3 and 18 percent respectively from forecasted levels for the year 2000. Such a reduction in new car sales would be detrimental not only to automobile manufacturers but to all the suppliers and supporting industries. Those who must pay the higher registration fees will also be negatively impacted by this policy.

Controlling the size of the fleet will extend the amount of time before new facilities are needed to handle a higher load, thus delaying capacity expansion costs. A lower than projected stock could mean less congestion (in the short-term) and even fewer accidents. All of which carry both social and economic benefits. As with any fee or tax, however, there is again the question of allocation and use of revenue. A subsidy to auto-makers for the production of low emission vehicles (which could be exempt from the higher registration fees) could be one use of the collected funds. This would promote cleaner technology while helping to off-set the auto industries’ lost sales.

Interested parties

Auto manufacturers and other associated industries would most likely be the most vocal opponents of this proposed policy. Passenger vehicle owners could be expected to cite inequity in an approach that targets their group while not affecting the commercial fleet which is also a large contributor to emissions. Supporters would include environmentalists and traffic planners. Other active parties would be, as with the other suggested measures, law makers. This proposal seems especially susceptible to the Machievellian perspective

quoted in the first chapter: those who oppose this policy are likely to be vocal while many of the others are likely to be merely apathetic; leaving a gap for support.

Feasibility

A graduated registration fee, as with other proposed measures has both attributes and faults that bring into question the feasibility of such a proposal. Because the majority of people would not be subject to the higher fees, and because registration fees are already being paid by drivers, consumers may not have strong objection to this approach. The weight of the automobile lobby could, however, prevent such a measure from making it past the proposal stage. If such a measure could survive the legislative process, it could be implemented relatively quickly.

Setting the appropriate fee level could prove difficult and may have to vary region to region. The level at which the fee is set is crucial. As with any pricing mechanism, a level that is too low will not have the desired effect. Again, as with nearly any pricing mechanism, the wealthy will be less affected by the higher registration fees. From a social perspective, a registration fee structure such as the one proposed could be construed as privilege for the wealthy to pollute more than the majority of the population.

Though many households that own three or more vehicles have one or more that are non essential “extra” vehicles, there are other households that legitimately need and use the three or more vehicles that they own. For these households, the steep registration fees may seem unfair. One solution to this problem would be to make ultra-low or zero emission vehicles exempt from the registration fee. Because the ultimate goal of this policy is to reduce greenhouse emissions, and uses fleet reduction only as the means to reach this goal, exempting vehicles that contribute a relatively small or even no amount to the greenhouse gases, would still keep with the objective.

A graduated registration fee would also be vulnerable to fraud. Owners of three or more vehicles would seek means to register their cars under different households so as not to be subject to the high fee. Fraud such as this would be fairly simple to carry off and difficult to prevent.

4.3 System Assessment of Policy Options

This section will use the system model developed in section 4.1.1 to further evaluate the policy options introduced and discussed in section 4.2. While the qualitative and quantitative evaluation provided above provides a useful assessment of how these policies are expected to work in isolation, the consideration within a systems context provides some insight into their effectiveness as they interact with the various elements of the system.

Increasing the fuel efficiency standard (CAFE standard) was the first proposal introduced above. Introduced as well was the concept of “backlash”, which suggests that higher fuel efficiency will increase VMT and fuel consumed, thereby diminishing the effects of the higher vehicle efficiency. Referring to the model diagram in Figure 4.1, the validity of this argument is put into question. Following the path of loop # 5, the higher efficiency decreases the amount of fuel consumed. If at this point we diverge from loop #5 and follow the other arrow that extends from “fuel consumed” we see that lower fuel consumption will increase the price of fuel and also the operating and maintenance costs of a vehicle. At this juncture the path of the loop diverges along three paths - loop #1, loop #2 and loop #3. If followed full-circle, loop #1 would have the effect of reinforcing the efficiency of vehicles. Loops #2 and #3 involve directly the other primary elements of emissions production - VMT and stock size. Following loop #2 we see that the higher operating costs reduce the desire to drive and thus the VMT, contradicting the suggestion of backlash. Following loop #3, the higher operating costs increase the vehicle scrappage rates, thereby decreasing the vehicle stock and thus the VMT; again contradicting the backlash theory. This contradiction is tenuous, however, depending largely on the assumed effect of lower gasoline consumption on the price of gas and the elasticity of fuel price. Historically, gasoline price has had an incredibly low growth rate (very near or even below zero percent). So, though the assumed effect of lower consumption on fuel price may be logical in a classic economic sense, it may not be valid in reality. To ensure the effectiveness of an efficiency standard, policy makers could implement policy to also control VMT. Because fuel price appears to be a crucial element, policies such as those discussed in 4.2.2 (fuel tax and pay at the pump insurance) may be good complements to increased efficiency standards.

Though it appears that an increase in fuel price might be sufficiently effective to act alone, because there is uncertainty as to the future growth rate and the elasticity of fuel price, policies that affect other elements in the system such stock size and efficiency through means other than fuel price can reinforce the effectiveness of each policy on the other by targeting different yet crucial elements in the system. As noted above, the increased efficiency standard provides a good complement as does the policy described in 4.3 - increasing registration fees. This final policy option targets vehicle stock size and associatively VMT, as indicated by loop #7. Increasing registration fees proposes to have the effect of decreasing VMT, but through a different means (by decreasing vehicle stock) than an increase in fuel price, thus providing a good complement.

Examining the greenhouse emission reduction policies within the broader system provides a perspective on their strength and specific areas of effectiveness. It also gives the

policy maker structure in which policies and their effects can be more fully considered. By understanding how policies overlap and complement each other policy makers can develop more robust and effective policy plans.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

This thesis has examined policy options for reduction of greenhouse gas emissions from the light-duty vehicle sector. With the goal of reaching a 1990 emissions level by the year 2000 (as voiced by President Clinton in April of 1993), selected policy options were analyzed for their quantitative potential (with the aid of a computer model, see Chapter 3) and their qualitative attributes. Perhaps more importantly, a framework was established for the consideration of greenhouse reduction policies for the light-duty vehicle sector.

Assuming a fleet that is fueled in the overwhelming majority by gasoline, this framework identifies three primary elements as the major contributing factors to continued greenhouse emissions growth - size of vehicle stock, vehicle miles traveled and fuel efficiency of the fleet. With the aid of the computer model described in Chapter 3, a solution space was developed which indicated the levels at which the primary elements could be combined to meet the Clinton goal. The purpose of this space is to enable policy-makers develop a powerful mental model of how the three primary emission factors interact. However, it is narrow in the appropriateness of its application for addressing global warming. The focus of the space is on reaching the emission levels experienced in 1990. While this goal is an improvement on the forecasted conditions for the year 2000, there is no evidence to suggest that achieving the 1990 emissions level is sufficient. How emissions will continue to grow or be mitigated beyond that level and beyond the year 2000 is crucial and is not addressed by the solution space.

The solution space is also limited to the consideration of a the emissions problem within a *single nation* even though it is a *global* problem. The plane of feasible solutions only measures the extent to which the U.S. goal might be reached. The implications for a global solution do not necessarily translate directly. Much depends on the likelihood of other nations to emulate U.S. behavior. This, in turn, could depend on which policies are

implemented and how they are structured. For example, an emissions reduction plan that emphasizes reduction in the vehicle fleet might not have a high emulation effect in developing nations in the short-term, as their vehicle to driver ratio is already fairly low. In the long-term, emulation of this approach by developing nations could result in the avoidance of an over abundance of vehicles. If policy-makers accept the full responsibility of addressing the global climate change problem through national policy, careful thought must be given to how choice of policy in the U.S. will manifest itself world wide.

5.2 Alternatives Considered

5.2.1 Short-term Alternatives

The policies considered in detail in this thesis included an increase in the corporate automobile fuel efficiency standard; an increase in the fuel tax or pay at the pump insurance; and the establishment of graduated registration fees. These policies were chosen for their current relevance in this and other policy debates, for their solution potential and to demonstrate how policies might be developed and considered within the proposed framework. Frameworks, models and standards exist because policy makers seek indisputable and objective means by which policy options might be evaluated. However, there exists a strong subjective element in all policy making. Given this fact, many policy options get excluded from almost any evaluation. Presented briefly below are short-term end-use policy options that were not considered in this thesis but may very well carry potential as effective measures.

The model presented in Chapter 3 makes several assumptions about the transportation system and its structure. As such, it is suited to test only certain types of policies and measure only certain effects. The model narrowly focuses on end-use emissions from cars and light-duty trucks in the short-term only. It assumes that the light-duty vehicle fleet is primarily gasoline based (currently true) and will remain so in the near future. While the model can represent a reduction in the use and number of vehicles, it does not provide any means for evaluating a specific information on shifts in mode. The model is designed to test policies which either affect a pricing component of the system or the fuel efficiency standard. The model can not very well test behavioral changes from, for example, transportation demand measures. This is not to totally discount the usefulness of the model, but to make the reader aware of its limitations and the need to examine and evaluate other policy measures - specifically those that affect behavioral change through mechanisms other than pricing and those which are longer term.

As has been stated repeatedly in this thesis, given the current structure of the light-duty sector of the transportation system (i.e. personal transport), to affect greenhouse emissions levels, VMT, fuel efficiency and/or vehicle stock need to change. A change in just one of these components is surely temporary. For example, the emissions reductions achieved by higher fuel efficiency will eventually be undermined by increased VMT (either by higher individual vehicle use or growth in the fleet size at the same utilization rate). Thus, the measure only serves to delay the emissions growth. Changing two or more of these components may also prove to be a temporary solution, but will have a greater impact. Assuming, as before, the efficiency standard is raised. If in addition, VMT is decreased, the effects of each measure will be reinforced. This is perhaps most important when applying fuel efficiency standards since such standards do not require people to consider their driving behavior.

An alternative to changing the components of emissions from the light-duty sector, as described above, is to alter its structure. Altering the structure in this sense means changing some of the underlying assumptions of the system. This would include a significant change in fuel type used, mode(s) or means (for example, telecommuting or other technological or land-use plans that significantly alter the way people use vehicles). Unlike changing the system's components, changing the structure of the system addresses many of the root causes of the emissions problem (e.g. the use of single occupancy vehicles instead of transit or bicycles, the gasoline powered internal combustion engine, etc.). Changes in the root causes, are potentially much longer lasting than what amounts to delay tactics in changing only the system components. However, changing the system would be met with technological challenges and/or strong political and social resistance. While the obstacles may be great, the potential benefits could also be significant.

There are many measures that have been proposed for the reduction of greenhouse emissions, several of which were introduced in Chapter 3. As part of a broad study performed in the summer of 1993 to address climate change, the U.S. Department of Transportation evaluated the potential of some of these measures for both their technical emissions reduction potential and their overall feasibility. Table 5-1 summarizes the findings. It should be clear that there are many other possible means through which greenhouse emissions might be reduced from the light-duty vehicle sector. While further examining and implementing some of these measures is important it is also important that work continues in the generation of new proposals and suggestions. Though ultimately success in the political process and implementation is vital, it is equally important to consider and propose measures and means that expand the realm of possibilities without too much initial concern with political popularity or feasibility. Broadening the spectrum of

possibilities can also broaden the spectrum of feasibility. While narrowing the focus is important for promoting on a large scale a policy and implementing it, a continued effort to generate new proposals can provide new and helpful insight into the problem and its solution.

5.2.2 Long-term Considerations

Not included up to this point in the discussion were long-term measures. Developing long-term policies and strategies are vitally important if lasting solutions our problems are to be found. The following section addresses some of the long-term considerations in addition to the short-term alternatives

It is worthwhile to explore some of the long term considerations and policy options. Long-term in this context refers to approaches that for practical or technological reasons can not be implemented (to a significant degree) in the next five years but when adopted and implemented can have long lasting effects. Many of the long term policies are agents for changing the architecture of the system as described above. The implementation of Clean Air Act Amendments of 1990 and the California compliance plan has direction towards alternative fueled vehicles (AFVs). AFVs include vehicles that run on alcohol based fuels, natural gas and electricity. These fuels release fewer tail-pipe carbon emissions (alcohol and natural gas fuels) or none at all (electric vehicles). While these characteristics sound promising, there are several factors that should be considered as these vehicles are adopted more widely. Assuming that the technological and practical obstacles of their implementation can be overcome (e.g. developing new refueling infrastructure for NGVs and electric vehicles and developing a marketable vehicle in the case of an electric car) there remain questions as to the overall effectiveness of these fuels in the reduction of greenhouse emissions.

Table 5-1: An Overview of Short-term Policy Alternatives

Measure	Greenhouse Reduction (MMT/yr)	Comments
Non Pricing Transportation Control Measures	< 4	Most effective if implementation is locally based (or even employer based) where program can be customized to local driving behavior and demand.
Increase Transit Subsidies/Investment	< 5	Effectiveness depends on elasticity of driving.
New Vehicle Feebate/Rebate	3 - 10	Charge fee or provide rebate on purchase of new vehicle based on fuel efficiency.
Accelerate Scrappage of Older Cars	< 1	Incentives offered to encourage scrappage of older vehicles. An estimated 870,000 inefficient vehicles would be removed from the road.
Eliminate Employer Subsidized Parking	10	SOV commuters would be required to confront the market costs of parking. This measure would have a significant impact on ridesharing and mode shift.
Full Cost Road Pricing	10 - 38	Drivers charged for costs of road. Includes congestion pricing but could also include charges for long-term costs such as capital costs, operation and maintenance, etc.
Vehicle Emissions Taxes	2 - 10	On board monitoring of vehicle emissions and remote sensing would be used to measure and directly tax criteria pollutants.
Fuel Efficient Oil, Tires and Air Conditioning	< 1	Standards and mandates for oil, tires and air conditioning to require use of most efficient products.

Work by Deluchi (1991) has raised concern over the greenhouse gases emitted during the transport of some fuels (natural gas) and during the generation of electricity if fossil fuels are used. When the life-cycle view is taken for these vehicles and fuels the total amount of greenhouse gas emissions attributed to their use increases. The second factor that detracts from this approach is that it does not affect driving behavior. Currently there is no widely manufactured vehicle whose use does not contribute to greenhouse emissions. Therefore any measure that does not address vehicle utilization can not be fully effective. Another long-term option that has received considerably less attention in the popular press is land-use planning. Land-use planning involves the decisions of how land will be developed and used in the future. Included in this broad label are such things as zoning for new building development and housing. Land use decisions also directly affect such transportation decisions as the expansion of highway capacity and the building of new roads and transit lines. Land-use planning has the potential of making a significant impact on the way in which vehicles are used in the future.

As the economy of metropolitan areas has become more global and information rather than product based, industry and the economy has become less dependent upon a central core or business district (Blakely, 1992). Due to the advances in information technology and especially telecommunication, businesses relocate to campuses away from central metropolitan areas. Also, there is continued movement of people and housing from the urban centers to more suburban and rural settings. This decentralization has had the effect of increased vehicle travel as people travel more to get from home, to work, to shopping and other destinations that previously were located in urban centers.

The role of land-use planning in greenhouse emissions reduction is to develop land-use patterns that will decrease peoples' dependency on the automobile. Some planners and architects who adopt this goal seek to increase housing density by clustering homes with nearby services and such as shopping and schools and convenient access to commercial installations. A suburban setting with this mixture of uses is one way of encouraging people to use their vehicles less (Cervero, 1992). Unfortunately, the concept of clustering and high density housing goes against the heritage of a land rich nation. Historically public demand has been for lower density housing.

Telecommunications provides another option for reducing vehicle utilization and therefore greenhouse gas emissions. Increasingly people are using the advantages of modems, fax machines and telephones to avoid traveling sometimes long distances to go to work. While telecommuting can be done from the home, in some suburban communities there exist centers where employees can find the facilities they need to telecommute. In addition to the emissions and fuel use that can be avoided, companies benefit from needing

to provide less office space in the high rent downtown business areas. Incentives could be established that would encourage businesses to promote telecommuting. Other land-use options include placing residential housing for convenient access to light rail. Because land-use decisions can have such a lasting impact on transportation patterns and policy, this is one area that deserves attention immediately.

Promoting a modal shift in transportation is another policy that could be included in long term policies. Currently the car and light duty truck are by far the primary source for personal transportation. Initiating a significant change in the mode of travel chosen by individuals will depend on several factors including building the appropriate infrastructure (where necessary) such as light rail lines and high occupancy vehicle (HOV) lanes and motivating individuals to change their behavior. Because both establishing the infrastructure and motivating this behavioral change will in some cases require some time investment, this option has been identified as long term.

The effective life of long term measures make their emissions reduction potential significant. Unfortunately, often the time and monetary investment necessary to see these policy plans through from proposal to fruition is too great to gain and maintain the social and political support needed for their success. Government, business and the public have all been accused as being short sighted. For issues such as global warming and others that have extensive long term effects it is especially pertinent to adopt a long range vision and mind set.

5.3 Strategies for Implementation

While this framework focuses on the technical potential of the policy options the political potential and social impacts of the proposed policies were also considered. A particular challenge of the global warming/greenhouse gas problem is developing sufficient political motivation to support policies addressing this issue and creating an architecture for the effective implementation of policy measures. This is discussed in further detail in section 5.3.1, below.

As noted earlier in the thesis, because greenhouse emissions produced now will have a cumulative effect and a lasting impact for decades to come, addressing this problem promptly and efficiently is desirable. While pondering and developing policies which are expected to address the problem is vital, these could be rendered ineffective if a robust implementation plan is not also developed and followed.

Currently policy and implementation plans involving air quality are anchored in the Clean Air Act (CAA). This legislation considers air quality from a public health perspective

and on a regional basis. In contrast, climate is not constrained to health concerns, it threatens entire biospheres and economies. Climate change is also not restricted to regional areas, but is in fact global. Production of greenhouse emissions in the United States or any other nation will affect the climate world-wide. An appropriate implementation policy must reflect the wide-reaching characteristics of the greenhouse emissions problem. Currently, compliance plans for the Clean Air legislation (Clean Air Act Amendments of 1990) is centered on metropolitan planning organizations (MPOs). The legislation categorizes each metropolitan area as based on its air quality. Cities that are not in compliance with the Clean Air Act's minimum air quality standards are further distinguished based on the level of severity of the pollution problem. Based on the assigned category, the MPO for a given city must design, submit for approval and implement plans that will bring the cities into compliance with the legislation. While this point source approach to addressing air quality issues may be appropriate and effective for local pollution problems, an equivalent approach is not appropriate for addressing the climate change problem. Greenhouse emissions reduction strategies must involve all cities and regions in the United States. Both rural and urban areas must participate in the emission reduction efforts. This poses some implementation challenges.

There has been a great deal of effort to create an implementation structure for the Clean Air Act compliance plans. A system has now been established which places the responsibility for implementation on MPOs of the non-compliance cities while exempting other cities (those who meet air quality plans) from formal plans for compliance. Because the MPO system has been established, political inertia may promote its use for the implementation of greenhouse emission policy. If this system is subscribed to without modification, large areas of the United States would be neglected, diminishing the effectiveness of a national climate change plan. Entirely restructuring an implementation is not practical and probably politically infeasible. One implementation alternative is to develop a network system where the established MPOs act as "compliance nodes". In areas that are disproportionately sparse in the existence of compliance nodes, new nodes would need to be established. Because many of the existing CAA non-compliance areas are often metropolitan areas that also exhibit traffic problems, these cities may be especially appropriate implementation centers if policies include traffic control measures such as VMT reduction. In the node-network implementation system, the compliance nodes would be responsible for a defined region which would be adjacent to a region or regions under jurisdiction of another node or nodes. It would be the responsibility of each node to ensure that its implementation plan in some way overlaps or complements the adjacent regions'

implementation plans. This would allow for some regionally specific plans to be implemented while ensuring contiguous coverage throughout the nation.

Though this proposal takes advantage of some existing implementation infrastructure, there are several factors which would need to be resolved if it were to be used. First, such a large system has inherent logistical obstacles. More serious obstacles have political roots. The existing MPOs may argue that they are unfairly burdened by having to extend their responsibilities to a region and the new compliance nodes, having not been included in other air quality plans, are likely to resist taking on the large responsibility. Another difficulty arises as state borders are reached. Not only, then, must there be cooperation among the MPOs or “compliance nodes”, but also among states. This additional layer of required cooperation only adds to the complexity of the logistics.

5.3.1 Developing Political Motivation for Policy Support

Though the goal of preventing global warming may receive support by the general population, this same population, and those who represent them in the legislature, may be less supportive of the particular policies proposed to meet this goal. Policies that affect the light-duty vehicle sector impact some very sensitive areas from a political perspective such as the petroleum industry, the automobile industry and the behavior of individuals. The petroleum and automobile industries are both important parts of the economy and have established strong lobby groups in the United States. Politicians may on the one hand want to be sensitive to threatening environmental situations such as global warming or issues of national security such as energy dependence but be resistant to support policies which could negatively impact large and powerful industries. Similarly, policies whose objective is to change individuals’ behavior (such as changing travel mode, amount or frequency) are often met with strong resistance. While broad goals that are socially beneficial may seem worthy to these individuals, when achieving them imposes on their pattern of behavior, these same individuals are often quick to claim that there “must be another way.”

One way to address this duality in apparent desires, is to place more onus for solutions in the policy detractors. Often in the course of debate over specific policy proposals other options emerge (often from the policy detractors) that draw attention away and even cast a negative light on the original proposals. To the extent that this process reveals flaws in the original proposal or promotes a superior solution, it is good. However, this tactic often only results in a stalled policy-making process. While it is crucial in an open political system not to silence the voice of dissent, once a general objective has been agreed upon, more responsibility could be placed on those who are not

agreeable to certain policy measures to develop and implement comparable (in terms of effectiveness) alternative policies.

The global warming problem faces particular difficulty in the political arena. Because its effects are manifest over a very long time frame, it is difficult to generate the urgency often necessary to first gather support and then induce necessary concessions and cooperation among differing parties to establish and implement effective policy. Implementing policies that have multiple purposes can help overcome this obstacle. Policies such as pay at the pump insurance which addresses energy dependence (by encouraging less consumption), the problem of uninsured vehicles and high rates, as well as addressing greenhouse emissions concerns will have a better chance at gaining support than single objective policies.

5.4 Recommendations for Continued Research

As one of the largest consumers of fossil fuel in the United States, the light-duty vehicle sector is an undeniably large contributor to the emissions of greenhouse gases and global warming. Though time is a critical element in addressing this problem, there certainly exist many areas where the time and monetary investment of continued research will benefit the effort to control global warming. Research continues both on the large scale (global) and the small scale (sectoral, point source) to understand the production and effects of greenhouse gas sources and sinks and their effect on global warming. If global warming is as serious a concern as many believe, this additional research can help turn the tide of uncertainty around this issue.

On a more specific level, continued research concerning the light-duty vehicle sector's contribution to both the emissions and their eventual reduction is also necessary. This thesis focused on end-use emissions and policies to address them. However, some time was spent in Chapter 2 examining the full life-cycle of greenhouse emissions from this sector. If policy that is in the best interest of society and the emission reduction objective is to be implemented, research must continue on the life-cycle of light-duty vehicles. The effect of policies from raw material recovery through to production, use and scrappage must be carefully considered. While the focus on individual pieces of the life-cycle such as end-use, production or scrappage can be helpful, without consideration of the full life-cycle policies, they could prove less effective than or even opposite of the intended outcome.

Policies for vehicles that are evaluated from a life-cycle approach must also be considered with the context of the vehicle/emissions system. This narrows the focus from the full life-cycle to the end-use system. As was indicated in Chapter 4, if a policy is only

considered in isolation and not in a systems context, its actual effect can not be understood. This could lead to misguided decisions or unexpected outcomes. More work needs to be done in understanding both the elements of the system and their interactive relationships. For example determining what components impact the increase (and decrease) in VMT can give invaluable insight into additional VMT reduction strategies.

Both long term policies and effects are other areas that deserve further research. The two long-term approaches discussed above are just examples of the types of policies that need to be investigated in greater depth. Because of the inherent difficulty in obtaining a high level of accuracy in long term research it is often difficult to attain support for such projects and policies. Long-term research in the light duty vehicle sector has the potential to benefit more than the effort to control global warming. With congestion, pollution and limited fuel supply as other factors intimately affected by the future of light-duty vehicle growth and use, research in this area will be far reaching. However, especially for a topic that has such long term and far reaching effects, the investigation of global warming and policies to control it in the long term are vital.

Though these suggestions for further research are important to understanding global warming, the light duty vehicle's contribution to this problem and its possible solutions, most important is the motivation of political support and further investigation of effective implementation plans. Because the light-duty vehicle is not simply a mode of personal transportation but, in fact, an essential component of the American lifestyle, development of policy regarding this sector is of personal interest to a majority of the U.S. population. Just as people's personal interest in the mobility and "freedom" they associate with their vehicles is a powerful influence in their resistance to some transportation policy, it is perhaps through people's personal interest that global warming and light-duty vehicles impact on it can and should be addressed.

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Appendix A

The Light-Duty Vehicle Emissions Model

Climate Change Mitigation

Summary of Carbon Emissions Forecasts

Base Case

Assumptions	%/yr.	1990	2000	2010	1990-2000	2000-2010
Population	0.70%	251	269	289	7.22%	7.22%
GNP (real)	2.00%	5467	6664	8124	21.90%	21.90%
Price of Gas (real) *	0.00%	1.27	1.19	1.19	-6.30%	0.00%
Price of Cars (real)	1.50%	16,315	18,935	21,975	16.05%	16.05%
Price of LDTs (real)	1.50%	15,857	18,403	21,358	16.05%	16.05%

* drops to 1.19 in 1991-93, then increases at the assumed rate.

Outputs	Actual	Model Predictions				
Automobiles	1990	1990	2000	2010	1990-2000	2000-2010
Sales (thousand)	9,301	10,200	10,676	10,344	14.78%	-3.11%
Stock (mil)	121.562	121.594	142.116	160.828	16.88%	13.17%
Avg. VMT/vehicle	12,208	12,347	12,470	12,412	0.99%	-0.47%
Total VMT	1,484,029	1,501,320	1,772,155	1,996,119	18.04%	12.64%
New Road MPG	24.3	24.6	24.0	23.9	-2.52%	-0.41%
Fit. Road MPG	21.2	21.5	23.1	22.9	7.11%	-0.75%
Gallons/yr (mil)	70,001	69,752	76,869	87,238	10.20%	13.49%
Carbon (MMT Ce)	170.4	169.8	187.2	212.4	10.20%	13.49%
Increase in Carbon above 1990 level			17.3	42.6		

Light Duty Trucks						
Sales (thousand)	3,823	3,863	3,985	3,670	3.15%	-7.91%
Stock (mil)	48.734	48.102	62.515	63.097	29.96%	0.93%
Avg VMT/vehicle	11,390	11,940	12,905	12,793	8.08%	-0.87%
Total VMT	555,080	574,317	806,740	807,177	40.47%	0.05%
New Road MPG	17.2	17.2	18.7	18.7	8.55%	0.00%
Fit. Road MPG	15.5	15.3	17.2	17.6	12.26%	2.72%
Gallons/yr (mil)	35,812	37,557	46,993	45,774	25.12%	-2.59%
Carbon (MMT Ce)	87.2	91.4	114.4	111.5	25.12%	-2.59%
Increase in Carbon above 1990 level			23.0	20.0		

Total Light Duty Vehicles						
Sales (thousand)	13,124	14,064	14,661	14,014	4.24%	-4.41%
Stock (mil)	170.296	169.696	204.631	223.925	20.59%	9.43%
Total VMT	2,039,109	2,075,638	2,578,895	2,803,296	24.25%	8.70%
VMT/capita	8,124	8,269	9,582	9,714	15.87%	1.38%
Fuel: mil gal/yr	105,813	107,309	123,862	133,012	15.43%	7.39%
Fuel: mil bar/day	6.90	7.00	8.08	8.68		
Energy (quads)	13.23	13.41	15.48	16.63		
Carbon (MMT Ce)	257.6	261.3	301.6	323.9	15.43%	7.39%
Increase in Carbon above 1990 level			40.30	62.58		
Base Case Increase above 1990 level			40.30	62.58		
C Reduction from Base Case			0.00	0.00		

Appendix A

Volpe TSC Model of Fuel Consumption and CO2 Emissions

7/27/94

Regression Results: Behavioral Equations

Note: all equations are in log-log form with autocorrelation correction.

1. New Vehicle Sales (Ownership)

	a. cars	
	coeff.	t-stat
constant	14.23	6.78
Gas cost/mi	-0.33	-2.14
GNP/cap	0.76	5.72
P_car	-0.85	-3.79
N	41	
adj. R ²	0.81	
rho	0.20	
data range:	1950-1990	

	b. LDTs	
	coeff.	t-stat
constant	14.47	3.83
Gas cost/mi *	-1.34	-4.81
GNP/cap	0.80	0.61
P_LDT	-1.24	-2.86
N	13	
adj. R ²	0.89	
rho	0.12	
data range:	1978-1990	

2. VMT per vehicle (Utilization)

	a. cars	
	coeff.	t-stat
constant	7.24	15.24
Gas cost/mi	-0.16	-4.43
GNP/cap	0.46	3.23
Stock/cap	-0.38	-2.82
N	41	
adj. R ²	0.91	
rho	0.67	
data range:	1950-1990	

	b. LDTs	
	coeff.	t-stat
constant	8.12	8.91
Gas cost/mi *	-0.28	-3.62
GNP/cap	0.21	0.78
Stock/cap	0.18	0.70
N	40 *	
adj. R ²	0.94	
rho	0.78	
data range:	1951-1990 *	

3. New Vehicle MPG (Fuel Efficiency)

	a. cars	
	coeff.	t-stat
constant	0.47	2.55
Pgas (\$/gal)	0.09	2.14
new MPG (-1)	0.85	14.87
N	13	
adj. R ²	0.96	
rho	0.16	
data range:	1978-1990	

	b. LDTs	
	coeff.	t-stat
constant	0.04	0.16
Pgas (\$/gal)	0.14	2.93
new MPG (-1)	0.97	10.44
N	13	
adj. R ²	0.93	
rho	0.23	
data range:	1978-1990	

* note: gas cost/mi based on this year's price of gas and last year's fleet fuel efficiency in equations 1.b and 2.b.

EXOGEN.XLS

EXOGENOUS VARIABLES						
Assumptions						
Population	0.70%	per year		Cafe (yes/no):	yes	
GNP	2.00%	per year		Feebate	no	
Price of Gas	0.00%	per year				
Price of Cars	1.50%	per year				
Year	Pop	GNP	GNP/pop	Add-On	Base gas	Pgas
1950	152	1583	10.41			1.51
1951	155	1704	10.99			1.42
1952	158	1756	11.11			1.42
1953	160	1834	11.46			1.46
1954	163	1809	11.10			1.47
1955	166	1891	11.39			1.48
1956	169	1982	11.73			1.5
1957	172	2011	11.69			1.5
1958	175	1988	11.36			1.43
1959	178	2115	11.88			1.43
1960	181	2190	12.10			1.43
1961	184	2247	12.21			1.4
1962	187	2366	12.65			1.38
1963	189	2463	13.03			1.35
1964	192	2595	13.52			1.33
1965	194	2745	14.15			1.35
1966	197	2904	14.74			1.35
1967	199	2987	15.01			1.35
1968	201	3111	15.48			1.32
1969	203	3187	15.70			1.29
1970	205	3177	15.50			1.25
1971	208	3268	15.71			1.23
1972	210	3430	16.33			1.18
1973	212	3608	17.02			1.19
1974	214	3589	16.77			1.47
1975	216	3544	16.41			1.44
1976	218	3717	17.05			1.41
1977	220	3891	17.69			1.4
1978	223	4096	18.37			1.36
1979	225	4198	18.66			1.65
1980	228	4191	18.38			2.02
1981	230	4272	18.57			2.03
1982	233	4163	17.87			1.81
1983	235	4312	18.35			1.68
1984	237	4604	19.43			1.57
1985	239	4759	19.91			1.51
1986	242	4889	20.20			1.16
1987	244	5057	20.73			1.15
1988	246	5282	21.47			1.11
1989	249	5415	21.75		Base	1.16
1990	251	5467	21.78		1.27	1.27

EXOGEN.XLS

1990-pred	251	5523	22.03		1.19	1.19
1991	253	5576	22.06		1.19	1.19
1992	255	5688	22.35		1.19	1.19
1993	256	5802	22.64		1.19	1.19
1994	258	5918	22.93	0.000	1.19	1.19
1995	260	6036	23.22	0.000	1.19	1.19
1996	262	6157	23.52	0.000	1.19	1.19
1997	264	6280	23.83	0.000	1.19	1.19
1998	265	6405	24.13	0.000	1.19	1.19
1999	267	6534	24.45	0.000	1.19	1.19
2000	269	6664	24.76	0.000	1.19	1.19
2001	271	6798	25.08	0.000	1.19	1.19
2002	273	6933	25.41	0.000	1.19	1.19
2003	275	7072	25.73	0.000	1.19	1.19
2004	277	7214	26.07	0.000	1.19	1.19
2005	279	7358	26.40	0.000	1.19	1.19
2006	281	7505	26.74	0.000	1.19	1.19
2007	283	7655	27.09	0.000	1.19	1.19
2008	285	7808	27.44	0.000	1.19	1.19
2009	287	7964	27.79	0.000	1.19	1.19
2010	289	8124	28.15	0.000	1.19	1.19

EXOGEN.XLS

		Sales				
	Intercept	14.23				Intercept
	lnC/m	-0.33				lnC/m
	lnGNP/pop	0.76				lnGNP/pop
	lnPrice	-0.85				lnStock/pc
Pcar-avg	Cost/mi	Sales	MPG-fleet	Stock	Stock/pop	VMT
15,148	0.10		15	36.708	0.2415	9932
15,018	0.10		14.8	38.980	0.2515	9932
14,890	0.10		14.6	39.804	0.2519	10238
14,760	0.10		14.4	42.279	0.2642	10079
14,631	0.10		14.2	44.056	0.2703	9979
14,503	0.11		14	47.404	0.2856	9929
14,241	0.11		13.9	49.367	0.2921	9925
13,987	0.11		13.7	51.301	0.2983	9826
13,743	0.11		13.6	52.227	0.2984	9942
13,507	0.11		13.6	54.720	0.3074	9926
13,276	0.11	6641	13.4	56.655	0.3130	9752
13,191	0.11	5935	13.3	58.122	0.3159	9647
13,096	0.10	7092	13.3	60.641	0.3243	9629
13,016	0.10	7720	13.1	63.556	0.3363	9340
12,802	0.10	8101	13.1	66.402	0.3458	9377
13,002	0.10	9332	13	69.745	0.3595	9254
12,323	0.10	9028	12.9	71.094	0.3609	9946
11,667	0.11	8337	12.8	73.163	0.3677	10036
11,812	0.10	9656	12.6	74.321	0.3698	10380
11,591	0.10	9852	12.5	78.650	0.3874	10266
10,687	0.10	8400	12.4	81.310	0.3966	10326
10,621	0.10	10,242	12.3	85.529	0.4112	10219
10,483	0.10	10,940	12.1	90.114	0.4291	10252
10,244	0.10	11,424	12	94.825	0.4473	9922
10,280	0.12	8,853	12	96.595	0.4514	9351
10,483	0.12	8,211	12.1	97.360	0.4507	9493
10,849	0.11	9,706	12.3	99.289	0.4555	9864
10,946	0.11	11,264	12.6	102.513	0.4660	9913
11,320	0.10	11,176	13.1	105.473	0.4730	10104
10,717	0.12	10,763	13.5	107.920	0.4796	9692
10,217	0.14	9,465	14.1	109.018	0.4781	9317
12,662	0.14	8,635	14.8	109.257	0.4750	9606
13,730	0.12	7,771	15.4	108.622	0.4662	9859
14,190	0.10	7,961	16.2	108.183	0.4604	10286
14,397	0.09	10,527	17.1	110.324	0.4655	10407
14,885	0.08	10,633	17.9	112.574	0.4710	10757
14,917	0.06	11,732	18.8	115.893	0.4789	11230
14,222	0.06	10,561	19.6	117.987	0.4836	11331
15,264	0.05	10,573	20.4	120.037	0.4880	11727
15,325	0.06	9,927	21	121.412	0.4876	11942
16,315	0.06	9,301	21.5	121.562	0.4843	12208

EXOGEN.XLS

15,554	0.06	10,512	21.52	1.991	0.0079
16,560	0.05	10,781	21.94	123.590	0.4890
16,809	0.05	10,803	22.27	125.717	0.4939
17,061	0.05	10,812	22.52	127.923	0.4991
17,317	0.05	10,810	22.71	130.139	0.5042
17,576	0.05	10,799	22.85	132.305	0.5090
17,840	0.05	10,782	22.94	134.388	0.5135
18,108	0.05	10,761	23.00	136.389	0.5175
18,379	0.05	10,735	23.03	138.326	0.5212
18,655	0.05	10,706	23.05	140.228	0.5247
18,935	0.05	10,676	23.05	142.116	0.5280
19,219	0.05	10,644	23.05	144.004	0.5313
19,507	0.05	10,611	23.03	145.894	0.5346
19,800	0.05	10,577	23.02	147.784	0.5377
20,097	0.05	10,543	23.00	149.670	0.5408
20,398	0.05	10,510	22.98	151.549	0.5438
20,704	0.05	10,476	22.96	153.420	0.5467
21,015	0.05	10,443	22.93	155.283	0.5495
21,330	0.05	10,409	22.92	157.137	0.5522
21,650	0.05	10,377	22.90	158.985	0.5548
21,975	0.05	10,344	22.88	160.828	0.5573

EXOGEN.XLS

		MPG				
VT		Intercept	0.4666			
7.24		lnPgas	0.09			
-0.16		GNP/cap	0	D9		
0.46		lnMPGlag1	0.848			
-0.38		lnMPGlag2	0	Q7		
Pred						
VT/veh	VT grow	New MPG	Pred MPG	lnVT	lnC/m	lnGNP/pop
10,149		15	#VALUE!	9.204	-2.296	2.343
10,325		14.8	#VALUE!	9.204	-2.344	2.397
10,348		14.6	16.2	9.234	-2.330	2.408
10,239		14.4	16.0	9.218	-2.289	2.439
9,968		14.2	15.8	9.208	-2.268	2.407
9,847		13.9	15.7	9.203	-2.247	2.433
9,861		13.8	15.4	9.203	-2.226	2.462
9,747		13.7	15.3	9.193	-2.212	2.459
9,679		14.1	15.2	9.205	-2.252	2.430
9,771		13.9	15.5	9.203	-2.252	2.475
9,762		13.4	15.3	9.185	-2.238	2.493
9,791		13.6	14.8	9.174	-2.251	2.502
9,876		14	15.0	9.173	-2.266	2.538
9,885		12.6	15.4	9.142	-2.273	2.567
9,969		13.5	14.0	9.146	-2.287	2.604
9,996		13	14.9	9.133	-2.265	2.650
10,159		13	14.4	9.205	-2.257	2.691
10,159		12.9	14.4	9.214	-2.249	2.709
10,292		12.4	14.3	9.248	-2.256	2.739
10,202		12.2	13.8	9.237	-2.271	2.754
10,089		12.5	13.6	9.242	-2.295	2.741
10,028		12.2	13.8	9.232	-2.303	2.754
10,085		12	13.5	9.235	-2.328	2.793
10,090		11.7	13.3	9.203	-2.311	2.834
9,655		13.7	13.3	9.143	-2.100	2.820
9,608		13.6	15.2	9.158	-2.129	2.798
9,799		14.7	15.0	9.197	-2.166	2.836
9,929		15.8	16.1	9.202	-2.197	2.873
10,156		16.7	17.0	9.221	-2.265	2.911
9,913		17.9	18.2	9.179	-2.102	2.926
9,609		20.7	19.6	9.140	-1.943	2.911
9,747		22.2	22.2	9.170	-1.987	2.922
9,885		23.2	23.3	9.196	-2.141	2.883
10,258		23.4	24.0	9.239	-2.266	2.910
10,692		23.6	24.1	9.250	-2.388	2.967
10,913		23.9	24.2	9.283	-2.473	2.991
11,477		24.3	23.8	9.326	-2.785	3.006
11,664		24.7	24.2	9.335	-2.836	3.031
11,958		25	24.4	9.370	-2.911	3.067
12,003		24.6	24.8	9.388	-2.896	3.079
11,914		24.3	24.6	9.410	-2.829	3.081

EXOGEN.XLS

57,716						Feebate/Ret
12,105	-0.85%	24.5	24.5	23.913	24.488	1.000
12,159	-0.40%	24.4	24.4	23.913	24.393	1.000
12,204	-0.03%	24.3	24.3	23.913	24.314	1.000
12,245	0.31%	24.2	24.2	23.913	24.246	1.000
12,285	0.63%	24.2	24.2	23.913	24.189	1.000
12,325	0.96%	24.1	24.1	23.913	24.141	1.000
12,367	1.30%	24.1	24.1	23.913	24.100	1.000
12,409	1.65%	24.1	24.1	23.913	24.065	1.000
12,452	2.00%	24.0	24.0	23.913	24.036	1.000
12,496	2.36%	24.0	24.0	23.913	24.011	1.000
12,540	2.72%	24.0	24.0	23.913	23.990	1.000
12,584	3.08%	24.0	24.0	23.913	23.972	1.000
12,628	3.44%	24.0	24.0	23.913	23.957	1.000
12,674	3.81%	23.9	23.9	23.913	23.944	1.000
12,720	4.20%	23.9	23.9	23.913	23.933	1.000
12,768	4.59%	23.9	23.9	23.913	23.924	1.000
12,817	4.99%	23.9	23.9	23.913	23.916	1.000
12,867	5.40%	23.9	23.9	23.913	23.913	1.000
12,918	5.82%	23.9	23.9	23.913	23.913	1.000
12,971	6.25%	23.9	23.9	23.913	23.913	1.000

Tot Stock/pc	InStock/pc
0.274	-1.421
0.285	-1.380
0.286	-1.379
0.299	-1.331
0.305	-1.308
0.322	-1.253
0.330	-1.231
0.337	-1.210
0.338	-1.209
0.348	-1.180
0.355	-1.162
0.359	-1.152
0.369	-1.126
0.383	-1.090
0.395	-1.062
0.411	-1.023
0.415	-1.019
0.425	-1.001
0.430	-0.995
0.451	-0.948
0.464	-0.925
0.483	-0.889
0.508	-0.846
0.535	-0.805
0.546	-0.795
0.551	-0.797
0.564	-0.786
0.585	-0.764
0.603	-0.749
0.619	-0.735
0.619	-0.738
0.618	-0.744
0.610	-0.763
0.607	-0.776
0.619	-0.765
0.630	-0.753
0.646	-0.736
0.658	-0.727
0.671	-0.718
0.677	-0.718
0.678	-0.725

MODELS.XLS

	Pldts:	2%							
	Sales		MPG		VMT: Based on truck fleet, 1950-1990				
	Intercept	14.47	Intercept	0.0439			Intercept	8.124	
	lnCost/mi	-1.34	lnPgas	0.1435			lnCost/mi	-0.276	
	lnGNP/pop	0.797	lnnpcap	0			lnGNP/pop	0.207	
	lnPldt	-1.24	mpglag1	0.971			lstock/pop	0.177	
Year	Sales	PrdSales	MPG	pred MPG	MPG use	MT-LDT	PredVMT	VMT-car	PredVMTgrow
1950	719	#VALUE!	7.9	#VALUE!		6,579	#VALUE!	9932	
1951	700	995	8.0	#VALUE!		6,795	7,126	9932	
1952	544	1,015	8.1	8.3		7,083	7,146	10238	
1953	608	1,012	8.2	8.4		7,034	7,197	10079	
1954	541	988	8.2	8.5		7,205	7,160	9979	
1955	639	1,010	8.3	8.5		7,270	7,255	9929	
1956	582	1,027	8.3	8.6		7,421	7,302	9925	
1957	586	1,035	8.3	8.6		7,435	7,324	9826	
1958	509	1,090	8.3	8.6		7,432	7,380	9942	
1959	661	1,143	8.4	8.6		7,599	7,490	9926	
1960	674	1,172	8.4	8.7		7,654	7,543	9752	
1961	665	1,250	8.6	8.7		7,742	7,644	9647	
1962	793	1,325	8.8	8.8		7,800	7,769	9629	
1963	928	1,437	9.1	9.0		8,178	7,944	9340	
1964	1034	1,573	9.3	9.3		8,369	8,108	9377	
1965	1168	1,595	9.5	9.5		8,491	8,238	9254	
1966	1247	1,827	9.6	9.7		7,618	8,376	9946	
1967	1194	2,026	9.9	9.8		7,288	8,471	10036	
1968	1434	2,137	10.3	10.1		7,681	8,623	10380	
1969	1564	2,347	10.3	10.4		8,099	8,830	10266	
1970	1456	2,791	10.5	10.4		8,231	8,985	10326	
1971	1,748	2,986	10.8	10.6		8,494	9,171	10219	
1972	2,190	3,374	11.0	10.8		8,839	9,462	10252	
1973	2,651	3,721	11.2	11.0		8,964	9,692	9922	
1974	2,263	2,833	11.9	11.5		8,353	9,199	9351	
1975	2,175	2,845	12.1	12.2		8,531	9,276	9493	
1976	2,857	2,922	11.9	12.4		8,921	9,497	9864	
1977	3,296	3,086	13.4	12.1		9,061	9,701	9913	
1978	3,665	3,321	13.1	13.6		9,228	10,012	10104	
1979	3,087	2,835	13.7	13.7		9,028	9,636	9692	
1980	1,863	2,217	15.2	14.7		8,520	9,131	9317	
1981	1,821	1,795	16.6	16.2		8,555	9,179	9606	
1982	1,903	1,995	16.9	17.4		8,893	9,444	9859	
1983	2,287	2,308	17.4	17.5		9,667	9,751	10286	
1984	3,399	2,688	17.1	17.9		10,406	10,156	10407	
1985	3,314	2,888	17.5	17.5		10,914	10,463	10757	
1986	4,319	4,390	17.7	17.2		11,229	11,456	11230	
1987	4,137	4,306	17.8	17.4		11,817	11,699	11331	
1988	4,580	4,633	17.6	17.4		11,810	12,058	11727	
1989	4,448	4,519	17.3	17.3		11,378	12,054	11942	
1990	3,823	3,863	17.2	17.2		11,390	11,828	12208	

MODELS.XLS

1991		4,292	18.7	17.0	18.7		12,168		6.83%
1992		4,257	18.7	18.4	18.7	Feebate	12,235		7.42%
1993		4,222	18.7	18.4	18.7	Rebate	12,302		8.00%
1994		4,187	18.7	18.4	18.7	Increase	12,366		8.57%
1995		4,153	18.7	18.4	18.7	100.00%	12,427		9.11%
1996		4,119	18.7	18.4	18.7	100.00%	12,485		9.62%
1997		4,085	18.7	18.4	18.7	100.00%	12,540		10.09%
1998		4,051	18.7	18.4	18.7	100.00%	12,591		10.55%
1999		4,018	18.7	18.4	18.7	100.00%	12,640		10.97%
2000		3,985	18.7	18.4	18.7	100.00%	12,686		11.38%
2001		3,952	18.7	18.4	18.7	100.00%	12,731		11.77%
2002		3,920	18.7	18.4	18.7	100.00%	12,774		12.15%
2003		3,888	18.7	18.4	18.7	100.00%	12,815		12.51%
2004		3,856	18.7	18.4	18.7	100.00%	12,855		12.86%
2005		3,824	18.7	18.4	18.7	100.00%	12,894		13.20%
2006		3,793	18.7	18.4	18.7	100.00%	12,931		13.53%
2007		3,762	18.7	18.4	18.7	100.00%	12,968		13.86%
2008		3,731	18.7	18.4	18.7	100.00%	13,004		14.17%
2009		3,700	18.7	18.4	18.7	100.00%	13,040		14.48%
2010		3,670	18.7	18.4	18.7	100.00%	13,075		14.79%

MODELS.XLS

			Rate of increase (from EXOGEN.XLS)								
			Pop	GNP		Pgas					
			0.70%	2.00%		0.00%					
Stock-ldt	Stock-car	t Stock/pc	Pop	GNP	GNP/pop	Pgas	Cost/mi	Sales-sm	Sales-lg	P-sm	
4.923	36.708	0.274	152	1583	10.41	1.51	#VALUE!	78	641	11143	
5.150	38.980	0.285	155	1704	10.99	1.42	0.18	76	624	11093	
5.305	39.804	0.286	158	1756	11.11	1.42	0.18	59	485	11043	
5.611	42.279	0.299	160	1834	11.46	1.46	0.18	66	542	10993	
5.698	44.056	0.305	163	1809	11.10	1.47	0.19	59	482	10943	
6.101	47.404	0.322	166	1891	11.39	1.48	0.19	69	570	10893	
6.391	49.367	0.330	169	1982	11.73	1.5	0.19	63	519	10843	
6.626	51.301	0.337	172	2011	11.69	1.5	0.19	64	522	10793	
6.849	52.227	0.338	175	1988	11.36	1.43	0.18	55	454	10743	
7.272	54.720	0.348	178	2115	11.88	1.43	0.18	72	589	10693	
7.565	56.655	0.355	181	2190	12.10	1.43	0.18	73	601	10644	
7.901	58.122	0.359	184	2247	12.21	1.4	0.18	72	593	10594	
8.355	60.641	0.369	187	2366	12.65	1.38	0.17	86	707	10544	
8.841	63.556	0.383	189	2463	13.03	1.35	0.17	101	827	10494	
9.407	66.402	0.395	192	2595	13.52	1.33	0.16	112	922	10388	
10.072	69.745	0.411	194	2745	14.15	1.35	0.16	127	1041	10469	
10.640	71.094	0.415	197	2904	14.74	1.35	0.16	135	1112	10168	
11.433	73.163	0.425	199	2987	15.01	1.35	0.16	130	1064	9876	
12.127	74.321	0.430	201	3111	15.48	1.32	0.15	156	1278	9942	
12.818	78.650	0.451	203	3187	15.70	1.29	0.14	170	1394	9859	
13.838	81.310	0.464	205	3177	15.50	1.25	0.14	158	1298	9450	
14.986	85.529	0.483	208	3268	15.71	1.23	0.13	190	1558	9429	
16.557	90.114	0.508	210	3430	16.33	1.18	0.13	238	1952	9356	
18.567	94.825	0.535	212	3608	17.02	1.19	0.12	288	2363	9239	
20.161	96.595	0.546	214	3589	16.77	1.47	0.15	246	2017	9256	
21.635	97.360	0.551	216	3544	16.41	1.44	0.14	236	1939	9368	
23.754	99.289	0.564	218	3717	17.05	1.41	0.14	232	2625	9568	
26.267	102.513	0.585	220	3891	17.69	1.4	0.13	405	2891	9612	
29.092	105.473	0.603	223	4096	18.37	1.36	0.12	429	3236	9782	
31.271	107.920	0.619	225	4198	18.66	1.65	0.15	632	2455	9055	
32.151	109.018	0.619	228	4191	18.38	2.02	0.18	671	1192	9515	
32.881	109.257	0.618	230	4272	18.57	2.03	0.18	593	1228	11274	
33.564	108.622	0.610	233	4163	17.87	1.81	0.15	730	1173	11550	
34.486	108.183	0.607	235	4312	18.35	1.68	0.14	1112	1175	11778	
36.363	110.324	0.619	237	4604	19.43	1.57	0.13	1806	1593	11965	
37.985	112.574	0.630	239	4759	19.91	1.51	0.12	1833	1481	12698	
40.454	115.893	0.646	242	4889	20.20	1.16	0.09	2783	1536	12512	
42.595	117.987	0.658	244	5057	20.73	1.15	0.08	2963	1174	13778	
45.045	120.037	0.671	246	5282	21.47	1.11	0.08	2984	1596	14482	
47.251	121.412	0.677	249	5415	21.75	1.16	0.08	2886	1562	14695	
48.734	121.562	0.678	251	5467	21.78	1.27	0.08	2411	1412	15638	

MODELS.XLS

50.159	123.590	0.687	253	5,576	22.06	1.19	0.08			
52.114	125.717	0.699	255	5,688	22.35	1.19	0.08			
53.960	127.923	0.710	256	5,802	22.64	1.19	0.08			
55.679	130.139	0.720	258	5,918	22.93	1.19	0.08			
57.255	132.305	0.729	260	6,036	23.22	1.19	0.08			
58.667	134.388	0.738	262	6,157	23.52	1.19	0.08			
59.902	136.389	0.745	264	6,280	23.83	1.19	0.08			
60.953	138.326	0.751	265	6,405	24.13	1.19	0.08			
61.822	140.228	0.756	267	6,534	24.45	1.19	0.08			
62.515	142.116	0.760	269	6,664	24.76	1.19	0.08			
63.046	144.004	0.764	271	6,798	25.08	1.19	0.08			
63.432	145.894	0.767	273	6,933	25.41	1.19	0.08			
63.688	147.784	0.769	275	7,072	25.73	1.19	0.08			
63.831	149.670	0.771	277	7,214	26.07	1.19	0.08			
63.877	151.549	0.773	279	7,358	26.40	1.19	0.08			
63.840	153.420	0.774	281	7,505	26.74	1.19	0.08			
63.733	155.283	0.775	283	7,655	27.09	1.19	0.08			
63.568	157.137	0.776	285	7,808	27.44	1.19	0.08			
63.353	158.985	0.776	287	7,964	27.79	1.19	0.08			
63.097	160.828	0.776	289	8,124	28.15	1.19	0.08			

		HP/CID	
		0.50%	
P-Ig	P LDT	HP/CID	litMPG
13720	13440.44		7.9
13602	13329.59		7.9
13483	13218.37		7.9
13365	13107.51		7.9
13246	12994.84		7.9
13128	12886.66		7.9
13009	12774.54		7.9
12891	12661.87		7.9
12773	12553.65		7.9
12654	12440.4		7.9
12536	12331.08		8.0
12417	12219.62		8.0
12299	12108.67		8.1
12180	11996.5		8.2
11930	11762.97		8.3
12121	11941.37		8.5
11408	11273.76		8.6
10717	10625.43		8.7
10873	10771.72		8.9
10677	10588.09		9.1
9706	9678.22		9.3
9656	9631.326		9.4
9483	9469.198		9.7
9207	9210.476		9.9
9247	9247.978		10.1
9511	9495.484	0.476	10.3
9987	9952.975	0.458	10.5
10091	10032.14	0.482	10.9
10494	10410.66	0.481	11.2
10222	9983.081	0.486	11.4
10080	9876.503	0.528	11.6
12269	11944.98	0.508	11.9
13011	12450.55	0.524	12.2
13259	12538.9	0.543	12.5
13547	12706.43	0.557	13.0
13949	13257.06	0.586	13.5
14512	13223.28	0.621	14.0
15738	14334.21	0.654	14.5
15733	14917.94	0.650	14.9
15759	15068.64	0.653	15.2
16232	15857.39	0.668	15.5

MODELS.XLS

	16095.25	0.681	15.5	15.62
	16336.68	0.673	15.5	15.91
	16581.73	0.698	15.5	16.16
	16830.46	0.701	15.5	16.37
	17082.91	0.705	15.5	16.55
	17339.16	0.709	15.5	16.71
	17599.24	0.712	15.5	16.85
	17863.23	0.716	15.5	16.97
	18131.18	0.719	15.5	17.07
	18403.15	0.723	15.5	17.17
	18679.2	0.726	15.5	17.25
	18959.38	0.730	15.5	17.32
	19243.77	0.734	15.5	17.38
	19532.43	0.737	15.5	17.44
	19825.42	0.741	15.5	17.49
	20122.8	0.745	15.5	17.53
	20424.64	0.748	15.5	17.56
	20731.01	0.752	15.5	17.59
	21041.98	0.756	15.5	17.61
	21357.61	0.760	15.5	17.63

MODELS.XLS

Year	lnFtMPG	lnSales	lnMPG	lnVMT/ldt	lnPgas	lnCost/mi	lnstock/pop	lnGNP/pop	lnHP/CID
2007	2.07	6.58	2.07	8.79	0.41	#VALUE!	-1.30	2.34	
2007	2.07	6.55	2.08	8.82	0.35	-1.72	-1.26	2.40	
2007	2.07	6.30	2.09	8.87	0.35	-1.72	-1.25	2.41	
2007	2.07	6.41	2.10	8.86	0.38	-1.69	-1.21	2.44	
2007	2.07	6.29	2.10	8.88	0.39	-1.68	-1.19	2.41	
2007	2.07	6.46	2.12	8.89	0.39	-1.67	-1.13	2.43	
2007	2.07	6.37	2.12	8.91	0.41	-1.66	-1.11	2.46	
2007	2.07	6.37	2.12	8.91	0.41	-1.66	-1.09	2.46	
2007	2.07	6.23	2.12	8.91	0.36	-1.71	-1.09	2.43	
2007	2.07	6.49	2.13	8.94	0.36	-1.71	-1.05	2.48	
2008	2.08	6.51	2.13	8.94	0.36	-1.71	-1.04	2.49	
2008	2.08	6.50	2.15	8.95	0.34	-1.74	-1.02	2.50	
2009	2.09	6.68	2.17	8.96	0.32	-1.76	-1.00	2.54	
2110	2.10	6.83	2.21	9.01	0.30	-1.79	-0.96	2.57	
2112	2.12	6.94	2.23	9.03	0.29	-1.82	-0.93	2.60	
2114	2.14	7.06	2.25	9.05	0.30	-1.82	-0.89	2.65	
2115	2.15	7.13	2.26	8.94	0.30	-1.84	-0.88	2.69	
2116	2.16	7.09	2.29	8.89	0.30	-1.85	-0.86	2.71	
2119	2.19	7.27	2.33	8.95	0.28	-1.89	-0.84	2.74	
2221	2.21	7.36	2.33	9.00	0.25	-1.93	-0.80	2.75	
2223	2.23	7.28	2.35	9.02	0.22	-1.99	-0.77	2.74	
2224	2.24	7.47	2.38	9.05	0.21	-2.02	-0.73	2.75	
2227	2.27	7.69	2.40	9.09	0.17	-2.08	-0.68	2.79	
2229	2.29	7.88	2.42	9.10	0.17	-2.10	-0.63	2.83	
2331	2.31	7.72	2.48	9.03	0.39	-1.91	-0.61	2.82	
2333	2.33	7.68	2.49	9.05	0.36	-1.95	-0.60	2.80	-0.74
2335	2.35	7.96	2.48	9.10	0.34	-1.99	-0.57	2.84	-0.78
2339	2.39	8.10	2.60	9.11	0.34	-2.01	-0.54	2.87	-0.73
2442	2.42	8.21	2.57	9.13	0.31	-2.08	-0.51	2.91	-0.73
2443	2.43	8.03	2.62	9.11	0.50	-1.92	-0.48	2.93	-0.72
2445	2.45	7.53	2.72	9.05	0.70	-1.73	-0.48	2.91	-0.64
2448	2.48	7.51	2.81	9.05	0.71	-1.74	-0.48	2.92	-0.68
2550	2.50	7.55	2.83	9.09	0.59	-1.88	-0.49	2.88	-0.65
2553	2.53	7.73	2.86	9.18	0.52	-1.98	-0.50	2.91	-0.61
2556	2.56	8.13	2.84	9.25	0.45	-2.07	-0.48	2.97	-0.59
2660	2.60	8.11	2.86	9.30	0.41	-2.15	-0.46	2.99	-0.53
2664	2.64	8.37	2.87	9.33	0.15	-2.45	-0.44	3.01	-0.48
2667	2.67	8.33	2.88	9.38	0.14	-2.50	-0.42	3.03	-0.42
2770	2.70	8.43	2.87	9.38	0.10	-2.57	-0.40	3.07	-0.43
2772	2.72	8.40	2.85	9.34	0.15	-2.55	-0.39	3.08	-0.43
2774	2.74	8.25	2.84	9.34	0.24	-2.48	-0.39	3.08	-0.40

Car Stock Model							
1. Automobile Population Projection by Model Year							
						Intercept	12.248128
						lnPgas	-0.367944
						lnGNP/pop	0.905258
						lnPrice	-0.589611
		Calendar Year					
	Sales	1990	1991	1992	1993	1994	1995
Model Yr	Total	121,594	123,590	125,717	127,923	130,139	132,305
1960	6641	2	1	1	1	1	1
1961	5935	2	2	1	1	1	1
1962	7092	4	3	3	2	2	1
1963	7720	7	6	4	3	3	2
1964	8101	11	9	7	6	4	4
1965	9332	20	15	12	10	8	6
1966	9028	29	23	18	14	11	9
1967	8337	42	32	25	19	15	12
1968	9656	74	56	43	34	26	21
1969	9852	116	87	67	51	40	32
1970	8400	151	113	86	66	51	40
1971	10,242	283	210	158	120	93	72
1972	10,940	465	342	255	193	147	114
1973	11,424	743	544	402	302	229	176
1974	8,853	878	639	470	350	264	201
1975	8,211	1,228	894	655	485	363	275
1976	9,706	2,148	1,574	1,155	853	636	479
1977	11,264	3,580	2,667	1,973	1,461	1,087	816
1978	11,176	4,889	3,746	2,821	2,108	1,574	1,180
1979	10,763	6,137	4,895	3,793	2,887	2,178	1,640
1980	9,465	6,620	5,537	4,463	3,496	2,689	2,048
1981	8,635	6,982	6,130	5,173	4,211	3,334	2,590
1982	7,771	6,909	6,331	5,593	4,758	3,910	3,127
1983	7,961	7,496	7,100	6,530	5,802	4,973	4,124
1984	10,527	10,236	9,921	9,414	8,688	7,760	6,699
1985	10,633	10,510	10,339	10,029	9,532	8,824	7,921
1986	11,732	11,684	11,594	11,407	11,072	10,540	9,785
1987	10,561	10,550	10,517	10,435	10,267	9,971	9,505
1988	10,573	10,571	10,561	10,527	10,444	10,277	9,985
1989	9,927	9,927	9,925	9,915	9,882	9,803	9,647
1990	9,301	9,301	9,301	9,299	9,289	9,257	9,182

CARS.XLS

1990-pred	10,200						
1991	10,477		10,477	10,477	10,475	10,462	10,425
1992	10,507			10,507	10,507	10,504	10,491
1993	10,537				10,537	10,536	10,533
1994	10,566					10,566	10,566
1995	10,596						10,596
1996	10,626						
1997	10,657						
1998	10,687						
1999	10,717						
2000	10,748						
2001	10,778						
2002	10,809						
2003	10,839						
2004	10,870						
2005	10,901						
2006	10,932						
2007	10,963						
2008	10,994						
2009	11,025						
2010	11,056						

CARS.XLS

1996	1997	1998	1999	2000	2001	2002	2003
134,388	136,389	138,326	140,228	142,116	144,004	145,894	147,784
0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0
1	1	1	1	1	0	0	0
2	2	1	1	1	1	1	1
3	2	2	2	1	1	1	1
5	4	3	3	2	2	2	1
7	6	5	4	3	3	2	2
10	8	6	5	4	4	3	3
17	13	11	9	7	6	5	4
25	20	16	13	11	9	7	6
32	25	20	16	13	11	9	8
57	45	36	29	23	19	16	13
89	70	56	45	36	29	24	20
136	107	84	67	54	44	36	29
155	121	95	75	60	49	39	32
211	163	127	100	80	64	52	42
364	280	218	171	135	108	87	71
618	472	365	285	224	178	143	116
891	679	522	405	318	251	200	161
1,239	942	722	558	435	343	272	218
1,555	1,184	906	698	543	426	336	268
1,991	1,525	1,170	901	699	546	430	342
2,453	1,903	1,470	1,136	882	688	540	428
3,330	2,637	2,065	1,609	1,253	978	768	607
5,603	4,565	3,650	2,884	2,265	1,777	1,397	1,104
6,883	5,803	4,770	3,848	3,067	2,428	1,920	1,520
8,823	7,715	6,554	5,433	4,421	3,553	2,836	2,259
8,848	8,012	7,047	6,029	5,038	4,133	3,350	2,695
9,531	8,894	8,085	7,149	6,158	5,185	4,288	3,503
9,377	8,961	8,380	7,646	6,795	5,890	4,995	4,163
9,036	8,786	8,405	7,877	7,210	6,439	5,614	4,794

CARS.XLS

[illegible]

CARS.XLS

[illegible]

CARS.XLS

5,522	4,669	3,901	3,234	2,669	2,199	1,814
6,539	5,654	4,813	4,050	3,380	2,809	2,329
7,503	6,646	5,781	4,953	4,195	3,526	2,949
8,358	7,583	6,749	5,903	5,089	4,338	3,669
9,068	8,413	7,659	6,846	6,019	5,219	4,477
9,624	9,104	8,464	7,730	6,938	6,130	5,346
10,037	9,648	9,137	8,512	7,796	7,025	6,236
10,330	10,056	9,670	9,168	8,556	7,859	7,107
10,529	10,349	10,074	9,691	9,196	8,598	7,917
10,661	10,550	10,367	10,091	9,710	9,222	8,636
10,745	10,685	10,571	10,383	10,106	9,727	9,246
10,800	10,773	10,709	10,591	10,399	10,120	9,742
10,838	10,830	10,800	10,732	10,609	10,414	10,132
10,870	10,869	10,859	10,827	10,755	10,627	10,427
	10,901	10,900	10,888	10,853	10,777	10,644
		10,932	10,930	10,918	10,879	10,798
			10,963	10,961	10,947	10,904
				10,994	10,992	10,975
					11,025	11,023
						11,056

CARS.XLS

Variables		8.36	Survival Rates			
AVL by Model Year		121,594		Model Year		
Year	AvgLife	Alpha	Age	1970	1990	2000
1950	7.43	7.58	1	100.00%	100.00%	100.00%
1951	7.57	7.50	2	99.99%	99.98%	99.94%
1952	7.72	7.42	3	99.94%	99.87%	99.72%
1953	7.86	7.35	4	99.67%	99.53%	99.19%
1954	8.01	7.27	5	98.74%	98.72%	98.17%
1955	8.15	7.19	6	96.31%	97.15%	96.45%
1956	8.29	7.11	7	91.15%	94.46%	93.89%
1957	8.44	7.04	8	82.16%	90.36%	90.35%
1958	8.58	6.96	9	69.35%	84.69%	85.81%
1959	8.72	6.88	10	54.52%	77.52%	80.35%
1960	8.87	6.80	11	40.28%	69.22%	74.17%
1961	9.01	6.73	12	28.53%	60.36%	67.52%
1962	9.16	6.65	13	19.76%	51.54%	60.71%
1963	9.30	6.57	14	13.61%	43.28%	53.99%
1964	9.44	6.50	15	9.41%	35.89%	47.61%
1965	9.59	6.42	16	6.58%	29.54%	41.70%
1966	9.73	6.34	17	4.66%	24.21%	36.35%
1967	9.87	6.26	18	3.35%	19.82%	31.60%
1968	10.02	6.19	19	2.44%	16.25%	27.43%
1969	10.16	6.11	20	1.80%	13.36%	23.81%
1970	10.31	6.03	21	1.35%	11.02%	20.68%
1971	10.45	5.95	22	1.02%	9.14%	18.00%
1972	10.59	5.88	23	0.78%	7.61%	15.69%
1973	10.74	5.80	24	0.61%	6.37%	13.71%
1974	10.88	5.72	25	0.48%	5.36%	12.02%
1975	11.02	5.64	26	0.38%	4.54%	10.56%
1976	11.17	5.57	27	0.30%	3.86%	9.31%
1977	11.31	5.49	28	0.24%	3.30%	8.23%
1978	11.46	5.41	29	0.19%	2.83%	7.30%
1979	11.60	5.33	30	0.16%	2.44%	6.49%

CARS.XLS

1980	11.74	5.26				
1981	11.89	5.18				
1982	12.03	5.10				
1983	12.17	5.03				
1984	12.32	4.95				
1985	12.46	4.87				
1986	12.61	4.79				
1987	12.75	4.72				
1988	12.89	4.64				
1989	13.04	4.56				
1990	13.18	4.48				
1991	13.32	4.41				
1992	13.47	4.33				
1993	13.61	4.25				
1994	13.76	4.17				
1995	13.90	4.10				
1996	14.04	4.02				
1997	14.19	3.94				
1998	14.33	3.86				
1999	14.47	3.79				
2000	14.62	3.71				
2001	14.76	3.63				
2002	14.91	3.56				
2003	15.05	3.48				
2004	15.19	3.40				
2005	15.34	3.32				
2006	15.48	3.25				
2007	15.62	3.17				
2008	15.77	3.09				
2009	15.91	3.01				
2010	16.06	2.94				

LDT Stock Model							
1. LDT Population							
		Calendar Year					
	Sales	1990	1991	1992	1993	1994	1995
Model Yr		48,102	50,159	52,114	53,960	55,679	57,255
1960	674	21	19	16	15	13	11
1961	665	25	22	19	17	15	13
1962	793	35	30	26	23	20	18
1963	928	48	42	36	31	28	24
1964	1034	63	55	47	41	36	31
1965	1168	85	73	63	54	47	41
1966	1247	109	93	80	69	59	52
1967	1194	125	106	91	78	67	58
1968	1434	180	153	130	111	95	82
1969	1564	237	200	170	144	124	106
1970	1456	266	224	190	161	137	117
1971	1,748	384	323	273	231	196	167
1972	2,190	578	487	410	346	293	249
1973	2,651	839	707	596	502	424	359
1974	2,263	854	723	610	515	434	367
1975	2,175	971	828	702	593	500	422
1976	2,857	1,492	1,286	1,098	931	787	665
1977	3,296	1,985	1,733	1,495	1,278	1,085	918
1978	3,665	2,502	2,220	1,941	1,676	1,434	1,218
1979	3,087	2,342	2,117	1,881	1,646	1,423	1,218
1980	1,863	1,540	1,418	1,283	1,141	1,000	865
1981	1,821	1,605	1,505	1,386	1,254	1,116	977
1982	1,903	1,758	1,677	1,573	1,449	1,311	1,166
1983	2,287	2,184	2,113	2,015	1,890	1,741	1,575
1984	3,399	3,317	3,247	3,141	2,995	2,809	2,588
1985	3,314	3,277	3,235	3,165	3,062	2,920	2,739
1986	4,319	4,300	4,270	4,215	4,125	3,991	3,806
1987	4,137	4,131	4,119	4,090	4,038	3,951	3,823
1988	4,580	4,579	4,574	4,560	4,528	4,470	4,375
1989	4,448	4,448	4,447	4,442	4,428	4,398	4,341
1990	3,823	3,823	3,823	3,822	3,818	3,806	3,780
1991	4,292		4,292	4,292	4,291	4,286	4,273
1992	4,257			4,257	4,256	4,255	4,251
1993	4,222				4,222	4,222	4,221
1994	4,187					4,187	4,187
1995	4,153						4,153
1996	4,119						
1997	4,085						
1998	4,051						
1999	4,018						
2000	3,985						
2001	3,952						
2002	3,920						
2003	3,888						
2004	3,856						
2005	3,824						
2006	3,793						
2007	3,762						
2008	3,731						
2009	3,700						
2010	3,670						

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2004	2005	2006	2007	2008	2009	2010
63,831	63,877	63,840	63,733	63,568	63,353	63,097
4	4	4	3	3	3	3
5	4	4	4	3	3	3
7	6	5	5	4	4	4
9	8	7	6	6	5	5
11	10	9	8	7	7	6
14	13	11	10	9	8	8
17	15	14	12	11	10	9
19	17	15	13	12	11	10
26	23	20	18	17	15	13
32	28	25	23	20	18	17
34	30	27	24	22	19	17
47	42	37	33	29	26	24
68	60	53	47	42	37	34
95	83	74	65	58	51	46
94	82	72	64	56	50	45
105	91	80	70	62	55	49
160	139	122	107	94	83	73
217	188	163	142	125	110	97
283	244	212	184	161	141	124
281	241	208	181	157	137	120
200	172	148	127	110	96	84
229	196	168	144	125	108	94
282	240	205	175	151	130	113
399	338	288	246	211	181	156
699	592	503	428	365	313	269
806	682	578	490	417	356	305
1,241	1,050	889	753	639	544	464
1,402	1,189	1,006	851	721	612	521
1,823	1,552	1,316	1,114	942	798	678
2,066	1,771	1,508	1,278	1,082	915	775
2,052	1,776	1,522	1,296	1,099	930	787
2,630	2,304	1,993	1,708	1,455	1,233	1,044
2,932	2,608	2,285	1,977	1,694	1,443	1,223
3,214	2,908	2,587	2,266	1,961	1,681	1,431
3,460	3,188	2,884	2,565	2,247	1,945	1,667
3,659	3,432	3,162	2,861	2,544	2,229	1,929
3,805	3,629	3,404	3,136	2,837	2,523	2,211
3,902	3,774	3,599	3,376	3,110	2,814	2,503
3,954	3,870	3,743	3,570	3,348	3,085	2,791
3,973	3,922	3,838	3,713	3,540	3,321	3,059
3,967	3,940	3,889	3,806	3,682	3,511	3,293
3,947	3,935	3,908	3,858	3,775	3,652	3,482
3,919	3,915	3,902	3,876	3,826	3,744	3,622
3,888	3,887	3,883	3,870	3,844	3,794	3,713
3,856	3,856	3,855	3,851	3,839	3,812	3,763
	3,824	3,824	3,823	3,819	3,807	3,781
		3,793	3,793	3,792	3,788	3,776
			3,762	3,762	3,761	3,757
				3,731	3,731	3,730
					3,700	3,700
						3,670

	Survival Rates			AVL by Model Year		
	1970	1990	1970 change	Year	AvgLife	Alpha
	1	1		1950	12.60	4.20
1	0.9999	0.9996	1E-04	1951	12.67	4.20
2	0.9993	0.9979	0.0006	1952	12.74	4.20
3	0.9964	0.9935	0.0029	1953	12.81	4.20
4	0.9879	0.9843	0.0085	1954	12.88	4.20
5	0.9677	0.9681	0.0202	1955	12.95	4.20
6	0.9276	0.9424	0.0401	1956	13.02	4.20
7	0.8601	0.9056	0.0675	1957	13.09	4.20
8	0.7628	0.8569	0.0973	1958	13.16	4.20
9	0.6431	0.7971	0.1197	1959	13.23	4.20
10	0.5161	0.7285	0.127	1960	13.30	4.20
11	0.398	0.6545	0.1181	1961	13.37	4.20
12	0.2986	0.579	0.0994	1962	13.44	4.20
13	0.2207	0.5056	0.0779	1963	13.51	4.20
14	0.1623	0.4369	0.0584	1964	13.58	4.20
15	0.1196	0.3748	0.0427	1965	13.65	4.20
16	0.0887	0.3199	0.0309	1966	13.72	4.20
17	0.0664	0.2723	0.0223	1967	13.79	4.20
18	0.0501	0.2316	0.0163	1968	13.86	4.20
19	0.0383	0.1971	0.0118	1969	13.93	4.20
20	0.0295	0.1681	0.0088	1970	14.00	4.20
21	0.023	0.1436	0.0065	1971	14.05	4.20
22	0.0181	0.1231	0.0049	1972	14.10	4.20
23	0.0144	0.1059	0.0037	1973	14.15	4.20
24	0.0115	0.0914	0.0029	1974	14.20	4.20
25	0.0093	0.0792	0.0022	1975	14.25	4.20
26	0.0076	0.0688	0.0017	1976	14.30	4.20
27	0.0062	0.0601	0.0014	1977	14.35	4.20
28	0.0051	0.0526	0.0011	1978	14.40	4.20
29	0.0043	0.0463	0.0008	1979	14.45	4.20
30	0.0036	0.0408	0.0007	1980	14.50	4.20
31			0.9964	1981	14.50	4.20

					1982	14.50	4.20
					1983	14.50	4.20
					1984	14.50	4.20
					1985	14.50	4.20
					1986	14.50	4.20
					1987	14.50	4.20
					1988	14.50	4.20
					1989	14.50	4.20
					1990	14.50	4.20
					1991	14.50	4.20
					1992	14.50	4.20
					1993	14.50	4.20
					1994	14.50	4.20
					1995	14.50	4.20
					1996	14.50	4.20
					1997	14.50	4.20
					1998	14.50	4.20
					1999	14.50	4.20
					2000	14.50	4.20
					2001	14.50	4.20
					2002	14.50	4.20
					2003	14.50	4.20
					2004	14.50	4.20
					2005	14.50	4.20
					2006	14.50	4.20
					2007	14.50	4.20
					2008	14.50	4.20
					2009	14.50	4.20
					2010	14.50	4.20

Car Stock Model						
2. VMT by model year and calendar year						
	New Car	Calendar Year				
Model Yr	VMT	1990	1991	1992	1993	1994
pct Incr		0.00%	-0.85%	-0.40%	-0.03%	0.31%
1960	16,100	3,373	3,175	3,027	2,884	2,747
1961	16,100	3,553	3,345	3,189	3,038	2,894
1962	16,100	3,743	3,523	3,359	3,201	3,049
1963	16,100	3,944	3,712	3,539	3,372	3,212
1964	16,100	4,155	3,910	3,728	3,552	3,383
1965	16,100	4,377	4,119	3,928	3,742	3,564
1966	16,100	4,611	4,340	4,138	3,943	3,755
1967	16,100	4,857	4,572	4,359	4,153	3,956
1968	16,100	5,117	4,816	4,592	4,376	4,167
1969	16,100	5,391	5,074	4,838	4,610	4,390
1970	15,763	5,560	5,233	4,990	4,754	4,528
1971	15,425	5,732	5,395	5,144	4,901	4,668
1972	15,088	5,907	5,559	5,301	5,050	4,810
1973	14,750	6,083	5,726	5,459	5,202	4,954
1974	14,413	6,262	5,894	5,620	5,354	5,100
1975	14,075	6,442	6,064	5,782	5,509	5,246
1976	13,738	6,624	6,235	5,945	5,664	5,395
1977	13,400	6,807	6,407	6,109	5,820	5,543
1978	14,000	7,492	7,052	6,724	6,406	6,101
1979	14,600	8,231	7,747	7,387	7,038	6,703
1980	15,200	9,028	8,497	8,102	7,719	7,352
1981	15,800	9,886	9,305	8,872	8,453	8,051
1982	16,400	10,810	10,175	9,701	9,243	8,803
1983	17,000	11,805	11,111	10,594	10,094	9,614
1984	17,000	12,436	11,705	11,161	10,634	10,128
1985	17,000	13,101	12,331	11,757	11,202	10,669
1986	17,000	13,802	12,991	12,386	11,801	11,240
1987	17,000	14,540	13,685	13,049	12,433	11,841
1988	17,000	15,318	14,417	13,746	13,098	12,474
1989	17,000	16,137	15,188	14,482	13,798	13,141

MPG.XLS

1990	16,900	16,900	15,906	15,166	14,450	13,763
1991	16,900		16,900	15,978	15,223	14,499
1992	16,900			16,900	16,037	15,274
1993	16,900				16,900	16,091
1994	16,900					16,900
1995	16,900					
1996	16,900					
1997	16,900					
1998	16,900					
1999	16,900					
2000	16,900					
2001	16,900					
2002	16,900					
2003	16,900					
2004	16,900					
2005	16,900					
2006	16,900					
2007	16,900					
2008	16,900					
2009	16,900					
2010	16,900					

1995	1996	1997	1998	1999	2000
0.63%	0.96%	1.30%	1.65%	2.00%	2.36%
2,616	2,491	2,373	2,260	2,153	2,051
2,756	2,624	2,500	2,381	2,268	2,160
2,903	2,765	2,633	2,508	2,389	2,276
3,058	2,913	2,774	2,642	2,517	2,398
3,222	3,068	2,922	2,784	2,652	2,526
3,394	3,233	3,079	2,933	2,793	2,661
3,576	3,405	3,243	3,089	2,943	2,803
3,767	3,588	3,417	3,255	3,100	2,953
3,969	3,779	3,600	3,429	3,266	3,111
4,181	3,982	3,792	3,612	3,441	3,277
4,312	4,107	3,911	3,725	3,549	3,380
4,445	4,234	4,032	3,841	3,658	3,485
4,581	4,362	4,155	3,957	3,770	3,591
4,718	4,493	4,279	4,076	3,882	3,698
4,856	4,625	4,405	4,196	3,996	3,807
4,996	4,758	4,532	4,316	4,112	3,917
5,137	4,892	4,660	4,438	4,228	4,027
5,279	5,027	4,788	4,561	4,344	4,138
5,810	5,533	5,270	5,020	4,782	4,555
6,383	6,079	5,790	5,515	5,253	5,004
7,001	6,667	6,350	6,049	5,762	5,488
7,667	7,301	6,954	6,624	6,309	6,010
8,383	7,984	7,604	7,243	6,899	6,572
9,155	8,719	8,304	7,909	7,534	7,177
9,645	9,185	8,748	8,332	7,937	7,560
10,160	9,676	9,216	8,778	8,361	7,965
10,704	10,194	9,709	9,248	8,809	8,391
11,276	10,739	10,228	9,742	9,280	8,839
11,879	11,313	10,775	10,263	9,776	9,312
12,515	11,918	11,351	10,812	10,299	9,810

MPG.XLS

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MPGXLS

MPG.XLS

9,787	9,322	8,880	8,460	8,060	7,680
10,310	9,821	9,355	8,912	8,491	8,090
10,861	10,346	9,856	9,389	8,945	8,523
11,442	10,900	10,383	9,891	9,424	8,979
12,054	11,482	10,938	10,420	9,928	9,459
12,699	12,097	11,523	10,978	10,458	9,965
13,378	12,743	12,139	11,565	11,018	10,498
14,094	13,425	12,789	12,183	11,607	11,059
14,847	14,143	13,473	12,835	12,228	11,651
15,641	14,899	14,193	13,521	12,882	12,274
16,478	15,696	14,952	14,244	13,571	12,930
16,900	16,536	15,752	15,006	14,296	13,622
	16,900	16,594	15,809	15,061	14,350
		16,900	16,654	15,867	15,118
			16,900	16,715	15,926
				16,900	16,778
					16,900

2007	2008	2009	2010
4.99%	5.40%	5.82%	6.25%
1,461	1,392	1,326	1,264
1,539	1,466	1,397	1,332
1,621	1,545	1,472	1,403
1,708	1,627	1,551	1,478
1,799	1,714	1,634	1,557
1,895	1,806	1,721	1,640
1,996	1,903	1,813	1,728
2,103	2,004	1,910	1,821
2,216	2,111	2,012	1,918
2,334	2,224	2,120	2,020
2,408	2,294	2,186	2,084
2,482	2,365	2,254	2,148
2,558	2,437	2,323	2,214
2,634	2,510	2,392	2,280
2,711	2,584	2,462	2,347
2,790	2,658	2,533	2,415
2,868	2,733	2,605	2,483
2,947	2,809	2,677	2,551
3,244	3,091	2,946	2,808
3,564	3,396	3,237	3,085
3,909	3,725	3,550	3,383
4,281	4,079	3,888	3,705
4,681	4,460	4,251	4,052
5,111	4,871	4,642	4,424
5,385	5,131	4,890	4,661
5,673	5,406	5,152	4,910
5,976	5,695	5,427	5,173
6,296	6,000	5,718	5,450
6,633	6,320	6,024	5,741
6,987	6,658	6,346	6,048

7,318	6,973	6,646	6,334
7,709	7,346	7,001	6,673
8,121	7,739	7,376	7,030
8,556	8,153	7,770	7,406
9,013	8,589	8,186	7,802
9,495	9,048	8,623	8,219
10,003	9,532	9,085	8,658
10,538	10,042	9,570	9,121
11,102	10,579	10,082	9,609
11,695	11,145	10,621	10,123
12,321	11,741	11,189	10,665
12,980	12,369	11,788	11,235
13,674	13,030	12,418	11,836
14,405	13,727	13,082	12,469
15,175	14,461	13,782	13,136
15,987	15,235	14,519	13,838
16,842	16,050	15,296	14,578
16,900	16,908	16,114	15,358
	16,900	16,975	16,179
		16,900	17,045
			16,900

Car Stock Model						
3. Fuel Efficiency by Model Year and Calendar Year						
	New Car	Calendar Year				
Model Yr	MPG	1990	1991	1992	1993	1994
1960	13.4	12.5	12.5	12.5	12.5	12.5
1961	13.6	12.7	12.7	12.7	12.7	12.7
1962	14.0	13.1	13.1	13.1	13.1	13.1
1963	12.6	11.8	11.8	11.8	11.8	11.8
1964	13.5	12.6	12.6	12.6	12.6	12.6
1965	13.0	12.1	12.1	12.1	12.1	12.1
1966	13.0	12.1	12.1	12.1	12.1	12.1
1967	12.9	12.1	12.1	12.1	12.1	12.1
1968	12.4	11.6	11.6	11.6	11.6	11.6
1969	12.2	11.4	11.4	11.4	11.4	11.4
1970	12.5	11.7	11.7	11.7	11.7	11.7
1971	12.2	11.4	11.4	11.4	11.4	11.4
1972	12.0	11.2	11.2	11.2	11.2	11.2
1973	11.7	10.9	10.9	10.9	10.9	10.9
1974	13.7	12.8	12.8	12.8	12.8	12.8
1975	13.6	12.7	12.7	12.7	12.7	12.7
1976	14.7	13.8	13.8	13.8	13.8	13.8
1977	15.8	14.8	14.8	14.8	14.8	14.8
1978	16.7	15.7	15.7	15.7	15.7	15.6
1979	17.9	16.8	16.8	16.8	16.8	16.8
1980	20.7	19.5	19.5	19.5	19.4	19.4
1981	22.2	20.9	20.9	20.9	20.9	20.8
1982	23.2	21.9	21.9	21.8	21.8	21.8
1983	23.4	22.2	22.1	22.1	22.0	22.0
1984	23.6	22.4	22.3	22.3	22.3	22.2
1985	23.9	22.7	22.7	22.6	22.6	22.5
1986	24.3	23.2	23.1	23.1	23.0	23.0
1987	24.7	23.7	23.6	23.5	23.4	23.4
1988	25.0	24.2	24.0	23.9	23.8	23.7
1989	24.6	24.3	23.8	23.6	23.5	23.4
1990	24.3	24.3	24.0	23.5	23.3	23.2
1991	24.5		24.5	24.2	23.7	23.5
1992	24.4			24.4	24.1	23.6
1993	24.3				24.3	24.0
1994	24.2					24.2
1995	24.2					
1996	24.1					
1997	24.1					
1998	24.1					
1999	24.0					
2000	24.0					
2001	24.0					
2002	24.0					
2003	24.0					
2004	23.9					
2005	23.9					
2006	23.9					
2007	23.9					
2008	23.9					
2009	23.9					
2010	23.9					

[illegible]

2001	2002	2003	2004	2005	2006
12.5	12.5	12.5	12.5	12.5	12.5
12.7	12.7	12.7	12.7	12.7	12.7
13.1	13.1	13.1	13.1	13.1	13.1
11.8	11.8	11.8	11.8	11.8	11.8
12.6	12.6	12.6	12.6	12.6	12.6
12.1	12.1	12.1	12.1	12.1	12.1
12.1	12.1	12.1	12.1	12.1	12.1
12.1	12.1	12.1	12.1	12.1	12.1
11.6	11.6	11.6	11.6	11.6	11.6
11.4	11.4	11.4	11.4	11.4	11.4
11.7	11.7	11.7	11.7	11.7	11.7
11.4	11.4	11.4	11.4	11.4	11.4
11.2	11.2	11.2	11.2	11.2	11.2
10.9	10.9	10.9	10.9	10.9	10.9
12.8	12.8	12.8	12.8	12.8	12.8
12.7	12.7	12.7	12.7	12.7	12.7
13.7	13.7	13.7	13.7	13.7	13.7
14.8	14.8	14.8	14.8	14.8	14.8
15.6	15.6	15.6	15.6	15.6	15.6
16.7	16.7	16.7	16.7	16.7	16.7
19.3	19.3	19.3	19.3	19.3	19.3
20.7	20.7	20.7	20.7	20.7	20.7
21.7	21.7	21.7	21.7	21.7	21.7
21.9	21.9	21.9	21.9	21.9	21.9
22.1	22.1	22.1	22.1	22.1	22.1
22.4	22.4	22.4	22.3	22.3	22.3
22.8	22.8	22.7	22.7	22.7	22.7
23.2	23.1	23.1	23.1	23.1	23.1
23.5	23.5	23.4	23.4	23.4	23.4
23.1	23.1	23.1	23.1	23.0	23.0
22.9	22.8	22.8	22.8	22.8	22.8
23.1	23.0	23.0	23.0	23.0	23.0
23.0	23.0	22.9	22.9	22.9	22.9
23.0	22.9	22.9	22.9	22.8	22.8
23.0	22.9	22.9	22.8	22.8	22.8
23.0	22.9	22.9	22.8	22.8	22.8
23.0	22.9	22.9	22.8	22.8	22.7
23.0	22.9	22.9	22.8	22.8	22.7
23.1	23.0	22.9	22.8	22.8	22.7
23.3	23.1	23.0	22.9	22.8	22.8
23.7	23.2	23.1	22.9	22.8	22.8
24.0	23.7	23.2	23.0	22.9	22.8
	24.0	23.7	23.2	23.0	22.9
		24.0	23.7	23.2	23.0
			23.9	23.6	23.2
				23.9	23.6
					23.9

2007	2008	2009	2010
12.5	12.5	12.5	12.5
12.7	12.7	12.7	12.7
13.1	13.1	13.1	13.1
11.8	11.8	11.8	11.8
12.6	12.6	12.6	12.6
12.1	12.1	12.1	12.1
12.1	12.1	12.1	12.1
12.1	12.1	12.1	12.1
11.6	11.6	11.6	11.6
11.4	11.4	11.4	11.4
11.7	11.7	11.7	11.7
11.4	11.4	11.4	11.4
11.2	11.2	11.2	11.2
10.9	10.9	10.9	10.9
12.8	12.8	12.8	12.8
12.7	12.7	12.7	12.7
13.7	13.7	13.7	13.7
14.8	14.8	14.8	14.8
15.6	15.6	15.6	15.6
16.7	16.7	16.7	16.7
19.3	19.3	19.3	19.3
20.7	20.7	20.7	20.7
21.7	21.7	21.7	21.7
21.9	21.9	21.9	21.9
22.1	22.1	22.1	22.1
22.3	22.3	22.3	22.3
22.7	22.7	22.7	22.7
23.1	23.1	23.1	23.1
23.4	23.4	23.4	23.4
23.0	23.0	23.0	23.0
22.7	22.7	22.7	22.7
22.9	22.9	22.9	22.9
22.9	22.8	22.8	22.8
22.8	22.8	22.8	22.7
22.8	22.7	22.7	22.7
22.7	22.7	22.7	22.7
22.7	22.7	22.7	22.6
22.7	22.7	22.6	22.6
22.7	22.7	22.6	22.6
22.7	22.7	22.6	22.6
22.7	22.7	22.7	22.6
22.8	22.7	22.7	22.6
22.8	22.7	22.7	22.7
22.9	22.8	22.7	22.7
23.0	22.9	22.8	22.7
23.2	23.0	22.9	22.8
23.6	23.2	23.0	22.8
23.9	23.6	23.2	23.0
	23.9	23.6	23.2
		23.9	23.6
			23.9

LDT Stock Model						
2. VMT by model year and calendar year						
	New LDT		Calendar Year			
Model Yr	VMT	1990	1991	1992	1993	1994
		0.00%	6.83%	7.42%	8.00%	8.57%
1960	16,100	3,373	3,420	3,265	3,116	2,973
1961	16,100	3,553	3,603	3,439	3,283	3,132
1962	16,100	3,743	3,796	3,623	3,458	3,300
1963	16,100	3,944	3,999	3,817	3,643	3,476
1964	16,100	4,155	4,213	4,021	3,838	3,662
1965	16,100	4,377	4,438	4,236	4,043	3,858
1966	16,100	4,611	4,676	4,463	4,259	4,064
1967	16,100	4,857	4,926	4,702	4,487	4,282
1968	16,100	5,117	5,189	4,953	4,727	4,511
1969	16,100	5,391	5,467	5,218	4,980	4,752
1970	15,763	5,560	5,638	5,382	5,136	4,901
1971	15,425	5,732	5,813	5,548	5,295	5,053
1972	15,088	5,907	5,990	5,717	5,456	5,206
1973	14,750	6,083	6,169	5,888	5,619	5,362
1974	14,413	6,262	6,350	6,061	5,785	5,520
1975	14,075	6,442	6,533	6,236	5,951	5,679
1976	13,738	6,624	6,717	6,412	6,119	5,839
1977	13,400	6,807	6,903	6,589	6,288	6,000
1978	14,000	7,492	7,597	7,252	6,921	6,604
1979	14,600	8,231	8,347	7,967	7,604	7,255
1980	15,200	9,028	9,155	8,738	8,339	7,957
1981	15,800	9,886	10,025	9,569	9,132	8,714
1982	16,400	10,810	10,962	10,463	9,986	9,528
1983	17,000	11,805	11,971	11,426	10,905	10,405
1984	17,000	12,436	12,611	12,037	11,488	10,962
1985	17,000	13,101	13,285	12,681	12,102	11,548
1986	17,000	13,802	13,996	13,359	12,750	12,166
1987	17,000	14,540	14,744	14,074	13,432	12,816
1988	17,000	15,318	15,533	14,826	14,150	13,502
1989	17,000	16,137	16,364	15,619	14,907	14,224
1990	16,900	16,900	17,138	16,358	15,612	14,896
1991	16,900		18,054	17,233	16,446	15,693
1992	16,900			18,154	17,326	16,532
1993	16,900				18,253	17,417
1994	16,900					18,348
1995	16,900					
1996	16,900					
1997	16,900					
1998	16,900					
1999	16,900					
2000	16,900					
2001	16,900					
2002	16,900					
2003	16,900					
2004	16,900					
2005	16,900					
2006	16,900					
2007	16,900					
2008	16,900					
2009	16,900					
2010	16,900					

[illegible]

2001	2002	2003	2004	2005	2006
11.77%	12.15%	12.51%	12.86%	13.20%	13.53%
2,126	2,024	1,928	1,836	1,748	1,664
2,239	2,133	2,031	1,934	1,841	1,753
2,359	2,247	2,140	2,037	1,940	1,847
2,485	2,367	2,254	2,146	2,043	1,945
2,618	2,493	2,375	2,261	2,153	2,049
2,758	2,627	2,502	2,382	2,268	2,159
2,906	2,767	2,635	2,509	2,389	2,274
3,061	2,915	2,776	2,644	2,517	2,396
3,225	3,071	2,925	2,785	2,651	2,524
3,397	3,235	3,081	2,934	2,793	2,659
3,504	3,337	3,178	3,026	2,881	2,743
3,612	3,440	3,276	3,120	2,970	2,828
3,722	3,545	3,376	3,214	3,060	2,914
3,833	3,651	3,477	3,311	3,152	3,001
3,946	3,758	3,579	3,408	3,245	3,089
4,060	3,867	3,682	3,506	3,338	3,178
4,174	3,976	3,786	3,605	3,432	3,268
4,289	4,085	3,890	3,704	3,527	3,358
4,721	4,497	4,282	4,077	3,882	3,696
5,187	4,940	4,704	4,479	4,265	4,060
5,689	5,418	5,160	4,913	4,678	4,453
6,230	5,933	5,650	5,380	5,122	4,877
6,812	6,488	6,178	5,883	5,601	5,332
7,439	7,085	6,747	6,424	6,117	5,823
7,837	7,464	7,108	6,768	6,444	6,135
8,256	7,863	7,488	7,130	6,788	6,463
8,697	8,284	7,888	7,511	7,151	6,808
9,162	8,727	8,310	7,913	7,534	7,172
9,652	9,193	8,755	8,336	7,937	7,556
10,169	9,685	9,223	8,782	8,361	7,960
10,649	10,143	9,659	9,197	8,757	8,336
11,219	10,685	10,176	9,689	9,225	8,782
11,819	11,257	10,720	10,207	9,718	9,252
12,451	11,859	11,293	10,753	10,238	9,747
13,117	12,493	11,897	11,328	10,786	10,268
13,819	13,161	12,533	11,934	11,362	10,817
14,558	13,865	13,204	12,572	11,970	11,396
15,336	14,606	13,910	13,245	12,610	12,005
16,156	15,388	14,654	13,953	13,285	12,647
17,020	16,211	15,437	14,699	13,995	13,324
17,931	17,078	16,263	15,485	14,744	14,036
18,890	17,991	17,133	16,314	15,532	14,787
	18,953	18,049	17,186	16,363	15,578
		19,014	18,105	17,238	16,411
			19,074	18,160	17,288
				19,131	18,213
					19,187

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2007	2008	2009	2010
13.86%	14.17%	14.48%	14.79%
1,584	1,508	1,435	1,366
1,669	1,588	1,512	1,439
1,758	1,673	1,593	1,516
1,852	1,763	1,678	1,597
1,951	1,857	1,768	1,682
2,055	1,956	1,862	1,772
2,165	2,061	1,962	1,867
2,281	2,171	2,067	1,967
2,403	2,287	2,177	2,072
2,531	2,410	2,294	2,183
2,611	2,485	2,366	2,251
2,692	2,562	2,439	2,321
2,774	2,640	2,513	2,392
2,857	2,719	2,588	2,463
2,940	2,799	2,664	2,536
3,025	2,880	2,741	2,609
3,111	2,961	2,818	2,682
3,196	3,043	2,896	2,756
3,518	3,349	3,187	3,034
3,865	3,679	3,502	3,333
4,239	4,035	3,841	3,656
4,642	4,419	4,206	4,003
5,076	4,832	4,599	4,377
5,543	5,276	5,022	4,780
5,840	5,559	5,291	5,036
6,152	5,856	5,574	5,305
6,481	6,169	5,872	5,589
6,828	6,499	6,186	5,888
7,193	6,847	6,517	6,203
7,577	7,213	6,865	6,534
7,936	7,554	7,190	6,843
8,360	7,958	7,574	7,209
8,807	8,383	7,980	7,595
9,278	8,832	8,406	8,001
9,775	9,304	8,856	8,429
10,297	9,802	9,330	8,880
10,848	10,326	9,828	9,355
11,428	10,878	10,354	9,855
12,039	11,460	10,908	10,382
12,683	12,073	11,491	10,937
13,362	12,719	12,106	11,522
14,076	13,399	12,753	12,138
14,829	14,115	13,435	12,787
15,622	14,870	14,154	13,471
16,457	15,665	14,911	14,192
17,338	16,503	15,708	14,951
18,265	17,386	16,548	15,750
19,242	18,316	17,433	16,593
	19,295	18,366	17,480
		19,348	18,415
			19,400

LDT Stock Model						
3. Fuel Efficiency by Model Year and Calendar Year						
	New Car	Calendar Year				
Model Yr	MPG	1990	1991	1992	1993	1994
1960	8.4	7.9	7.9	7.9	7.9	7.9
1961	8.6	8.0	8.0	8.0	8.0	8.0
1962	8.8	8.2	8.2	8.2	8.2	8.2
1963	9.1	8.5	8.5	8.5	8.5	8.5
1964	9.3	8.7	8.7	8.7	8.7	8.7
1965	9.5	8.9	8.9	8.9	8.9	8.9
1966	9.6	9.0	9.0	9.0	9.0	9.0
1967	9.9	9.3	9.3	9.3	9.3	9.3
1968	10.3	9.6	9.6	9.6	9.6	9.6
1969	10.3	9.6	9.6	9.6	9.6	9.6
1970	10.5	9.8	9.8	9.8	9.8	9.8
1971	10.8	10.1	10.1	10.1	10.1	10.1
1972	11.0	10.3	10.3	10.3	10.3	10.3
1973	11.2	10.5	10.5	10.5	10.5	10.5
1974	11.9	11.1	11.1	11.1	11.1	11.1
1975	12.1	11.3	11.3	11.3	11.3	11.3
1976	11.9	11.2	11.2	11.1	11.1	11.1
1977	13.4	12.6	12.6	12.6	12.5	12.5
1978	13.1	12.3	12.3	12.3	12.3	12.3
1979	13.7	12.9	12.9	12.9	12.9	12.8
1980	15.2	14.3	14.3	14.3	14.3	14.3
1981	16.6	15.7	15.6	15.6	15.6	15.6
1982	16.9	16.0	15.9	15.9	15.9	15.9
1983	17.4	16.5	16.4	16.4	16.4	16.4
1984	17.1	16.2	16.2	16.2	16.1	16.1
1985	17.5	16.7	16.6	16.6	16.5	16.5
1986	17.7	16.9	16.8	16.8	16.8	16.7
1987	17.8	17.1	17.0	16.9	16.9	16.9
1988	17.6	17.0	16.9	16.8	16.7	16.7
1989	17.3	17.1	16.7	16.6	16.5	16.5
1990	17.2	17.2	17.0	16.7	16.5	16.4
1991	18.7		18.7	18.5	18.1	18.0
1992	18.7			18.7	18.5	18.1
1993	18.7				18.7	18.5
1994	18.7					18.7
1995	18.7					
1996	18.7					
1997	18.7					
1998	18.7					
1999	18.7					
2000	18.7					
2001	18.7					
2002	18.7					
2003	18.7					
2004	18.7					
2005	18.7					
2006	18.7					
2007	18.7					
2008	18.7					
2009	18.7					
2010	18.7					

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[illegible]

2001	2002	2003	2004	2005	2006
7.9	7.9	7.9	7.9	7.9	7.9
8.0	8.0	8.0	8.0	8.0	8.0
8.2	8.2	8.2	8.2	8.2	8.2
8.5	8.5	8.5	8.5	8.5	8.5
8.7	8.7	8.7	8.7	8.7	8.7
8.9	8.9	8.9	8.9	8.9	8.9
9.0	9.0	9.0	9.0	9.0	9.0
9.3	9.3	9.3	9.3	9.3	9.3
9.6	9.6	9.6	9.6	9.6	9.6
9.6	9.6	9.6	9.6	9.6	9.6
9.8	9.8	9.8	9.8	9.8	9.8
10.1	10.1	10.1	10.1	10.1	10.1
10.3	10.3	10.3	10.3	10.3	10.3
10.5	10.5	10.5	10.5	10.5	10.5
11.1	11.1	11.1	11.1	11.1	11.1
11.3	11.3	11.3	11.3	11.3	11.3
11.1	11.1	11.1	11.1	11.1	11.1
12.5	12.5	12.5	12.5	12.5	12.5
12.2	12.2	12.2	12.2	12.2	12.2
12.8	12.8	12.8	12.8	12.8	12.8
14.2	14.2	14.2	14.2	14.2	14.2
15.5	15.5	15.5	15.5	15.5	15.5
15.8	15.8	15.8	15.8	15.8	15.8
16.3	16.3	16.3	16.3	16.3	16.3
16.0	16.0	16.0	16.0	16.0	16.0
16.4	16.4	16.4	16.4	16.4	16.4
16.6	16.6	16.6	16.6	16.5	16.5
16.7	16.7	16.7	16.7	16.7	16.6
16.5	16.5	16.5	16.5	16.5	16.5
16.3	16.2	16.2	16.2	16.2	16.2
16.2	16.2	16.2	16.1	16.1	16.1
17.6	17.6	17.6	17.6	17.5	17.5
17.6	17.6	17.6	17.6	17.6	17.5
17.7	17.6	17.6	17.6	17.6	17.6
17.7	17.7	17.6	17.6	17.6	17.6
17.7	17.7	17.7	17.6	17.6	17.6
17.8	17.7	17.7	17.7	17.6	17.6
17.9	17.8	17.7	17.7	17.7	17.6
18.0	17.9	17.8	17.7	17.7	17.7
18.1	18.0	17.9	17.8	17.7	17.7
18.5	18.1	18.0	17.9	17.8	17.7
18.7	18.5	18.1	18.0	17.9	17.8
	18.7	18.5	18.1	18.0	17.9
		18.7	18.5	18.1	18.0
			18.7	18.5	18.1
				18.7	18.5
					18.7

LDT_MPG.XLS

2007	2008	2009	2010
7.9	7.9	7.9	7.9
8.0	8.0	8.0	8.0
8.2	8.2	8.2	8.2
8.5	8.5	8.5	8.5
8.7	8.7	8.7	8.7
8.9	8.9	8.9	8.9
9.0	9.0	9.0	9.0
9.3	9.3	9.3	9.3
9.6	9.6	9.6	9.6
9.6	9.6	9.6	9.6
9.8	9.8	9.8	9.8
10.1	10.1	10.1	10.1
10.3	10.3	10.3	10.3
10.5	10.5	10.5	10.5
11.1	11.1	11.1	11.1
11.3	11.3	11.3	11.3
11.1	11.1	11.1	11.1
12.5	12.5	12.5	12.5
12.2	12.2	12.2	12.2
12.8	12.8	12.8	12.8
14.2	14.2	14.2	14.2
15.5	15.5	15.5	15.5
15.8	15.8	15.8	15.8
16.3	16.3	16.3	16.3
16.0	16.0	16.0	16.0
16.4	16.4	16.4	16.4
16.5	16.5	16.5	16.5
16.6	16.6	16.6	16.6
16.4	16.4	16.4	16.4
16.2	16.2	16.2	16.2
16.1	16.1	16.1	16.1
17.5	17.5	17.5	17.5
17.5	17.5	17.5	17.5
17.5	17.5	17.5	17.5
17.6	17.5	17.5	17.5
17.6	17.6	17.5	17.5
17.6	17.6	17.6	17.5
17.6	17.6	17.6	17.6
17.6	17.6	17.6	17.6
17.7	17.6	17.6	17.6
17.7	17.7	17.6	17.6
17.7	17.7	17.7	17.6
17.8	17.7	17.7	17.7
17.9	17.8	17.7	17.7
18.0	17.9	17.8	17.7
18.1	18.0	17.9	17.8
18.5	18.1	18.0	17.9
18.7	18.5	18.1	18.0
	18.7	18.5	18.1
		18.7	18.5
			18.7

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