U.S. Department of
Transportation
**Federal Highway
Administration**

Transportation and Global Climate Change:

A Review and Analysis of the Literature

TRANSPORTATION AND GLOBAL CLIMATE CHANGE: A REVIEW AND ANALYSIS OF THE LITERATURE

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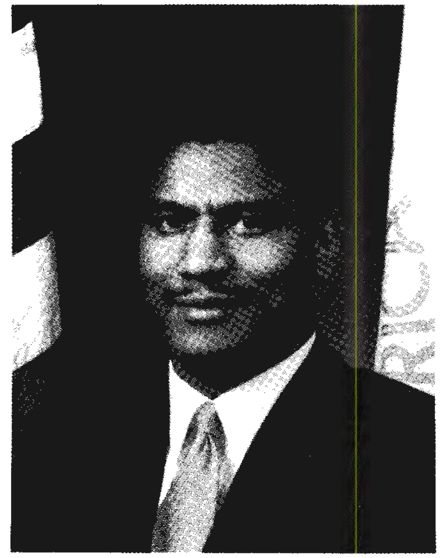
FOREWORD BY SECRETARY OF TRANSPORTATION RODNEY E. SLATER



Under President Clinton and Vice President Gore's stewardship, we have made great progress in preserving our natural heritage. Our air is cleaner, and our water purer. Magnificent old-growth forests are being spared, and endangered species protected. Critical resources are being conserved, and scenic vistas preserved. Much has been achieved, and yet much more needs to be done.

Perhaps the greatest environmental challenge we face is global climate change. The world's most respected scientists agree that the threat is real and that the potential impacts are significant: extreme weather, ranging from heat waves and droughts to severe storms and floods; rising sea levels which could inundate our coastal cities; and damage to agriculture and to entire ecosystems.

The long time required for change demands that we take immediate action, and President Clinton and Vice President Gore have stepped to the plate. In December 1997, they led the way to an historic agreement in Kyoto, Japan, demonstrating their support for market incentives and new technologies that will reduce the greenhouse gas emissions which contribute to climate change. Congress must ratify the Kyoto Protocol before United States implementation of this important agreement may begin.

The President also proposed tax cuts and research to encourage energy-efficient technologies and clean sources of energy here in the United States. In transportation, we are already developing clean, fuel-efficient cars and trucks and promoting transit ridership.

We want to build on these early steps with balanced, reasonable transportation strategies which will protect our environment while continuing to promote mobility and the economic growth it supports.

This report provides an overview of the issues surrounding climate change and summarizes transportation solutions currently being debated around the world. I hope that it will inspire serious discussion and analysis, so that we can find the measures which best meet our needs.

Over the past generation, we have persevered to find ways to protect our environment and to enhance our economy at the same time. As we face the challenges of global climate change, I am confident that working together we will continue to do all that is required to safeguard our earth.

Sincerely,

Rodney E. Slater

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1 Introduction

1.1 Background on Global Climate Change

The composition of the Earth's atmosphere is a primary determinant of the planet's temperature, which in turn affects all life on Earth. Greenhouse gases occur naturally and trap heat within the atmosphere, helping to keep the planet hospitable to life. The main greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (such as chlorofluorocarbons, or CFCs). According to the US Department of Energy (DOE), concentrations of greenhouse gases in the atmosphere have noticeably increased over the past one hundred years.[1]

Global climate change—often referred to as "global warming"—involves an increase in the average atmospheric temperature of the Earth. Such a temperature increase does not mean that temperatures will rise by a few degrees in all locations around the world. Rather, were global warming to occur, increases in atmospheric and oceanic temperatures might raise sea levels and alter associated weather patterns, which in turn could increase the frequency and severity of extreme weather worldwide. Such changes would likely alter current patterns of land use and human activity, as well as ecosystems and natural habitat.[2]

The ability to reliably predict global climate change involves some uncertainties with regard to magnitude, timing, and location.[3] However, the Intergovernmental Panel on Climate Change (IPCC), a group of the world's leading scientists, believes the increase in atmospheric concentrations in part can be attributed to human activities, such as emissions of greenhouse gases and deforestation.[4] The IPCC and many scientists believe that global climate change and its potentially disruptive effects are likely to occur unless we reduce greenhouse gas emissions.[5]

Despite the uncertainties as to the metes and bounds of future global climate change, including rising sea level and increased potential for drought, numerous governments agree that the risk of inaction is sufficient to justify nations to take action. At a conference held in December 1997 in Kyoto, Japan, the Parties to the UN Framework Convention on Climate Change (developed during the "Earth Summit" in Rio de Janeiro in June 1992) agreed to an historic Protocol calling for binding emission targets for developed nations to reduce greenhouse gas emissions.

The Kyoto Protocol in key respects reflects proposals advanced by the United States. In particular, the Protocol allows for the use of international emissions trading, in which countries or companies can purchase less expensive emissions permits from countries that have room to spare in meeting their targets. This market-based approach, pioneered in the US, should allow countries to seek out the cheapest emissions reductions, substantially lowering costs of compliance. In addition, emission targets are to be reached over a five-year budget period, as proposed by the US (the first budget period being 2008-2012), rather than by a single year. Emissions targets include six major greenhouse gases, and activities that absorb carbon, such as planting trees, can be used to offset emission targets.

Continuing policy development is likely to place additional analytical demands on Federal agencies, including the Department of Transportation (DOT), as the US government moves from general support to specific policies and activities to achieve targets. A global greenhouse gas trading program poses additional analytical challenges. If the US experience in other emissions trading programs holds true under global trading of greenhouse gases, the amount of reductions achieved by the US or the transportation sector could change from what it might have been under a no-trading scenario. A trading program for greenhouse gas reductions could provide another alternative to measures such as those discussed in Chapter 5 of this report. Rules and guidelines for verification, reporting, and accountability are to be discussed at the next meeting of the Parties at Buenos Aires in November 1998.

1.2 Purpose

This report provides a discussion of the relationship between transportation and global climate change, based on peer-reviewed literature and research findings. The report presents an overview of policy debates, scientific conclusions, unresolved issues, and strategies available as potential solutions. The principle focus of the report is to better identify an array of tools and highlight aspects of these tools that may be useful to DOT as it begins to develop a strategy for addressing the link between transportation and climate change.

The overall purpose of the report is to provide an overview of global climate change and review how transportation agencies may assist in reducing CO_2 and other greenhouse gas emissions from transportation sources. Federal, state, and local transportation and air quality agencies have already made advances toward attainment of the national ambient air quality standards, but have not yet pursued mitigation of greenhouse gases, since no legal/administrative approaches have yet become finalized.

This report is organized in four primary sections:

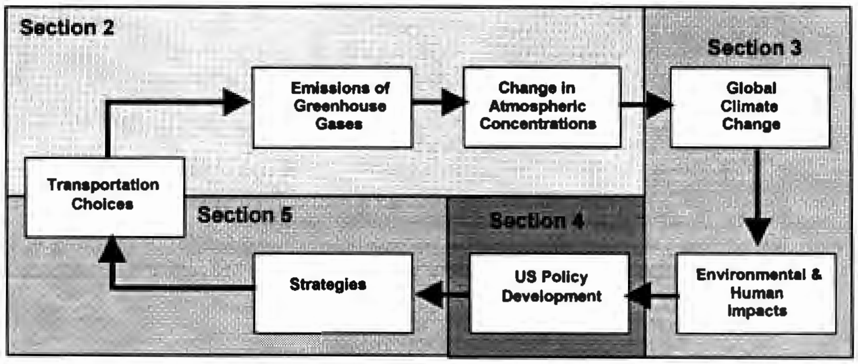
- Inventories of Emissions and Concentrations—The report begins by describing the sources of emissions and data on greenhouse gas concentrations; this section addresses the questions, how much are we emitting? What are the sources? What are the atmospheric concentrations?
- Potential Impacts of Global Climate Change—This section highlights the state of scientific knowledge regarding impacts, and addresses the questions, what may be happening? Should we care?
- Developments in Global Climate Change Policy—This section summarizes recent international and domestic debates and policies regarding climate change. It addresses the question, what is the global and national context in which to consider specific strategies to reduce emissions?
- Strategies to Reduce Greenhouse Gas Emissions—This section highlights strategies relevant to reducing emissions from the transportation sector; it addresses the questions, what are we currently doing to address greenhouse gas emissions? What alternative strategies exist?

The strategies discussed within this report focus predominantly on highway transportation associated with personal travel in single occupant vehicles (SOVs). This is done simply because there is more peer-reviewed literature on this subject in terms of vehicle technology and driver behavior; other strategies may prove to be as effective or more so upon implementation. In addition, more information is currently available regarding energy consumption and greenhouse gas emissions related to highway transportation.

An annotated bibliography (Appendix C) allows the reader to refer to some of the major publications on the subject.

The primary sections of this report are identified in the following exhibit, which outlines a framework for examining the issues related to transportation and potential global climate change.

Exhibit 1-1. Framework for Examining Transportation and Potential Global Climate Change



This framework is useful for characterizing the potential linkages between activities, emissions, and global climate change. Debate focuses around the certainty regarding links between boxes. Scientific debate concerns the links between anthropogenic emissions and changes in atmospheric concentrations of greenhouse gases, the effects of atmospheric concentrations on global climate, and the consequences of changes in global climate on the environment and human activity. Policy debate centers on the effectiveness of various strategies at reducing emissions, the costs and feasibility of pursuing particular actions, and the setting of proper targets. This report begins with a preliminary discussion of the issues pertaining to greenhouse gas emissions inventories and concentrations.

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[1] *See, e.g.,* US Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, *Emissions of Greenhouse Gases in the United States, 1987-1994* (Pittsburgh, PA: US Government Printing Office, October 1995), p. 2.

[2] *See, e.g.,* US Congress Office of Technology Assessment, *Preparing for an Uncertain Climate, Vol. I, II* (Washington, DC: US Government Printing Office, 1993), for a discussion of the range of potential impacts from climate change.

[3] *See, e.g.,* George C. Marshall Institute, *Are Human Activities Causing Global Warming?* (April 1996). (US DOE, 1995, pp.2-3).

[4] Intergovernmental Panel on Climate Change, *Second Scientific Assessment of Climate Change, Summary and Report,* World Meteorological Organization/UN Environment Program (Cambridge, UK: Cambridge University Press, 1995).

[5] *See, e.g.* US Environmental Protection Agency, *Policy Options for Stabilizing Global Climate: Report to* Congress, EPA No. 21P-2003.1 (December 1990); Intergovernmental Panel on Climate Change, *Second Scientific Assessment of Climate Change, Summary and Report,* World Meteorological Organization/US Environment Program (Cambridge, UK: Cambridge University Press, 1995).

2 Emissions Inventories and Atmospheric Concentrations

Greenhouse gases trap heat within the atmosphere. While most greenhouse gases occur naturally and serve to keep the Earth hospitable to life, they are also generated by human activities. Naturally occurring greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Man-made activities have produced additional emissions of CO_2, methane, nitrous oxide, and the precursors to ozone (NO_x, VOCs), as well as the production of entirely new "engineered" chemicals, such as halocarbons and related compounds including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), which are powerful greenhouse gases. As these gases are emitted into the atmosphere, the concentration of greenhouse gases changes. An increase in the concentrations of greenhouse gases suggests that increasing levels of emissions are altering the earth's atmosphere.

Central to any study of climate change is the understanding of concentrations and emissions inventories, which identify the primary sources and sinks of greenhouse gases.[i] Two of the most commonly referenced sources of data on greenhouse gas emissions in the United States are *Emissions of Greenhouse Gases in the United States*, published by the US Department of Energy (DOE) and *Inventory of US Greenhouse Gas Emissions and Sinks*, by the US Environmental Protection Agency (EPA). Both publications compile a broad range of information, and much of the information presented in this chapter refers to data presented in these two documents.

Measuring greenhouse gas concentrations is a fairly reliable procedure, as concentrations are directly measured using air samples. However, emissions inventories have inherent limitations in their accuracy since emissions cannot be directly measured at a national level and must be estimated. As a result, greenhouse gas emissions inventories are calculated based on available data and methodologies, just as emissions of criteria pollutants—such as NO_x and VOC—are estimated based on specific methodologies.

The calculation of CO_2 emissions from fossil fuels is straightforward: emissions are calculated by multiplying reported energy consumption by the estimated carbon content of fossil fuels. According to the DOE, this is a fairly reliable estimate since energy statistics and estimates of carbon content are probably accurate within a few percent.[1] Methane and nitrous oxide emissions estimates are much more uncertain since they are generally inferred by extrapolating experiments conducted on a small number of samples across a large national population. Detailed methodologies for estimating emissions are presented in *Emissions of Greenhouse Gases in the United States*, published by the US DOE.

2.1 Units for Measuring Emissions

Emissions of carbon dioxide are usually reported in terms of million metric tons of carbon equivalent (mmtCE) in US DOE and EPA publications.[ii] Carbon units are defined as the weight of the carbon content of carbon dioxide (i.e., just the "C" in CO_2). Carbon units are the most common measure by the

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[i] Sinks are natural features such as forests and oceans that absorb greenhouse gases from the atmosphere.

[ii] In addition, CO_2 emissions are reported in carbon equivalent units by the US Department of Transportation in *Transportation Statistics Annual Report 1995* (BTS, p. 79) and in the US *Climate Change Action Plan* submitted under the United Nations Framework Convention on Climate Change.

scientific community since not all carbon from combustion is emitted in the form of carbon dioxide and carbon units are more convenient for comparisons with data on fuel consumption and carbon sequestration.[2] Emissions of other greenhouse gases are often reported in terms of the full molecular weight of the gas but may be converted into a "carbon equivalent." [iii]

2.2 Anthropogenic and Biogenic Sources

The majority of greenhouse gases are emitted from natural (biogenic) sources, while human activities (anthropogenic sources) generate smaller amounts of greenhouse gases. Powerful natural mechanisms absorb these gases from the atmosphere. Estimates of global emissions are presented in Exhibit 2-1.

Exhibit 2-1. Global Natural and Anthropogenic Sources and Absorption of Greenhouse Gases

Gas	Biogenic Sources	Anthropogenic Sources	Absorption	Annual Increase in Gas in Atmosphere
CO_2 (mmtCE)	150,000	7,100	154,000	3,100–3,500
CH_4 (mmt gas)	110-210	300-450	460-660	35–40
N_2O (mmt gas)	6-12	4-8	13-20	3–5

Source: US Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1995*, p. 3, citing ranges from Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996).

According to data from the US Department of Energy presented in Exhibit 2-1, carbon dioxide is by far the most prevalent greenhouse gas emitted into the atmosphere aside from water vapor. Increasing concentrations of CO_2, CH_4, and N_2O in the atmosphere indicate that more gases are being emitted than absorbed each year, despite the ability of natural mechanisms to absorb greenhouse gases. Records from the Antarctic ice core reveal that the carbon cycle has been in a state of imbalance for the past 200 years, with emissions of carbon dioxide exceeding absorption capacities.[3]

Both naturally-occurring and human-induced greenhouse gas emissions arise from a variety of processes and activities. The following list is summarized from US DOE's 1995 report.[4]

Biogenic Sources

Carbon Dioxide

CO_2 is a common compound on Earth. Large quantities can be found in the atmosphere, in soils, in carbonate rocks, and dissolved in ocean water. All life on earth participates in the "carbon cycle:" CO_2 is extracted from the air by plants and the carbon is incorporated into plant biomass, and the oxygen is then released to the atmosphere; plant biomass ultimately decays (oxidizes), releasing CO_2 back into the atmosphere or storing organic carbon in soil or rock. Primary sources of carbon dioxide include: the oceans (100 billion metric tons per year), aerobic decay of vegetation (30 billion metric tons), and plant and animal respiration (30 billion metric tons).

[iii] Carbon dioxide units at full molecular weight can be converted into carbon units by dividing by 3.67, or multiplying by 12/44 (the weight of the carbon content of CO_2). Emissions of other gases, such as methane, can also be measured in "carbon equivalents" by multiplying their emissions (in metric tons) by their global warming potential and then dividing by 3.67.

Methane

Methane (CH_4) is also a common compound, though the methane cycle is not understood as well as the carbon cycle. Known biogenic sources of methane include anaerobic decay of vegetation, emissions from animal sources, and several other sources.

Nitrous Oxide

The sources and absorption of N_2O are much more speculative than those for other greenhouse gases. The principal biogenic sources are thought to be bacterial breakdown of nitrogen in soils and fluxes from ocean upwellings. The most important sink is thought to be decomposition in the stratosphere.

ANTHROPOGENIC SOURCES

Carbon Dioxide

The primary human source of CO_2 is the combustion of fossil fuels, which accounts for about three-quarters of total anthropogenic emissions of carbon worldwide. Fossil fuels are consumed for transportation, industrial processes, and residential purposes.

Methane

Principal anthropogenic sources are agricultural practices, including the burning of crop residue and animal husbandry, leakages from the production of fossil fuels, anaerobic decay in landfills, and the use of domesticated animals in ranching.

Nitrous Oxide

Primary human-made sources are application of nitrogen fertilizers, combustion of fuels, and certain industrial processes.

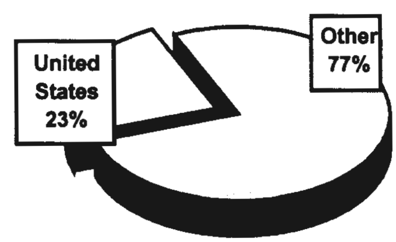
2.3 US CONTRIBUTION TO WORLD EMISSIONS

The US is currently the world's leading emitter of carbon dioxide. As shown in Exhibit 2-2, the US accounts for about 23 percent of global energy-related carbon emissions.

The US Energy Information Administration projects that carbon emissions will increase throughout the world in future years, with continued growth in energy consumption in developing countries as they become more industrialized.[5]

The US share of methane and nitrous oxide emissions, although uncertain, is likely to be much lower than its share of CO_2 emissions, since the principal sources of these emissions are more prevalent outside the US. The US share of

Exhibit 2-2. US Carbon Emissions as a Percent of World Emissions



Source: US DOE/EIA, Emissions of Greenhouse Gases in the United States, 1995. (Pittsburgh, PA: US Government Printing Office, 1996), p. 8.

halocarbons and other engineered gases is likely to be much larger than 23 percent since the use of cooling and refrigeration equipment is more common in the US than elsewhere in the world.[6]

According to estimates from the US Department of Energy presented in Exhibit 2-3, emissions of greenhouse gases from the United States (based on global warming potential) are estimated to have risen by about four percent between 1990 to 1994. During this four year period, methane and halocarbons levels remained constant or decreased slightly. DOE postulated that the reduction in methane during the early 1990s could have resulted from the decline in underground coal mine production and the increased proliferation of glass and paper recycling that has reduced the volume of trash being landfilled, hence reducing methane emissions from landfills.

Exhibit 2-3. US Emissions of Greenhouse Gases, Based on Global Warming Potential, 1988-1995 (million metric tons of Carbon Equivalent)

Gas	1988	1989	1990	1991	1992	1993	1994	1995p
Carbon Dioxide	1375	1384	1372	1359	1380	1405	1431	1442
Methane	177	177	179	180	180	174	178	NA
Nitrous Oxide	36	38	38	38	38	39	40	39
HFCs and PFCs	19	20	19	19	21	20	23	25
Total	**1606**	**1619**	**1608**	**1596**	**1619**	**1638**	**1672**	**NA**

p=preliminary

Source: US DOE/EIA, *Emissions of Greenhouse Gases in the United States, 1995.* (Pittsburgh, PA: US Government Printing Office, 1996), p. xi.

Carbon dioxide is the most significant greenhouse gas emitted by human sources, principally because of its abundance. Exhibit 2-3 shows that in 1994, the 1431 million metric tons of carbon dioxide emitted comprised about 86 percent of the 1672 million metric tons of carbon equivalent emitted by the US overall.

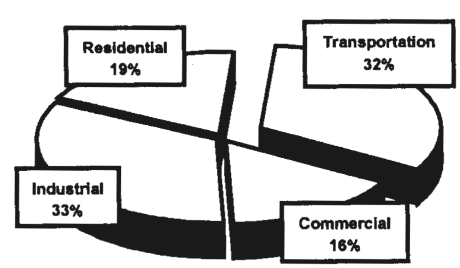
According to DOE, the burning of fossil fuels causes approximately 98.5 percent of anthropogenic carbon dioxide. Due to the economic value of fossil fuels, their consumption is carefully monitored, thus energy-related carbon dioxide emissions can be estimated more reliably than other emissions.[7]

2.4 Transportation Sector Contribution

The transportation sector accounted for about 32 percent of US carbon dioxide emissions in 1990 (See Exhibit 2-4), and it is expected to be the fastest growing source of greenhouse gas emissions through the year 2000.[8]

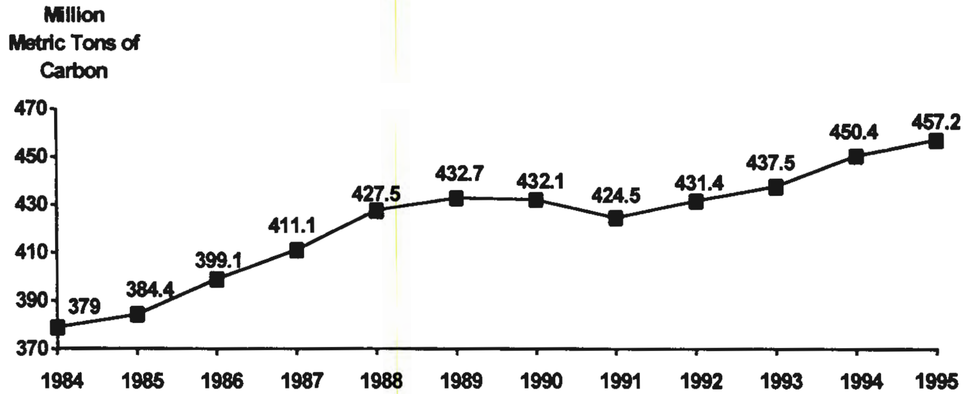
Carbon dioxide emissions from transportation have been increasing, as fuel consumption by transportation sources has grown. Carbon dioxide emissions from the transportation sector accounted for nearly 40 percent of the 25 million metric ton increase in energy-related carbon emissions since 1990, while the industrial and commercial sectors accounted for most of the remainder.[9]

Exhibit 2-4. US Carbon Dioxide Emissions from Fossil Fuels in 1995



Source: US DOE/EIA. *Emissions of Greenhouse Gases in the United States, 1995.* (Pittsburgh, PA: US Government Printing Office, 1996).

Exhibit 2-5. US Carbon Dioxide Emissions from Transportation Sector, 1984-1995



p=preliminary

Source: US DOE/EIA. *Emissions of Greenhouse Gases in the United States, 1995.* (Pittsburgh, PA: US Government Printing Office, 1996), p. 18.

Exhibit 2-5 above illustrates that emissions from the transportation sector are growing rapidly due to increased demand for motor gasoline, jet fuel, and diesel fuel. Transportation sector emissions have grown more rapidly than other sources over the past ten years, and transportation is projected to be the fastest growing sector in the near future.[iv] Historically, improvements in average fuel economy have curtailed some growth in transportation sector emissions that would have occurred given large increases in travel. However, the growing popularity of luxury cars, trucks, and recreational vehicles stabilized the US average fuel economy for all motor vehicles.[10]

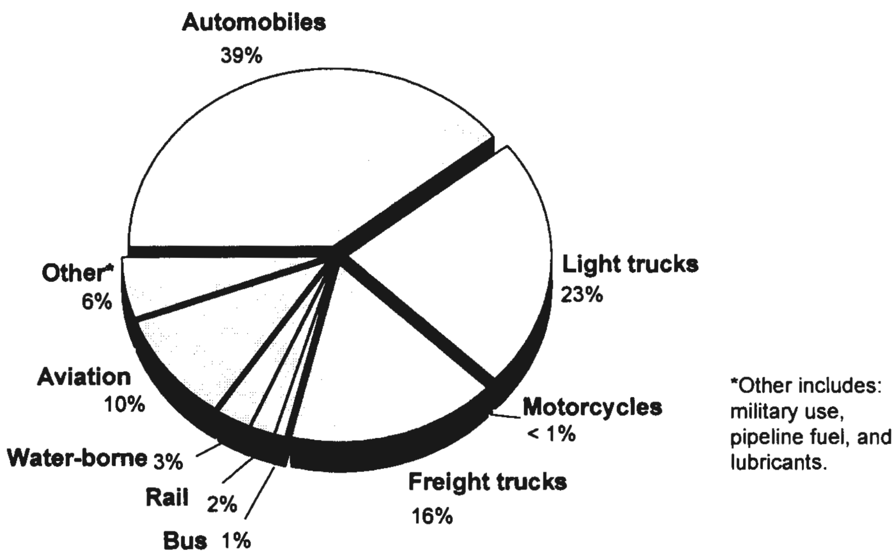
In addition to generating carbon dioxide emissions, DOE notes the transportation sector as responsible for about 31 percent of US nitrous oxide emissions, with the remainder stemming from agricultural and industrial sources.[11] Transportation is also responsible for less than one percent of US methane emissions, with the majority of methane emissions stemming from agricultural sources, landfills, coal mining, and oil and gas production.[12]

2.5 Modal Contribution

Despite the importance of carbon dioxide as the most significant anthropogenic greenhouse gas emission, there is relatively little published information on the contribution of various transportation modes to national CO_2 emissions. Inventories published by the US DOE and the US Environmental Protection Agency (EPA) only break down the transportation sector's emissions by fuel, not mode of transportation. The contribution of specific mobile sources to CO_2 emissions can be estimated based on fuel consumption information contained in US DOE's *Supplement to the Annual Energy Outlook, 1997,* as shown in Exhibit 2-6. Carbon dioxide emissions are a function of fuel use (Refer to Appendix A for a discussion of CO_2 emissions calculation and data sources).

[iv] Between 1985 and 1995, US carbon dioxide emissions grew by the following percent within each sector: transportation—18.9 percent; industrial—9.1 percent; residential—10.2 percent; commercial—15.2 percent (US DOE/EIA, *Emissions of Greenhouse Gases in the United States, 1995.* Pittsburgh, PA: US Government Printing Office, 1996,. pp.17-18). EIA's *Annual Energy Outlook, 1997* (December 1996, pp. 97-98) projects that transportation will be the fastest growing sector in terms of energy consumption, from 1995 to 2005.

Exhibit 2-6. Estimated US Carbon Dioxide Emissions from Mobile Sources, 1995



Source: Grant, M., M. Corrales, and D. Guruswamy. "Carbon Dioxide Emissions from Transportation by Mode and Submode: Estimates and Implications for Policy Development." Paper presented to Air & Waste Management Conference, Emissions Inventory: Planning for the Future, Research Triangle Park, NC: October 1997.

Exhibit 2-6 does not include carbon dioxide emissions from international bunker fuels, which are fuels purchased by merchant ships and international air carriers in the US. Under the Framework Convention, energy data used by the International Energy Agency exclude bunker fuels from national inventories. As Exhibit 2-6 shows, the majority of transportation-sector carbon dioxide emissions stem from light-duty vehicles, which include automobiles, light trucks, and motorcycles. Based on similar data from the *Annual Energy Outlook 1995*, the Policy Dialogue Advisory Committee asserted that reducing carbon emissions from personal motor vehicles could significantly contribute to overall reduction of greenhouse gases.[13]

Freight trucks contribute about 16 percent of emissions, so that on-road mobile sources contribute nearly 80 percent of all transportation emissions. Non-road sources are not insignificant. In particular, aviation contributes about 10 percent of transportation emissions, and projections suggest that aviation will be the fastest growing mode in terms of energy consumption and carbon dioxide emissions.[14]

According to DOE estimates, nearly half of mobile-source methane emissions in 1994 in the US were generated by passenger cars.[v] The combination of passenger cars and light-duty trucks comprised 75 percent of mobile sources of methane in 1994.[15] In addition, nitrous oxide emissions from mobile sources were estimated to be 145,000 metric tons in 1995, and DOE approximates that 88 percent of these emissions can be attributed to motor vehicles.[16]

According to energy projections through 2010 from US DOE's *Annual Energy Outlook 1997*, light trucks and aviation will comprise a growing share of transportation emissions. An explanation for the increase in light-duty truck emissions is the increasing use of mini-vans, recreational trucks, and other sport utility vehicles. Light trucks comprised 41 percent of light-duty vehicle sales in 1997, up from 17 percent in 1972, and are projected to be a growing portion of the in-use light duty vehicle fleet.[17] Such vehicles

[v] Mobile sources are responsible for less than one percent of methane emissions in the US (US DOE, /EIA, *Emissions of Greenhouse Gases in the United States, 1995*. Pittsburgh, PA: US Government Printing Office, 1996, Table 16, p. 31).

are not subject to the same fuel economy standards as automobiles. Thus, the increase in their use is an important consideration when examining strategies to reduce emissions in the transportation sector.

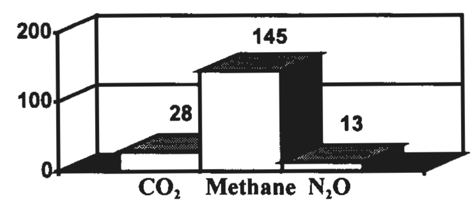
In addition to changes in the share of emissions from each transportation source, the total pie is projected to increase rapidly. Transportation CO_2 emissions are projected to grow by about 25 percent between 1995 and 2010, according to energy consumption estimates from the reference case in the Annual Energy Outlook 1997. Aviation is projected to be the fastest growing mode. Still, light-duty vehicles are projected to contribute the majority of the tonnage increase since they comprise a much larger portion of the emissions inventory. Among light-duty vehicles, nearly all of the emissions growth comes from light duty trucks, rather than automobiles.

Carbon dioxide emission growth projections depend heavily on assumptions about fuel prices, economic growth, and technology deployment. While there is considerable uncertainty regarding many of these factors and the total magnitude of emissions growth, the reference case from the Annual Energy Outlook suggests that significant growth in transportation emissions will occur over the next 15 years in the absence of specific measures to address greenhouse gas emissions.

2.6 Changes in Global Concentrations of Gases

Unlike emissions inventories that are calculated, atmospheric concentration of gases is directly measured using samples of air.[vi] Using samples of "fossil air" trapped in ice cores from Greenland and Antarctica, scientists have been able to measure historic concentrations.

Exhibit 2-7. Percent Increase in Atmospheric Concentrations, 1880-1992



Note that carbon dioxide is a much larger component of the atmosphere than other gases.

Empirical observations show that global atmospheric concentrations of greenhouse gases have increased steadily for decades. The US DOE reports that atmospheric concentrations of carbon dioxide have increased by about 28 percent, methane has more than doubled, and nitrous oxide has increased about 13 percent since the start of the industrial era, as shown in Exhibits 2-7. Records indicate that carbon dioxide and methane are currently at concentration levels not previously attained for any prolonged period over the past 160,000 years. The growth in concentrations has occurred largely in the past 200 years. [18] Pre-industrial (1880) and 1992 atmospheric concentrations are compared in Exhibit 2-8.

The atmospheric concentration of carbon dioxide is currently increasing about 30 to 100 times faster than the rate of natural fluctuation in the paleoclimatic record.[19] Similarly, the atmospheric concentration of methane is increasing more than 400 times natural rates of variability.[20] Other greenhouse gases—chlorofluorocarbons (CFCs) and halons—are synthetic chemicals that have been introduced into the atmosphere during only the last 50 years.

[vi] Carbon dioxide concentrations have been directly recorded using consistent methods since 1958. Concentrations of methane and nitrous oxide have been recorded since the early 1980s (US DOE, 1995, p. 6).

Exhibit 2-8. Estimated Global Concentrations of Greenhouse Gases, 1880 and 1992

Gas	Preindustrial (1880) Atmospheric Concentrations	1992 Atmospheric Concentrations	Percent Increase in Concentration
Carbon dioxide	278 parts per million	356 parts per million	28%
Methane	0.700 parts per million	1.714 parts per million	145%
Nitrous Oxide	0.275 parts per million	0.311 parts per million	13%
CFC-11	0 parts per trillion	268 parts per trillion	—
CFC-12	0 parts per trillion	503 parts per trillion	—

Source: US DOE/EIA, 1996, p. 2, citing M. Prather et al., "Other Trace Gases and Atmospheric Chemistry," in Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996). Percent increase calculated by Apogee Research, Inc.

According to the US DOE, the timing of the growth in concentrations, variations in observations between the northern and southern hemispheres, and observations of relative concentrations of isotopes in atmospheric CO_2 imply that the prime source for the increase in carbon dioxide concentrations is the combustion of fossil fuels by humans.[21] However, the mechanisms that link anthropogenic emissions with global concentrations are not entirely understood.

It is particularly striking that there was a sudden slowing in the growth rate of atmospheric concentrations of CO_2 and methane over the period 1990-93, which cannot be explained by changes in fossil fuel consumption, suggesting that either natural sources of emissions have declined or natural absorption has increased. The causes of reduced growth in methane concentrations have eluded scientists, although some theorize that global cooling from sulfate aerosols deposited in the atmosphere by the eruption of Mount Pinatubo in the Philippines may have stimulated absorption mechanisms. Clearly, concentrations have been increasing, but the forces that influence biogenic sources and sinks are not well understood.[22]

2.7 Global Warming Potential

Some greenhouse gases have a more potent effect on global temperatures than others based on their heat-absorption potential. Research on this topic has lead to the development of the concept of "global warming potential (GWP)." GWP is a measure of the relative effectiveness of various gases in trapping the Earth's heat, in comparison to CO_2. Exhibit 2-9 lists the GWPs of key greenhouse gases for time horizons of twenty and one hundred years.

Exhibit 2-9. Global Warming Potentials

Gas	Lifetime (years)	GWP, Direct Effect for Time Horizon of:	
		20 years	100 years
Carbon dioxide	variable	1	1
Methane	12 ± 3	56	21
Nitrous Oxide	120	280	310
CFC-11	na	4900	3800
CFC-12	na	7800	8100

Source: D.L. Albritton et al., "Trace Gas Radiative Forcing Indices," reported in US DOE/EIA, 1996, p. 6.

The IPCC's work has established that the effects of various gases on global warming are too complex to be summarized as a single number. The "atmospheric lifetime" of gases—the period of time it takes for natural processes to remove a unit of emissions from the atmosphere—differs widely for different gases. As a result, over different periods of time the relative GWP of gases differs. In addition, many gases react in the atmosphere to promote or hinder the formation of other greenhouse gases. These indirect effects are not summarized in the GWPs.[vii]

[vii] For example, CFCs tend to destroy atmospheric ozone, thus promoting global cooling. It is unclear whether CFCs have a net warming or cooling effect on the earth (US DOE, p. 5).

[1] US Department of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987-1994.* (Pittsburgh, PA: US Government Printing Office, 1995) p. 2.

[2] *Ibid.*

[3] *Ibid.* pp. 2-3.

[4] *Ibid.*

[5] *Ibid.*, p. 10.

[6] *Ibid.*

[7] US Department Of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1995.* (Pittsburgh, PA: US Government Printing Office, 1996), p. xi.

[8] *Ibid.*

[9] *Ibid.*, p. 13.

[10] US Department Of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987-1994.* (Pittsburgh, PA: US Government Printing Office, 1995), p. 12.

[11] US Department Of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1995.* (Pittsburgh, PA: US Government Printing Office, 1996), p. 41.

[12] *Ibid.*

[13] *Ibid.*, p. 7.

[14] US Department Of Energy/Energy Information Administration, *Supplement to the Annual Energy Outlook, 1995.*

[15] US Department Of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1995.* (Pittsburgh, PA: US Government Printing Office, 1996), p.34.

[16] *Ibid.*, p.39.

[17] US Department of Energy, Oak Ridge National Laboratory. *Transportation Energy Databook: Edition 17.* Washington, DC. August 1997. p. 3-21.

[18] US Department Of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987-1994.* (Pittsburgh, PA: US Government Printing Office, 1995), p. 6.

[19] Barnola, J.M., *et. al.*, "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2", *Journal of Geophysical Research 92: 14722-14780 (1987).*

[20] Intergovernmental Panel on Climate Change, *First Scientific Assessment of Climate Change*, Summary and Report, World Meteorological Organization/UN Environment Program (Cambridge, UK: Cambridge University Press, 1990).

[21] US Department Of Energy/Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987-1994.* (Pittsburgh, PA: US Government Printing Office, 1995), p. 7.

[22] *Ibid.*

3 Potential Impacts of Global Climate Change

The prospect of global warming caused by an increase in greenhouse gases became a major policy issue during the past decade. For some time, scientists and policymakers throughout the world have been seeking answers to a number of questions—is global climate change partly linked to human activity? How much warming? How soon? Should we worry? What kind of policy responses, if any, are appropriate now or in the future?

The Intergovernmental Panel on Climate Change (IPCC) was organized in November 1988 under the auspices of the United Nations to address these questions. The IPCC, comprised of more than 300 scientists and climatologists from around the world, drew upon the work of over 2,500 scientists worldwide. The signatories of the *Framework Convention of Climate Change* (*FCCC*) agreed on July 1996 to formally accept the IPCC's *Second Assessment Report on Climate Change*. For this reason, the IPCC reports are at the center of the debate about the possibility, sources, and extent of climate change due to human activities.

The potential impacts of climate change are difficult to describe with any confidence. Scientists largely disagree about the extent of a future global-temperature increase, even among scientists who believe global warming will occur. Temperature increase may, in turn, cause secondary impacts such as sea level rise, global hydrological patterns change, and general human health degradation. However, the likelihood and severity of such impacts depend on the extent of global temperature increase.

Potential impacts are usually discussed at a wide-ranging, global level for at least two reasons. First, global-climate models and computer simulations do not claim to predict with precision the extent and location of a particular type of impact from climate change. The magnitude and location of future global warming will depend, in part, on how geophysical and biological feedback enhance or reduce the warming. Second, many governments are undertaking activities that are expected to affect the extent of climate change, and, therefore, the type and scope of impacts.

3.1 Potential Global Temperature Increases

The US Environmental Protection Agency (EPA) estimated in 1990 that a doubling of CO_2 would increase average temperature by 1.2 to 1.3°C, causing an increase in atmospheric levels of water vapor, which in turn would increase the extent of warming to approximately 2 to 4°C. EPA noted that a variety of geophysical and biogenic feedback widen the range of potential warming to between 1.5 and 5.5°C for an initial doubling of CO_2.[1]

More recent estimates predict a lesser degree of warming. The IPCC's 1995 report predicted an increase of about 2 to 3.5°C between 1990 and 2100, depending on whether climate sensitivity was "moderate" or "high."[2] These figures are approximately one-third lower than the IPCC estimated in 1990. According to the IPCC, the drop is due primarily to lower emission scenarios, inclusion of the cooling effects of sulfate aerosols, and modeling improvements in the treatment of the carbon cycle.[3]

Global warming could have direct impacts on transportation. Some of these potential impacts could be beneficial, such as a decrease in snow-removal costs or a longer ocean transport season in northern regions. Other potential impacts may be less desirable. Urban areas may experience a greater number of summer days that fail to meet air quality standards, with implications for the transportation community. Highways may experience more wear and tear from longer- and higher-temperature summer heat waves. In Alaska, highways and railroads built on permafrost could recede if higher temperatures cause thawing.[4]

3.2 Potential Secondary Impacts from Temperature Increases

While scientists disagree as to the likelihood, extent, and causes of global warming, they seem to agree that global warming of the predicted 2 to 3.5°C would represent an enormous change in climate. For example, Chicago and Atlanta have very different climates with a difference in mean annual temperature of 6.7°C. The total global warming since the peak of the last ice age, 18,000 years ago, was only about 5°C. The range of predicted temperature increases, therefore, could result in significant secondary impacts.

Scientific debate in the literature tends to focus on the extent of global warming that might result from increases in greenhouse gas concentrations. The IPCC and other scientists who predict significant warming often discuss secondary impacts such as sea level rise, hydrologic cycle alteration, and human health degradation. In contrast, scientists who believe future temperature increases from greenhouse gases will be negligible appear to discuss secondary impacts less frequently. The result is a body of literature on potential secondary impacts that typically assumes a significant level of global warming. The discussion below should be viewed in such a light.

3.2.1 Sea Level Rise

If significant global warming occurs, average sea level is expected to rise as a result of thermal expansion of the oceans and melting of glaciers and ice-sheets. Available data show that global sea level has risen by between 10 and 25 cm over the past 100 years.[5] IPCC models project a global average increase in sea level during the next hundred years of between 20 and 86 cm by 2100, with 50 cm considered as most likely.[6] EPA recently estimated the potential sea level rise, using models that assume somewhat lower concentrations of CO_2 than the IPCC considered when discussing potential impacts of global warming.[i] EPA predicts a median estimate for global sea level rise of 45 cm by 2100.[7] Under both the IPCC and EPA estimates, regional sea level changes may differ from the global mean value due to land movement and ocean current changes.[8]

A significant rise in sea level would inundate wetlands and lowlands, accelerate coastal erosion, worsen coastal flooding, threaten coastal structures, raise water tables, and increase salinity of rivers, bays, and aquifers.[9]

Sea level rise would be a problem especially in the US along the Atlantic coast's low-lying barrier island system, and along the Gulf Coast. In both areas, small vertical rises in sea level would cause large, horizontal movements in the shorelines, where the full effects of storm surges, winds, waves, and tides are felt. The cost of these disturbances is potentially large, because of extensive development and high population density in most coastal areas in the US.[10] US EPA estimates that a 50 cm sea level rise would inundate more than 5000 square miles of dry land and 4000 square miles of wetlands in the US.[11] Total losses from a one-meter rise are estimated to be between $270 billion and $475 billion, ignoring future development.[12]

[i] The EPA study also incorporated the cooling effects of sulfate emissions, stratospheric ozone depletion, and possible declines in ocean circulation, and phaseout of chlorofluorocarbons (CFCs) under the Montreal Protocol.

Potential impacts of sea level rise on transportation include erosion of coastal highways and bridges as well as infrastructure damage from an increased frequency or intensity of storm events. Sea walls may be needed to keep flooding and storms from damaging roads and causeways.[13] If sea level rise causes shifts in population density, the resulting change in consumption patterns might require changes to transportation networks handling personal travel and freight. In addition, sea level rise would probably create a need for improvements in existing harbor and port facilities to handle higher tides.[14] Airports might also require sea walls and other additional protection because many have been built on once-swampy coastal areas and may not be high enough to withstand tides and storm surges.[15]

3.2.2 Changing Hydrologic Patterns

The hydrologic cycle traces the movement of water among the oceans, atmosphere, land and vegetation, and ice caps and glaciers. Scientists from the IPCC, US EPA, and the US Congress Office of Technology Assessment agree that significant global warming would intensify the global hydrologic cycle and have major impacts on regional water resources.[16] The increase in temperature that these organizations predict could increase average global precipitation from 7 to 15 percent, but models are unable to predict impacts on water supply for specific regions.[17] Climate modelers generally agree that, with an increase in global temperature, precipitation would increase at high latitudes and decrease at low to middle latitudes. The potential for more-intense or longer-lasting drought could increase. The 1990s have experienced an unusually high incidence of intense droughts and flooding.

Changing hydrologic patterns can have great significance. Some densely populated areas of the US currently experience water scarcity and lie in areas predicted to receive even less precipitation in the future. Global climate change might, therefore, result in a changed population distribution. Similarly, water-dependent activities such as agriculture are likely to be greatly affected by a change in hydrologic patterns.[18] Studies predict that agricultural productivity will increase in some areas and decrease in others, especially the tropics and subtropics.[19] In summary, then, hydrologic changes are likely to cause changes in production and consumption patterns. Transportation systems, particularly for freight, may have to adapt to these changes.[20]

Transportation may have to adapt to other changes in hydrologic patterns, as well. While ocean levels would rise globally by a uniform amount, inland rivers and lakes would rise or fall as a function of changes in precipitation, runoff, and evaporation. For example, if the level of warming predicted by the IPCC does occur, the Great Lakes could lose 15 percent of their net water supply and water levels could fall by 30 to 80 cm. While warmer temperatures could result in a longer shipping season, increased shipping costs would result from lower water tables.[21] Vulnerability of some river systems to drought has been demonstrated in the past. For example, commercial shipping was all but stopped in 1988 when drought decreased water levels in the Mississippi River.

3.2.3 Impacts on Human Health

Scientists affiliated with the IPCC believe that climate change could have wide-ranging and mostly adverse impacts on human health.[22] Health effects might include increases in mortality and illness due to a predicted increase in the intensity and duration of heat waves. Warming would result in increased levels of airborne pollen and spores, which would worsen respiratory disease.[23] The most significant, albeit indirect, effect could be an increase in the potential transmission of vector-borne infectious diseases, such as malaria, resulting from extensions of the geographical range and season for vector organisms. Limitations on freshwater supplies and nutritious food would also have human health consequences. Positive health benefits of temperature increases might include a reduction in cold-related deaths in colder regions.

The World Health Organization (WHO) has identified the health ramifications of global warming to be among the most pressing problems for the next century.[24] A 1990 report observed that several vector-borne diseases might be influenced by climate change, including malaria, lymphatic filariasis, dengue and yellow fever. Initial impacts would likely be at the margins of the diseases' current distributions, with expanding distributions as warmer temperatures expand toward the poles. WHO also predicted that climate change might affect the altitude at which vector-borne diseases are found. The IPCC predicts 50 to 80 million additional annual cases of malaria around the world.[25] On the positive side, climate change may cause the elimination of some disease vectors and pathogens as the result of very hot, dry conditions.

3.3 Extent of Scientific Certainty about Climate Change

It is difficult to prove the global climate change effect because of normal temporal and spatial variations in temperature. Information on historic concentrations show that CO_2 and methane are currently at levels not reached for prolonged periods in the last 160,000 years.[26] However, scientists have not firmly established links between such greenhouse gas concentrations and the record-setting warmth of the 1980s and 1990s or severe flooding and storms of the 1990s.

Predicting the future is even more difficult because of the need to rely on models, assumptions, and incomplete data. The general circulation models (GCMs) used to assess climate change tend to suggest that increasing concentrations of greenhouse gases will produce a change in the average temperature of the Earth, and predict that concentrations will continue to increase without specific actions. The IPCC reports and those scientists concerned about global climate change typically rely on the predictions of GCMs, or at least the general outcomes implied by the models. But even the IPCC acknowledges that some uncertainties exist. For example, differing GCM predictions typically give average global temperature increases ranging from 1.5 to 4.5°C.[27]

In the past, a major difficulty in developing an appropriate US global climate change policy has been scientific uncertainty about the likely extent of change, and its specific regional effects. A small number of scientists argue that global warming is not fully supported by empirical evidence, mostly as a result of an inadequate understanding of atmospheric and weather patterns and that the US should reach a better scientific understanding before taking measures to reduce greenhouse gases. Another, much larger, group of scientists asserts that human activity is altering the chemical makeup of the Earth's atmosphere. These scientists also assert that the time lag between emissions of greenhouse gases and their full impact is on the order of decades to centuries, as is the time needed to reverse any effects. Finally, these scientists, including those of the IPCC, feel that the potential risks are so great that some action is warranted.

The IPCC's *First Assessment Report on Climate Change* (1990) was cautious. It found that there is a natural greenhouse effect that already keeps the Earth warmer than it otherwise would be and that human activities are substantially increasing the atmospheric concentration of greenhouse gases. The IPCC's 1990 report did not explicitly conclude that human activities were causing the greenhouse effect. The IPCC noted that all predictions are subject to many uncertainties regarding the timing, magnitude, and regional patterns of climate change due to an incomplete understanding of greenhouse gas sources, clouds, oceans, and polar ice sheets.

The IPCC released its *Second Assessment Report on Global Climate* in December 1995. The *Second Assessment* sought to determine what concentrations of greenhouse gases might be regarded as a "dangerous anthropogenic interference with the climate system," and to highlight options that were sustainable.[ii] The IPCC report concluded that "the balance of evidence suggests that there is a discernible human influence on global climate." The IPCC identified several potentially serious repercussions for the well-being of human populations, including regional shifts in agricultural activity, changes in water-supply availability, sea level rise, and increased incidence of human illness and death. The IPCC report also referenced the *FCCC* principle that lack of full scientific certainty should not be used as a reason for postponing actions where there are threats of serious or irreversible damage.

- The IPCC and other scientists who believe global climate change is occurring have circumscribed what they assert as scientifically defensible. These assertions appear in the IPCC 1995 report, and peer-reviewed journals and studies: Greenhouse gas concentrations currently are increasing at a much faster rate than before the twentieth century.
- The rate of increase in greenhouse gases is partly caused by human activity.[28]
- An increased concentration of greenhouse gases in the atmosphere causes an increase in average global temperature level.

The 1995 IPCC report cites data indicating that global mean surface temperature has increased since the late nineteenth century by between about 0.3 and 0.6°C, a "change that is unlikely to be entirely natural in origin" and that corresponds to increases in greenhouse gas concentrations.[29] Many scientists also assert that global temperatures will continue to increase unless measures are taken to reduce greenhouse gas concentrations; the "no action" scenario in the IPCC report predicts a temperature increase could be as high as 3.5°C by 2100.[30]

Scientists are less confident about predicting the actual temperature increase that will result from current trends in greenhouse gas concentration, or providing a specific time frame.[31] Many are also reluctant to causally link recent weather extremes to global climate change. Most will not predict regional patterns of climate change because of the difficulty of modeling or simulating complex global climate impacts on relatively small areas. Even proponents of global warming theories agree that there is an incomplete understanding of biogenic and anthropogenic sources of greenhouse gases and do not fully comprehend the influence of clouds, oceans, and polar ice sheets on global climate. As the IPCC recently noted, "many uncertainties...arise from the non-linear nature of the climate system."[32]

As with any large-scale, complex issue, there are some scientists that disagree with one or more of the IPCC conclusions on global climate change. For example, scientists from the George C. Marshall Institute recently concluded that natural climate change is the most probable link to moderate temperature increases. It asserted that "as the climate models improve, the predictions get closer to a small, gradual warming indistinguishable from the natural warming we have been experiencing for the last several hundred years."[33] Others at the Marshall Institute and elsewhere concede that the magnitude of the rise in temperature predicted by GCMs seems to agree with the observed temperature increase, but argue that the predictions are inconsistent with the time frame of the warming.[34]

[ii] The IPCC, comprised of more than 300 scientists, drew on the work of 2,500 scientists from around the world, including peer-reviewed studies of empirical observations, statistical models, and climate models.

[1] US Environmental Protection Agency, *Policy Options for Stabilizing Global Climate: Report to Congress* (EPA 21P-2003.1, Dec. 1990), pp. 8-9.

[2] Intergovernmental Panel on Climate Change, Second Scientific Assessment of Climate Change, Summary and Report, World Meteorological Organization/UN Environment Program (Cambridge, UK: Cambridge University Press, 1995), p. 23.

[3] *Ibid.*

[4] Black, William, "Global Warming: Impacts on the Transportation Structure," in *TR News,* Vol. 150, (September-October 1990) pp. 2-8.

[5] Intergovernmental Panel on Climate Change, Second Scientific Assessment of Climate Change, Summary and Report, p. 22.

[6] *Ibid.*, p. 5.

[7] US EPA, *The Probability of Sea Level Rise*. (EPA 230-R-008, Oct. 1995), p. iii.

[8] *Ibid.*

[9] Titus, J., *et. al.*, "Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea," in *Coastal Management* Vol. 19, (1991) pp. 171-204; for a general discussion, *see also* US Congress Office of Technology Assessment, *Preparing for an Uncertain Climate, Vol. I* (Washington, DC: US Government Printing Office, 1993), pp. 153-207.

[10] Titus, J., US Environmental Protection Agency, "An Overview of the Nationwide Impacts of Rising Sea Level," peer review draft 1993.

[11] Gardiner, David, "Global Climate Change Negotiations." (Testimony Before the House Commerce Committee, Subcommittee on Energy and Power, June 19, 1996).

[12] Titus, J., *et. al.*, "Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea," in *Coastal Management* Vol. 19, (1991) pp. 171-204.

[13] Black, William, "Global Warming: Impacts on the Transportation Structure," in *TR News,* Vol. 150, (September-October 1990), pp. 2-8.

[14] *Ibid.*

[15] *Ibid.*

[16] Intergovernmental Panel on Climate Change, Response Strategies Working Group, Strategies for Adaptation to Sea Level Rise (The Hague, the Netherlands: Ministry of Transport and Public Works, 1990); US EPA, "Policy Options for Stabilizing Global Climate: Report to Congress." (21P-2003.1, December 1990).

[17] *See* US Congress Office of Technology Assessment, *Preparing for an Uncertain Climate Vol. I*, (Washington, DC: US Government Printing Office, 1993), p. 212.

[18] *See, e.g.,* Innes, Robert, and Kane, Sally, "Agricultural Impacts of Global Warming: Discussion." in *American Journal of Agricultural Economics*, Vol. 77, (August 1995), pp. 747-750.

[19] *See, e.g.,* US Congress Office of Technology Assessment, *Preparing for an Uncertain Climate Vol. I*, Washington, DC: US Government Printing Office, 1993).

[20] Black, William, "Global Warming: Impacts on the Transportation Structure," in *TR News,* Vol. 150, (September-October 1990), pp. 2-8.

[21] Environment Canada, "Impacts of Global Warming" at http://www.ns.doe.ca/uco/warm-3.html.

[22] Intergovernmental Panel on Climate Change, Second Scientific Assessment of Climate Change, Summary and Report, p. 35.

[23] *See, e.g.,* McMichael, Antony, "Global Health Watch: Monitoring Impacts of Environmental Change," in *The Lancet*, Vol. 342, (December 1993) p. 1464.

[24] World Health Organization Task Group, "Potential Health Effects of Climate Change." (Geneva: World Health Organization, 1990).

[25] IPCC, 1995, p. 12.

[26] Barnola, J.M. *et. al.*, "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2," *Journal of Geophysical Research 92:* 14722-14780 (1987).

[27] For discussions of the uncertainties in modeling atmospheric and climate change, see "Shaky Science Behind the Greenhouse Effect" and "The Scientific Myth Behind the Global Climate Treaty," both by S. John Singer at the University of Virginia's Science & Environmental Policy Project.

[28] *See, e.g.,* US Congress Office of Technology Assessment, *Changing By Degrees: Steps to Reduce Greenhouse Gases*, Washington, DC: US Government Printing Office, 1991; Intergovernmental Panel on Climate Change, *Second Scientific Assessment of Climate Change*, Summary and Report, World Meteorological Organization/UN Environment Program (Cambridge, UK: Cambridge University Press, 1995).

[29] Intergovernmental Panel on Climate Change, *Second Scientific Synthesis of Scientific-Technical Information Relevant to Interpreting Article 2 of the UN Framework Convention on Climate Change*, World Meteorological Organization/UN Environment Program (Cambridge, UK: Cambridge University Press, 1995).

[30] *Ibid.*

[31] *See, e.g.,* Baliunas, Sallie, "Uncertainties in Climate Modeling: Solar Variability and Other Factors," testimony before the Senate Committee on Energy and Natural Resources, September 17, 1996.

[32] *Ibid.*

[33] George C. Marshall Institute. *Are Human Activities Causing Global Warming?* (April 1996).

[34] *See* "Uncertainties in Climate Modeling: Solar Variability and Other Factors." Sallie Baliunas' Testimony to the Senate Committee on Energy and Natural Resources on September 17, 1996.

4 Developments in Global Climate Change Policy

The previous sections have explored what scientists know about emissions of greenhouse gases from transportation sources and the implications of global climate change. Given the risks, the United States and the international community have taken steps to learn about and respond to the threat of climate change. This section discusses developments in international global climate change policy and US policy initiatives aimed at reducing greenhouse gas emissions from transportation.

4.1 International Developments

Recognizing that climate change is a global issue, many nations of the world have worked together over the past decade to develop international consensus on the most appropriate means of response. These evolving discussions have recently culminated in the "Kyoto Protocol," which sets legally-binding collective targets for 39 developed and transitional countries to reduce greenhouse gas emissions.

The Kyoto Protocol comes after many years of international discussions on the issue of global climate change. Over this time, our knowledge on the issue has increased dramatically, setting the stage for the international actions that have recently taken place. This section of the report provides a brief chronology of these developments.

In November 1988, the Intergovernmental Panel on Climate Change (IPCC) was organized under the auspices of the United Nations (UN). The IPCC was formed to assess scientific information on global climate change and to assess response strategies, under a framework of wide peer-review. Since the IPCC's *First Assessment Report on Climate Change* in 1990, which concluded that emissions from human activity are substantially increasing greenhouse gas concentrations, many governments have adhered to a so-called "no regrets" policy. Under a "no regrets" policy, actions are implemented that would not only reduce greenhouse gas emissions but would also provide other benefits. Typical actions under a "no regrets" policy include energy efficiency and conservation, planting trees to enhance CO_2 sequestration from the atmosphere, and fuel substitution.

During the 1990s, the US position on global warming has become more proactive, just as many nations of the world have begun to more fully recognize the consequences of inaction. The Bush Administration followed a "no regrets" policy, without actually committing to CO_2 targets and timetables, as a step toward establishing a majority of industrialized nations whose governments pledged to stabilize their CO_2 emissions by the year 2000. In June 1992, representatives from 176 countries met in Rio de Janeiro at the "Earth Summit" to work together to develop a plan for global climate change. "No binding target" was a basic tenet of the US position during negotiations for the *Framework Convention on Climate Change (FCCC)* in 1992. The *FCCC* ended up calling for a voluntary reduction of greenhouse gases to 1990 levels by the year 2000. The United States signed the *FCCC* on June 12, 1992. In total, 170 other nations have joined the US in signing the agreement.

In April 1993, President Clinton announced he would reverse US policy and commit to the target and timetable expressed in the *FCCC*. The *Climate Change Action Plan (CCAP),* announced in October 1993, described how the US would meet those targets and respond to the *FCCC*. The *CCAP* laid out nearly 50 voluntary initiatives in all sectors of the economy, including transportation.

The First Conference of Parties to the *FCCC* (COP-1) met in Berlin, Germany, in March and April 1995. This was the first opportunity for *FCCC* parties to consider amendments or a separate protocol to the treaty. The US delegation affirmed that it remained the policy of the United States to pursue climate change measures beyond its 2000 stabilization goal but that the US would likely face a 30 percent shortfall in achieving 1990 greenhouse gas emission levels by 2000. Other countries announced they also were behind schedule in attaining *FCCC* targets.

Seeking grounds for a uniform approach toward climate protection, the COP expressed concerns about the adequacy of countries' current commitments under the *FCCC*. This concern was expressed in a United Nations ministerial declaration known as the "Berlin Mandate." Under the Berlin Mandate, parties launched a negotiating process designed to produce a new treaty protocol to deal with actions in the post-2000 period. The protocol was expected to include a "comprehensive menu of actions" from which countries may pick and choose options to address climate change. The protocol served also as a uniform approach to reporting emissions and measures.

In December 1995, the Intergovernmental Panel on Climate Change (IPCC) released its second report. The report concludes that available data and models confirm a link between human activities and global climate change. This report provided further impetus for international actions to reduce greenhouse gas emissions.

Representatives of those nations signing the *FCCC* met in Geneva in July 1996, to discuss how to accelerate reductions in greenhouse gas emissions. This Second Conference of Parties (COP-2) was to refine proposals into concrete actions that could be discussed at a later meeting. The United States voiced support during the conference for development of internationally enforceable targets for reducing greenhouse gases. US negotiators continued to reject the imposition of "harmonized policies and measures," including uniform Corporate Average Fuel Economy (CAFE) standards and energy taxes. They stressed a preference for flexible measures, such as bilateral efforts using emissions trading. The resulting *Ministerial Declaration of the Second Conference of Parties:*

- Accepted outright the scientific findings on climate change in the IPCC's *Second Assessment Report on Climate Change*;
- Rejected uniform "harmonized policies" in favor of flexibility; and
- Called for "legally binding mid-term targets."

On January 17, 1997, the US State Department released a draft protocol that lays out specific responsibilities for countries to help reduce the threat of global warming. The draft protocol was the United States' contribution to the negotiations initiated by the Berlin Mandate. The US plan would establish a multi-year "budget" for greenhouse gas emissions, with a specific cap on the amount of greenhouse gas emissions an industrialized country could release during that time. Caps would be a percentage of greenhouse gas emissions each nation released in 1990. If a nation fell under budget, it could transfer its savings to the next period, or sell off its excess emissions allowances. Alternatively, countries emitting over their budget could use part of the next budget period's allocation, but would have to include extra emission cuts in their paybacks—a form of "interest." The US proposal would set up an international trading regime for greenhouse gases. The US proposal also would require all developing countries to take "no-regrets" actions to control their greenhouse gas emissions, and report annually.

These actions fed into talks that resumed in late February 1997, which led to the US participation in the Kyoto Protocol. On December 11, 1997, the Third Conference of Parties (COP-3) to the *FCCC* adopted the "Kyoto Protocol" setting legally-binding collective targets for 39 developed and transitional countries (referred to as "Annex B" countries in the Protocol) to reduce greenhouse gas emissions. The Kyoto Protocol covers six major greenhouse gasses, including carbon dioxide (CO_2), methane, nitrous oxide, hydroflourocarbons (HFCs), perflourocarbons (PFCs), and sulfur hexaflouride (SF_6) and allows the latter three synthetic gases to use a 1995 baseline year in lieu of the 1990 baseline year use for anthropogenic CO_2 emissions.

The Kyoto Protocol calls for the aggregate reductions of all six greenhouse gas emissions collectively by 5.2 percent from a 1990 baseline in Annex B countries between the first commitment period of 2008-2012. The agreement includes individual reduction targets of 7 percent for the US, 8 percent for the European Union, and 6 percent for Japan. Emission increases above 1990 levels are approved for Australia, Iceland, and Norway (these countries will be allowed increases in greenhouse gas emissions by 8 percent, 10 percent, and 1 percent respectively). Each party must show demonstrable progress toward meeting its target by 2005.

The protocol will be opened for signature between March 16, 1998 and March 15, 1999 and afterward transmitted for acceptance by Parties. It will enter into force ninety days after 55 Parties or more (accounting for 55 percent of the carbon dioxide emissions from all developed countries in 1990) have ratified the Protocol. Rules and guidelines will be established by the Conference of the Parties, starting with its next session in November 1998 in Buenos Aires, Argentina. The next session may discuss topics such as emissions trading, joint implementation of reduction strategies among developed countries, and clean development mechanisms in developing countries. Compliance mechanisms will also be discussed for further development at the next meeting for the Conference of the Parties. The Protocol will be amended later to reflect the measures or penalties associated with non-compliance.

International discussions about greenhouse gas policies have progressed significantly in recent years. Exhibit 4-1 provides a chronological summary of US positions and key international negotiations and agreements. The sections that follow the table describe a few of the major US policy initiatives on climate change.

Exhibit 4-1. Milestones in Global Climate Policy

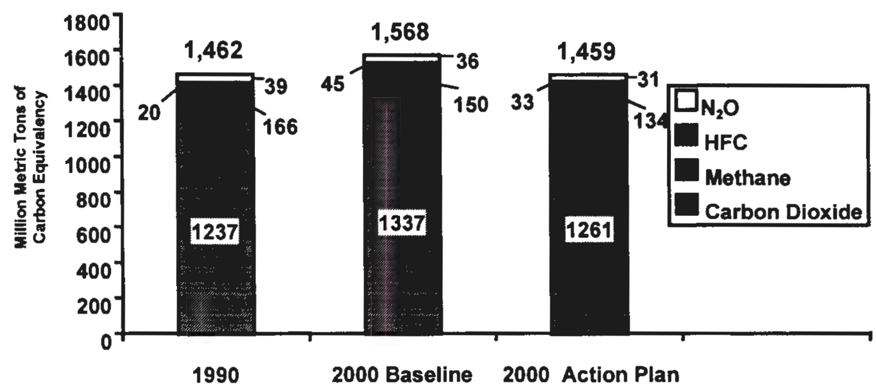
Date	Policy Milestone	Description
November 1988	Intergovernmental Panel on Climate Change (IPCC) organized under United Nations auspices	IPCC is organized to assess the scientific information "related to various components of the climate change issue" and to formulate "response strategies." IPCC work is to be widely peer-reviewed.
August 1990	IPCC "First Assessment Report on Climate Change"	IPCC concludes that emissions from human activity are substantially increasing greenhouse gas (GHG) concentrations. It stopped short of concluding that human activities are substantially affecting global warming.
June 1992	US agreement to work GHG reductions, without firm targets	President Bush supports policy of reducing GHG without committing to CO_2 targets and timetables. This is to be the US position while negotiating treaties.
June 1992	Framework Convention on Climate Change (FCCC)	The FCCC commits signatories' governments to voluntary reduction of GHG with the goal of stabilizing global emissions at 1990 levels by the year 2000. Treaty provides flexible, voluntary, and general framework. Signed by 154 nations, including the US.
April 1993	Firm targets for reducing US GHG emissions	President Clinton announces he will seek measures to stabilize US emissions of GHG by the year 2000.
October 1993	US Climate Change Action Plan (CCAP)	The CCAP highlights nearly 50 new or expanded initiatives to reduce US GHG emissions. Initiatives focus on all sectors of the economy, including transportation.
September 1994	US Policy Dialogue Advisory Committee to Assist in the Development of Measures to Significantly Reduce Greenhouse Gas Emissions from Personal Motor Vehicles established	Advisory committee is established to develop consensus on polices to cost-effectively reduce GHG emissions from motor vehicles. Interim report issued in 1995; no consensus reached.
March 1995	First Conference of Parties to the FCCC (COP-1) and the "Berlin Mandate"	Nations that signed the FCCC agree to negotiate additions to the FCCC that address specific actions to be taken in the post 2000 period, as well as a uniform approach to reporting emissions and measures.
March 1995	Reports on progress reducing greenhouse gases	US affirms its GHG reduction targets but notes that it is 30% behind in achieving those reductions by the year 2000. Other countries also announce they are behind on reducing gases.
December 1995	IPCC "Second Assessment Report on Climate Change"	Report concludes that evidence indicates (1) a discernible human influence on global climate, and (2) it is still not possible to link particular impacts with specific atmospheric concentrations of GHG.
July 1996	US commits to internationally binding targets and timetables for GHG reductions	Targets and timetables not yet specified; US plans to develop them by end of 1996.
July 1996	Second Conference of Parties to FCCC (COP-2)	Parties agree to (1) accept IPCC findings in Second Assessment, (2) reject uniform policies in favor of flexibility, (3) work toward legally binding mid-term targets.
January 1997	US Draft Protocol	The US proposes an emissions budget and trading program for greenhouse gas emissions after the year 2000.
December 1997	Third Conference of Parties to FCCC (COP-3)	Parties vote to accept the proposed protocols and amendments to the FCCC.

4.2 US Initiatives and Transportation

The US Climate Change Action Plan

The Climate Change Action Plan (CCAP), announced by President Clinton and Vice President Gore in October 1993, was the initial basis for the US response to the international *Framework Convention on Climate Change*. The goal of the Plan was to return US greenhouse gas emissions to 1990 levels by the year 2000. In order to meet this goal, the CCAP includes nearly 50 new or expanded initiatives in all sectors of the US economy—commercial, residential, industrial, and transportation. Cumulatively, actions—most of which were voluntary and built upon market-based strategies—were expected to reduce greenhouse gas emissions by 108.6 mmtCE from the year 2000 baseline. Emissions were to be reduced from 1,568 metric tons of carbon equivalent (mmtCE) in the base case to 1,459 mmtCE, with implementation of the Action Plan in the year 2000, as shown in Exhibit 4-2.

Exhibit 4-2.
CCAP Greenhouse Gas Emissions Estimates



Under the action plan, net carbon dioxide emissions were projected to be about 2 percent above their 1990 levels in the year 2000. Hydroflourocarbon (HFC) emissions were also projected to grow but at only half the rate of increase without the action plan. Offsetting these gains would be significant decreases in methane and nitrous oxide.

For the transportation sector, the Action Plan contains a package of four initiatives to reduce carbon dioxide emissions from fuel use. These efforts include:

- Reforming the Federal tax subsidy for employer-provided parking (Action #19);
- Adopting a Transportation System Efficiency Strategy (Action #20);
- Promoting greater use of telecommuting (Action #21); and
- Developing fuel economy labels for tires (Action #22).

Together, these four actions were projected to reduce emissions by 8.1 million metric tons of carbon equivalent compared to the baseline by 2000. The first three transportation actions target fuel consumption by reducing the rate of growth in vehicle travel by light-duty vehicles. According to the CCAP's technical appendix, light-duty vehicle travel was expected to grow approximately 2.2 percent annually without any actions—from 2,030 billion miles in 1990 to 2,515 billion miles in the year 2000.

Under the Action Plan, travel would be held to 2,470 billion miles in the year 2000, resulting in a reduction of 45 billion miles traveled and 6.6 million metric tons of carbon-equivalent in the year 2000.[1]

The fourth transportation action was an attempt to reduce fuel consumption per mile of travel. This action sought to encourage consumers and businesses to purchase—and manufacturers to produce—more fuel-efficient tires in response to the labeling requirements. Efficient tires increase fuel economy (gallons of fuel used per mile) by 4 percent over average replacement tires with comparable performance. As a result, this action was expected to reduce greenhouse gas emissions by 1.5 mmtCE in the year 2000.

The federal funding required to carry out the transportation actions was estimated at $89 million in FY1994–2000 for Action #20 (adopting a transportation system efficiency strategy), $2 million for Action #22 (developing fuel economy labels for tires), and less than $1 million for Action #21 (promoting telecommuting). Action #19 (reforming the federal tax subsidy for employer-provided parking) was expected to generate $2 billion over this time period. These revenues were expected to more than cover the federal outlay for the CCAP actions, resulting in a net revenue increase of $793 million for FY1994-2000 from the Action Plan. The value of energy savings to the private sector was projected to more than offset all private sector costs for transportation actions.

For a number of reasons, the US-proposed policies have not achieved their objective of reducing the rate of growth in transportation-sector emissions. Economic growth proved far more robust and energy prices were lower than anticipated. The Congress continued to look with disfavor on a wide range of Action Plan appropriations. Moreover, statutory prohibitions were imposed against any expenditure of Federal funds for tire labeling (and any tightening of US light-duty vehicle fuel efficiency standards).

As transportation is the fastest growing economic sector in terms of its contribution to the greenhouse gas burden, there could be added pressure in the future for action in the transportation arena. US support internationally for binding reduction targets in the years ahead (announced in Geneva in July 1996) suggests further steps may need to be considered.

Initiatives to Reduce Greenhouse Gas Emissions from Personal Motor Vehicles

On September 29, 1993, President Clinton, Vice President Gore, and the CEOs of Chrysler, Ford, and General Motors announced the Partnership for a New Generation of Vehicles (PNGV), a new and historic alliance between the Federal government and the domestic auto industry that aims to improve the environment by reducing vehicle pollution. Its long-term goal is to develop technologies for environmentally-friendly, fuel efficient, family size sedans that travel the equivalent of 80 miles per gallon without sacrificing affordability, performance, or safety. Beyond its impact on the environment, PNGV's success could help to create a globally competitive domestic auto industry, preserve US jobs (one out of seven jobs in the US is transportation-related), and reduce US dependence on foreign oil.

On the government side of the partnership, there are seven Federal agencies and nineteen government labs in participation. The seven Federal agencies are the Department of Commerce (lead agency), the Department of Energy, the Department of Transportation, the Environmental Protection Agency, the National Science Foundation, the Department of Defense, and the National Aeronautics and Space Administration.

On the industry side, the partnership includes USCAR (the pre-competitive research organization of the Big Three auto makers) and over 300 suppliers and universities. Candidate technologies are being explored in such areas as power generation, energy storage, electronics, materials, manufacturing, and systems analysis. Significant technical progress has been made in the partnership—which is just now at its halfway mark.

Another recent effort in the US to relate transportation to climate change was the creation of an advisory committee named the "Policy Dialogue Advisory Committee to Assist in the Development of Measures to Significantly Reduce Greenhouse Gas Emissions from Personal Motor Vehicles." In 1994, President Clinton appointed this committee to develop consensus on strategies to cost-effectively reduce greenhouse gas emissions from motor vehicles. More specifically, the goal was to develop consensus on three sets of policies that would, if adopted, most cost-effectively return emissions from cars and light trucks to 1990 levels by the years 2005, 2015, and 2025, respectively, with no increases in subsequent years.

This committee involved representatives of the auto industry, oil and utility industries, environmental and other public interest groups, states and localities, and Federal agencies. The group began meeting in September 1994 and issued an interim report to the President in March 1995. The Committee's goal was to provide recommendations by late 1995, but it completed its one-year charter without reaching a consensus. The committee was unable to reconcile a number of positions. In particular, the environmental community favored tougher fuel economy standards, which the auto industry opposed. The automobile industry proposed higher fuel taxes, which the oil industry representatives rejected.

No consensus report was issued. The group, however, did make a great deal of progress in gaining expertise and collecting information on the question of how to reduce greenhouse gas emissions. The exercise was useful in compiling a list of approximately 65 policy options and existing estimates of their effectiveness, where available. It also developed new estimates of baseline VMT projections and new estimates of nationwide impacts of certain strategies (e.g. VMT reduction estimates). The process included informative briefings, bibliographies, and unpublished lists of policy options and estimates of their potential effectiveness.

In December 1996, a subset of the Advisory Committee issued a "Majority Report" that called for a package of policies that addresses both fuel economy and the cost of travel. This report described a variety of strategies and forecast the greenhouse gas reductions associated with each one. Although this report did not reflect consensus, it did reflect some of the considerable amount of work done by the Committee. This work may be useful in future discussions of federal policies to reduce greenhouse gas emissions.

A recent study performed by five national labs[i] by the US Department of Energy (DOE) was released on September 15, 1997. While the study came out too late to be fully addressed in this report, its major findings are referenced to be as complete as possible within the time constraints. The DOE "5-labs" study presented the results of efforts to quantify the potential for energy efficient and low carbon technologies to reduce carbon emissions in the United States.[2] This report documented a wide array of advanced technology options that could be cost-effective by the year 2020. In addition, the study documented how four key sectors of the US economy (buildings, transportation, industry, and electric utilities) could respond to expansion of low carbon and energy efficient technologies.

Three main conclusions were drawn from the "5-labs" study: 1) a vigorous national commitment to develop and deploy energy-efficient and low-carbon emissions such that levels in 2010 are close to those in 1997 (for energy) and 1990 (for carbon); 2) carbon reduction necessary to stabilize US emission in 2010 may produce energy savings that are roughly equal to or exceed costs (in terms of energy savings to the nation); and 3) the next generation of energy-efficient and low-carbon technologies promises to enable the continuation of carbon reductions over the next quarter century.

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[i] Argonne National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, and the Pacific Northwest National Laboratory. Lawrence Berkeley and Oak Ridge were the co-leaders of this effort.

In terms of transportation, the DOE "5-labs" study concludes that increased public sector funding for R&D in order to advance alternative energy sources is necessary, perhaps two to ten times the current level of effort. In addition, the DOE report concludes that technology has an enormous potential to reduce greenhouse gas emissions; however, its full effects will not be felt for two decades or more. Significant reductions will demand the consideration of meaningful public policy initiatives to advance new technologies. Some of the strategies addressed in the DOE "5-labs" study, as well as other types of technological and driver behavior strategies, will be discussed in more detail in the next chapter.

Building on the approach taken with PNGV and the conclusion of DOE's "5-labs" study, the DOT and DOE announced on February 4, 1998, a new public-private research partnership to improve the efficiency of heavy duty bus and truck engines. This partnership is the civilian extension of the Department of Defense's Advanced Vehicle Program. The goal of this research effort, now referred to as the Advanced Vehicle Partnership, is to demonstrate a 50-percent improvement in fuel efficiency by 2004 in vehicles that are commercially viable. Twenty million dollars has been dedicated to the effort with DOT and DOE contributing equally.

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[1] US Department of Energy. Office of Policy, Planning, and Program Evaluation. *The Climate Change Action Plan: Technical Supplement.* March 1994. Table D13.

[2] Scenarios of US Carbon Reduction: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond, prepared for the Office of Energy Efficiency and Renewable Energy, US Department of Energy, by the Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, September 1997.

5 Strategies to Reduce Greenhouse Gas Emissions from Transportation Sources

A broad array of literature discusses potential strategies for reducing greenhouse gas emissions from transportation. This section discusses strategies that might be considered as part of a national effort to reduce greenhouse gas emissions from highway transportation. It identifies strategies, summarizes conclusions from the literature, and addresses sources of uncertainty and topics of debate. The section is designed to provide information useful for decision-makers to weigh the advantages and disadvantages of various strategies.

5.1 Uncertainty in Ranking Strategies

As discussed in Section 4, the Policy Dialogue Advisory Committee could not reach consensus on the most appropriate measures to reduce greenhouse gas emissions from personal motor vehicles. Although this report addresses strategies and their potential, it neither ranks strategies on the basis of potential emissions reductions or cost-effectiveness nor recommends that specific strategies become US policy. Ranking of strategies can be misleading for a number of reasons:

- *Strategies can vary in their degree of stringency*—A fuel tax of $.10 per gallon will have a different effect on emissions than a tax of $1.00 per gallon, and will have correspondingly different economic repercussions. Fuel economy standards could be set at various levels, as could subsidies for various alternative fuels.[i]
- *Estimates of effectiveness rely upon key economic and behavioral assumptions, which are somewhat uncertain*—Strategy effectiveness depends upon the response of travelers to changes in prices (usually expressed in terms of price elasticities), non-monetary travel costs (such as travel time), and land use. Estimates from different sources may not be strictly comparable if they use different assumptions. Alternative assumptions about economic parameters and determinants of travel demand can lead also to very different results in assessing policy impacts.[ii]
- *The effectiveness of strategies varies over time*—The timeframe for analysis is an important consideration. A strategy that involves significant time lags may not be effective in meeting goals for the year 2000 but may be more effective for the year 2010, 2020, or beyond. In addition, effectiveness can change over time for many strategies. For example, in the near-term, an increase in the price of fuel may encourage individuals to reduce travel. Over longer periods of time, individuals may shift to more fuel-efficient vehicles, which lowers fuel cost per mile. This lower fuel cost per mile could then lead to some rebound in travel and reduce the effectiveness of future fuel price increases.

[i] As a result, it is difficult to make judgments regarding the relative potential of different strategies without defining specific scenarios.

[ii] Assuming that gasoline demand and fuel economy are very sensitive to fuel prices leads to the conclusion that fuel taxes may be relatively more effective than fuel economy standards. On the other hand, assuming that travel is relatively insensitive to travel costs leads to the conclusion that fuel economy standards may be more effective than pricing strategies.

Since data from various sources are often not strictly comparable, a ranking of strategies based on emissions reduction potential and cost-effectiveness estimates from literature is not provided in this report. Rather than adding value to the debate, rankings may encourage decision-makers to rule out certain strategies that may be useful in specific contexts or in combination with other strategies.

Decision-makers do not need to rely on a one-or-the-other approach. They may wish to implement a spectrum of strategies, since it is likely that one strategy alone will be insufficient to reach transportation-sector goals, and different strategies may be suitable for different circumstances.[iii] Certain strategies may be complementary or synergistic.[iv] Various issues, such as non-greenhouse gas emission benefits, economic impacts, and costs, may influence political acceptability and ease implementation. Ultimately, decision-makers may wish to judge strategies on a number of attributes.

Attributes of Strategies for Decision-Makers to Consider

In order to consistently examine strategies, this section provides a summary of the following information for each of these strategies:

- Primary Target;
- Approach;
- Timing;
- Level of Implementation;
- Effectiveness Factors; and
- Implementation Issues.

Primary Target—There are three primary means to reduce greenhouse gas emissions from personal vehicle travel:

- Reduce vehicle travel;
- Increase fuel economy; and
- Switch to fuels with a lower life-cycle carbon content.[v]

Carbon emissions associated with transportation are simply a product of three factors:

$$\text{Grams of carbon} = \text{miles traveled} \times \frac{\text{gallons}}{\text{mile}} \times \frac{\text{grams of carbon}}{\text{gallon}}$$

These categories are useful since there is a body of knowledge with each: VMT reduction strategies, fuel economy, and alternative fuels.

[iii] The Majority Report to the President by the Policy Dialogue Advisory Committee noted that even if a stringent version of a single policy (such as a very high gasoline tax or carbon tax) could theoretically yield desired emissions reductions, such an approach would probably not be cost-effective, equitable, reliable, or politically realistic. A package is more robust if it includes a range of measures.

[iv] For example, a land use strategy, such as implementing zoning to increase densities in metropolitan areas, may work well with a strategy to increase investment in mass transit.

[v] In addition to carbon emitted from the burning of fossil fuels, carbon is also emitted through upstream processes associated with transportation, such as fuel extraction, processing, and distribution, as well as vehicle manufacturing and other activities that support transportation. "Life-cycle carbon emissions" refers to the amount of carbon emitted through fuel combustion and all of these upstream processes.

Approach—There are various approaches to achieve a target, which range from voluntary efforts to mandatory actions. Approaches may fall along the following continuum (Exhibit 5-1):

Exhibit 5-1. Strategy Approaches

For example, if one wishes to reduce vehicle travel, a range of options exists. A mandatory "no drive days" policy could be implemented, requiring that vehicles with certain license plate numbers not be used on certain days of the week. Alternatively, the program could be voluntary, relying on economic incentives or education to encourage individuals not to drive on certain days.

Timing—Some strategies, such as road pricing, have an immediate impact on travel behavior. Others, like land use planning measures, may not have observable impacts for many decades. This report assesses whether a strategy could reach its full effectiveness in the near-term (under 5 years), mid-term (5-15 years), or long-term (more than 15 years).

Level of Authority—Some strategies, such as land use planning, have been historically reserved for local decision-making authorities, while other decisions, such as fuel economy mandates on vehicle manufacturers, are more naturally suited to national authorities. Many strategies may see involvement at multiple levels, as is the case of gasoline taxes, which are imposed by federal and state governments. In cases where the public role is most suited to local control, a national strategy for greenhouse gas reduction may involve federal funding, incentives, education, mandates, or guidance to encourage local adoption of strategies.

Effectiveness Factors—The effectiveness of strategies depends on factors that can be altered by public policy—such as the level of taxes set—as well as factors that cannot be controlled—such as consumer responses to price increases. This section provides a brief discussion of the key factors that determine strategy effectiveness. If available, quantitative estimates of potential emissions reductions are presented.[vi]

Implementation Issues—Political feasibility, equity, and financial concerns can greatly impact the ability of decision-makers to implement a strategy. On the other hand, non-greenhouse gas emissions benefits, such as congestion relief, air quality improvement, and economic benefits, may encourage policy acceptance and adoption. This section discusses issues that could impede or support smooth implementation.

The following section discusses numerous strategies. They are grouped based on the target of the strategy, as shown in Exhibit 5-2.

[vi] Caution should be exercised when comparing quantitative estimates of greenhouse gas emissions reductions. Estimates from different sources may not be strictly comparable if they use different assumptions about travel, demand elasticities, or other factors that influence effectiveness.

Exhibit 5-2. Strategies to Reduce Greenhouse Gas Emissions from Motor Vehicles

Vehicle Travel Focused	Fuel Economy Focused	Carbon Content/Fuels Focused
Travel Pricing ◆ Road pricing ◆ VMT fees ◆ Fuel pricing * Provision for Alternative Modes: ◆ Transit investment ◆ Bicycle support strategies ◆ HOV lanes ◆ Park-and-ride facilities Parking Management: ◆ Parking pricing ◆ Mandatory parking cash-out ◆ Parking supply limits Land Use Planning ◆ Increasing density, mix of uses, and transit-oriented development ◆ Pedestrian environment improvements Other VMT-reduction Measures: ◆ Telecommuting ◆ Compressed work weeks ◆ Restrictions on vehicle use	Improving Traffic Operations ◆ Traffic flow improvements ◆ Speed limits ◆ Driver education Vehicle Technology Improvements + ◆ Mandates on new vehicle fuel economy (CAFE) ◆ Research and development on fuel economy Changing Vehicle Purchase/Retirement Decisions: ◆ Disseminate fuel economy information ◆ Vehicle efficiency tax or feebates ◆ Emissions-based vehicle registration fees ◆ Vehicle retirement/buyback programs	◆ Alternative fuel vehicle (AFV) mandates ◆ Research and development on fuels and AFVs ◆ Carbon taxes or differential taxes for fuels Notes: * Fuel pricing may reduce VMT and improve vehicle fuel economy. It is discussed once in order to reduce repetition. All strategies that reduce travel may also improve fuel economy as a secondary effect (by reducing traffic congestion). + Vehicle technology improvement efforts have involved study of alternative fuel vehicles in addition to improvements to conventional gasoline vehicles.

Strategies can be grouped and sorted in various ways depending on the purpose of the discussion. The grouping of strategies itself is not particularly significant since decision-makers should not select strategies or determine policy based on a categorization scheme. However, categorization of strategies is useful to emphasize the commonalties among different strategies.[vii]

5.2 Vehicle Travel Reduction Strategies

Vehicle travel reduction strategies attempt to reduce greenhouse gas emissions by reducing miles traveled in personal motor vehicles. Reductions in fuel consumption occur with the elimination of trips, reduction in trip lengths, or the replacement of vehicle trips with trips on alternative modes that consume less energy. A secondary impact of reducing vehicle travel is often reduced traffic congestion, which improves fuel economy for vehicles that remain on the road. Most of these strategies fall under the terms, "Transportation Control Measure" (TCM) or "Transportation Demand Management (TDM).[viii] Although there may be a federal presence in encouraging or mandating some of these measures, most TCMs require local implementation.

[vii] This report does not imply that each of these targets is effective or that decision-makers should attempt to meet all three targets. Rather, these are three methods that could potentially reduce greenhouse gas emissions.

[viii] Transportation control measures are often discussed in the context of criteria pollutant emissions. Sixteen TCMs are specifically listed in the 1990 Clean Air Act Amendments.

Vehicle travel reduction strategies may be divided into the following categories:

- Travel pricing mechanisms;
- Provision of alternative modes;
- Parking management;
- Land use planning measures; and
- Other measures.

5.2.1 Travel Pricing Mechanisms

Motor vehicle travel involves a cost to the user in terms of both monetary price as well as the value associated with the time spent in travel. Faced with alternative modes of transportation and routes, individuals make travel decisions on the basis of the variable costs that are incurred each time a trip is made.[ix] Vehicle travel demand is inversely related to the user-perceived variable cost of vehicle travel—as costs increase, the demand for motor vehicle travel decreases. The inverse nature of the relationship between travel demand and travel cost serves as the rationale for pricing and tax strategies designed to curb motor vehicle travel.

The effectiveness of policies designed to increase travel costs depends on the response of travel demand to travel price. This response is estimated by the *elasticity* of vehicle miles traveled (VMT) with respect to its variable cost, which represents the percent change in VMT associated with a certain percent change in variable user costs per mile.[x] In some cases, market strategies involve shifting a previously subsidized cost onto drivers or making a previously fixed cost into a variable cost. Economic theory suggests that incorporating the full social costs of travel into its price will result in a more efficient level of travel.[xi]

The economic literature contains a range of elasticity estimates of VMT to variable costs, ranging from about -0.20 to nearly -1.00.[2] For example, a study by Dahl from the 1980s suggested a long-run elasticity of VMT to its variable costs of -0.95, which means that a 10 percent increase in variable travel costs will result in a 9.5 percent decrease in vehicle miles traveled.[3] However, some more recent estimates suggest less responsiveness to price. A 1996 study by Haughton and Sarkar suggested that long-run elasticities of vehicle travel with respect to variable costs of travel may be

> ***Effectiveness Estimate***—The Majority Report to the President by the Policy Dialogue Advisory Committee to Recommend Options for Reducing Greenhouse Gas Emissions from Personal Motor Vehicles estimated that encouraging a shift of state and local road subsidies to cost-of-driving (VMT fees) could reduce greenhouse gas emissions by 30 million metric tons by 2005.[1]

[ix] Fixed costs, like auto ownership and most insurance costs, do not vary with the amount of travel.

[x] An elasticity is a dimensionless parameter that measures the percentage change in a factor that will be caused by a 1-percent change in some other factor. An elasticity of VMT to its variable costs of –0.38 implies that a 1-percent increase in the variable cost of travel will produce a 0.38 percent reduction in VMT.

[xi] If variable user costs do not account for the full marginal costs of travel, then individuals will travel more than the efficient level, resulting in a loss to consumer surplus. Variable user costs may not account for marginal social costs if there are externalities, such as air pollution, that create a cost to society but are not perceived by individuals when making driving decisions.

-0.38.[xii] This elasticity predicts that a 10 percent increase in per-mile fuel costs results in only a 3.8 percent reduction in VMT.[4] Not every recent study reports elasticity estimates this low.

Fuel prices affect both vehicle travel and fuel economy. In the near-term, drivers react to increased fuel prices by driving less; over longer periods, higher fuel prices also encourage individuals to purchase more fuel-efficient vehicles. The first effect can be measured in terms of the elasticity of VMT to fuel-cost-per-mile, since fuel price is a component of the variable cost of travel. The second effect can be measured in terms of the elasticity of fuel economy to fuel price.

These two effects may be expressed in one measure, called the elasticity of fuel consumption to fuel price (also called the "own price elasticity of fuel demand"). This value reflects the extent to which fuel price increases yield fuel consumption decreases. Estimates of the elasticity of fuel consumption to fuel price also exhibit a significant range.[5]

Elasticity estimates are very important, since they affect the projected relative effectiveness of pricing strategies versus other strategies. In addition, the level of adoption of pricing mechanisms is an important consideration since pricing that is imposed only on certain trips, time periods, or facilities may encourage shifts in the spatial and temporal distribution of trips, rather than the elimination of vehicle trips.

A number of pricing mechanisms designed to reduce vehicle travel is described below. These include:

- ROAD PRICING;
- VMT FEES; and
- FUEL PRICING

As with most types of taxes and fee increases, these pricing mechanisms have important political ramifications that constrain implementation. Furthermore, equity issues have been cited as implementation barriers. As a result, questions remain as to whether there is the political will to broadly implement these measures.

ROAD PRICING

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Economic Incentive	Near-term Effect	Local, State

Description of Strategy

Roadway pricing involves the use of fees to increase the price of driving in specific facilities or on roadways, or within specific regions. Drivers who have more flexibility in their trip choices (therefore placing a lower value on a specific route or time) will switch to less expensive options, which can include other non-priced roads or alternate modes (such as transit, high-occupancy vehicles, bicycling, or walking). Congestion pricing is a specific type of road pricing where the per trip charge varies by the time of day, based on changes in the demand for travel and resulting congestion. Congestion pricing may encourage drivers to switch their time of travel to less congested times, resulting in a more even distribution of traffic throughout the day.

[xii] The elasticity estimates presented here were derived from Dahl and Haughton and Sarkar's regression analyses, which presented an elasticity of VMT to fuel cost-per-mile. Elasticity of VMT to variable travel costs was estimated by dividing the elasticity of VMT to fuel cost-per-mile by the fuel cost share of variable costs, not including travel costs. Fuel costs were assumed to be 58 percent of variable costs per mile, from American Automobile Association. *Your Driving Costs.* 1996 Edition.

Road pricing is usually assessed at one or more points along a road. Currently, twenty states have toll roads, bridges, or tunnels with costs averaging between $0.02 and $0.10 per mile.[6] Toll booths traditionally have been pricing points in these systems; however, automation is playing an increasingly large role in road pricing. Road pricing often occurs at specific facilities such as bridges, tunnels, or similarly small and easily controlled segments of road. Cordon pricing is a related measure, which may be applied to a larger region where congestion is a severe problem. Cordon pricing establishes a series of pricing points in a ring around the congested area, whether it be a central business district or a greater metropolitan area. Motorists are charged as they enter the cordoned area.

Effectiveness Factors

Road pricing has the potential to reduce VMT across the entire in-use motor vehicle fleet, unlike some other pricing mechanisms that only affect new vehicles. The effectiveness of road pricing as a greenhouse gas reduction strategy depends on a number of factors, including:

- Level of fee that would be charged;
- Current cost of driving per mile;
- The responsiveness of travelers to the price of travel (measured in terms of price elasticity); and
- The nature and extent of pricing.

Road pricing directly addresses the demand for travel. As discussed earlier, the impact of travel pricing depends on the elasticity of VMT to the variable price of travel, which is a subject of debate. A 1991 study conducted for the Southern California Association of Governments investigated the potential congestion impacts of facility and area pricing schemes. Assuming an elasticity of -0.33, the study examined a fee of $0.15 to $0.25 per mile within the 800 miles of congested freeways in the region during a four-hour a.m. peak. This fee was estimated to increase speeds by 10 to 20 percent and to reduce VMT by 8 to 12 percent (600 to 900 million VMT annually).[7]

Since there are many possible ways to implement road pricing, the nature and extent of pricing affects the level of greenhouse gas reductions achieved by the strategy. Roadway fees may be applied based on miles traveled, as is practice on many turnpikes. If roadway fees are varied by the time of day, they are likely to have greater impacts on congestion than on VMT, since vehicles will be encouraged to make temporal shifts in addition to modal shifts in their driving patterns. While these temporal shifts do not reduce VMT, the improved flow of traffic does result in lower emissions of greenhouse gases and greater fuel efficiency. Fees based on vehicle occupancy create an incentive to carpool.

Effectiveness as a national strategy will depend upon the degree to which states and localities adopt road pricing on individual roads. Unlike some other market based measures, road pricing generally only affects a segment of vehicle travel, since pricing typically is imposed only on specific facilities rather than uniformly on all roads. Road pricing would most readily be applied only to interstates and other freeways, which comprise less than a quarter of all vehicle miles traveled nationwide, but up to 40 percent in major metropolitan areas.[8] Road pricing may be most effective in regions that offer alternative modes such as transit and that facilitate ridesharing. In places where there are few alternatives to vehicle travel and where ridesharing is difficult due to dispersed land use patterns, road pricing will be less effective.

Timing

Road pricing has an immediate effect on traveler behavior, encouraging a shift to higher occupancy vehicles and alternative transport modes. Effectiveness may change over time if significantly high levels of road pricing encourage residential or commercial relocation.

Implementation Issues

The use of roadway pricing has been facilitated in recent years by significant advances in technology that can reduce operational costs, radically improve traffic movement (by eliminating the need to stop at toll plazas), and facilitate toll collection and enforcement. The major innovations include automatic vehicle identification (AVI), which utilizes vehicle-mounted transponders and roadside sensors, and automatic toll collection (ATC), which often uses pre-paid monthly balances to facilitate billing.

Low public acceptance can be a crucial roadblock to implementation of roadway pricing measures. Road pricing may be politically unpopular for a number of reasons. First, charging a fee on facilities that have traditionally been free often generates public dissatisfaction.[xiii] Perhaps the leading objection to road pricing is that this measure is regressive and would disproportionately affect lower-income drivers. In the case of congestion pricing, drivers who could not alter their time of their trips due to inflexible work schedules would have no option but to pay the fees.[xiv] A cordon zone pricing system around a central business district or downtown could conflict with land use strategies that seek to encourage employment in developed areas, though the land use impacts of cordon pricing are still being debated.

Several US cities are either planning or have recently implemented single lane pricing projects, most commonly high occupancy toll (HOT) lane projects, which permit single occupant vehicles (SOVs) to use high occupancy vehicle (HOV) lanes during peak-travel periods if they are willing to pay a charge. HOT lanes may be a means to introduce the concept of pricing in an acceptable way to the public. In fact, HOT lane projects in Los Angeles (State Route 91 Express Lanes) and San Diego (I-15 HOV/Express Pass Lanes) have not met with serious public resistance since opening in December 1995 and November 1996, respectively.

AVI technology and toll systems that identify the time and location of vehicles traversing pricing points may be viewed as an invasion of privacy for individuals. Although the privacy issues may be solved with technology that allows accounting to be done in-vehicle (by deducting value from an on-board debit card) rather than centrally, failure to address privacy issues could make implementation more difficult.

Despite these significant political-feasibility hurdles, states and localities may wish to adopt road pricing because it yields localized benefits. The benefits of road pricing include improved regional air quality, more efficient use of the highway network, and improved travel reliability. In addition, revenues from road pricing may be used to fund other transportation investments or needs.

[xiii] However, when the public receives an improvement in some aspect of travel in exchange for a fee, the trade-off is generally viewed more favorably. In severely congested parts of California, some roadway pricing proposals have been implemented because of the perception that the potential time savings would be well worth the price. Significant public outreach and education explaining the project and how the revenues would be used also have helped to achieve public acceptance.

[xiv] In response to income inequity, it is possible to establish a system of rebates for lower-income drivers. Another option which has received much attention in the literature is the option of providing a lifeline—a certain allotment of free or lower priced trips that would conceivably allow low-income drivers to continue their daily commutes. These options would apply to drivers who meet specific income qualifications and would not be difficult to implement with AVI and ATC technologies.

VMT FEES

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Economic Incentive	Near-term Effect	Unknown

Description of Strategy

A VMT fee refers to a charge that is levied on an annual or semi-annual assessment based on the number of vehicle miles traveled per year. This system could work in tandem with existing vehicle registration fees and inspection and maintenance programs.

Effectiveness Factors

VMT fees target reductions in vehicle miles of travel. Unlike road pricing measures where costs can be reduced by switching travel times, use of routes, or type of vehicle used, the only way for an individual to reduce costs under this measure is to drive less, thus reducing traffic and emissions. VMT fees do not, however, discourage peak-period driving (since every mile costs the same regardless of when it is driven) or encourage a shift to cleaner burning engines. They are not facility- or time-specific and so affect the entire vehicle fleet.

Effectiveness as a national greenhouse gas emissions strategy depends upon:

- Level of fee that would be charged per mile;
- Current cost of driving per mile;
- Responsiveness of travelers to the price of travel (elasticity of demand for VMT); and
- Extent of adoption nationwide (number of states that adopt VMT fees or Federal adoption).

Some economists believe that even though these fees are charged per mile of travel, drivers may not respond as strongly to VMT fees as to other travel pricing measures since the fees would only be charged on an annual basis or semi-annual basis. A 1994 study conducted for the Puget Sound Regional Council analyzed the potential impacts of VMT fees in the Puget Sound area as well as in the San Francisco Bay area. The fees ranged from \$0.01 to \$0.05 per mile and yielded 9.3 to 11 percent decreases in VMT and 8 to 20 percent decreases in carbon dioxide.[9]

Timing

Travel pricing should have an immediate effect on traveler behavior, encouraging a shift to higher occupancy vehicles and alternative transport modes. Implementation may require some time since this strategy has not been implemented in the US to date; consequently, there is no experience upon which to build.

Implementation Issues

Like other market-based measures, VMT fees raise concern regarding political feasibility and issues of equity. Taxpayers may suffer "sticker-shock" when they receive their VMT fee assessments. A fee of \$0.05 per mile results in an annual VMT tax assessment of over \$566 for the average vehicle (which traveled 11,329 miles in 1995).[10] A household with two vehicles could easily receive a tax bill of over \$1,000 annually in association with this VMT fee. Even if other taxes are reduced, this "new tax" could be extremely unpopular. In addition, such taxes may be regressive in nature, unless designed to take equity into account.[xv] Developing a system to accurately assess vehicle miles traveled and address odometer tampering could be difficult. Despite significant implementation hurdles, states may wish to implement VMT fees because they have local benefits, including reduced traffic congestion and air pollutant emissions.

FUEL PRICING

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel Increase Fuel Economy	Economic Incentive	Near-term Effect	Federal, State, Local

Overview of Strategy

Fuel taxes have long been used in this country to recover road construction and maintenance costs. However, in recent years, raising federal and/or state fuel taxes has increasingly been viewed as a potential tool to reduce VMT and improve fuel efficiency. Currently fuel taxes comprise 30 to 40 percent of fuel prices, but a very small percentage of total car ownership costs.[11] Fuel tax advocates point out that American gasoline prices are a mere fraction of those in other industrialized nations, where the price of a gallon of gasoline can cost $2 to $3 more than in the US.[12] In addition to a conventional gas tax, there are alternative methods to increase the price of gasoline, which would have similar effects. Pay-at-the-pump insurance is a measure in which a portion of auto insurance costs would be collected through a per gallon premium on gasoline. Such a measure would convert a fixed cost of driving into a variable cost.

Effectiveness Factors

The effectiveness of fuel taxes as a national greenhouse gas emissions strategy depends upon:

- Level of the gas tax increase; and
- Long-term responses to the price of fuel, such as reductions in travel and increases in vehicle fuel economy.

Changes in fuel tax prices have two long-term effects:

- Increasing fuel prices raises the price of travel per mile, which encourages consumers to reduce vehicle miles of travel (measured in terms of the elasticity of VMT with respect to fuel-cost-per-mile).
- Since the amount paid for fuel is directly proportional to the amount of fuel consumed, fuel pricing provides incentives for the purchase of more efficient vehicles (measured in terms of the elasticity of fuel economy with respect to the price of fuel).

The effectiveness of fuel pricing depends on consumers' responses to increases in the price of fuel. Advocates of higher fuel taxes point to their ability to levy the costs at the source of the activity, thus making the cost more visibly related to the act of driving. Fees that are separated from their root behavior

[xv] While flat VMT fees may be regressive in nature, proposals have been developed to remedy this problem. One concept, called a "lifeline mileage" would provide drivers with some allotment of free miles, such as 2,000 miles per year, to allow a driver to commute to work daily at no cost. Another pricing option would begin with a certain allotment at no cost and assess a higher cost for each graduated level of vehicle miles. For example 1 to 2,000 miles at no cost; 2,000 to 5,000 miles at $0.25 per mile; and 5,000 to 10,000 miles at $0.40 per mile. Utility providers such as water suppliers already use this type of graduated fare structure.

may be less effective in influencing changes in that behavior. The oil crises of the 1970s are often cited as an indication of the enormous sensitivity of the American public to radically increased gasoline prices. However, some economists argue that scarcity and uncertainty about future price shocks played more of a role in those situations than price.[13] This argument is reflected in elasticity estimates for gasoline demand.

Elasticity estimates in economic literature have a significant range. Estimates from Dahl (1986), suggest that the elasticity of fuel demand to fuel price may be -0.81, meaning that a 10 percent increase in fuel price leads to an 8 percent decrease in fuel consumption. Large price elasticities, such as this estimate, suggest that tax policies to reduce fuel consumption could be successful.[14] However, Haughton and Sarkar's study (1996) yields an elasticity of -0.38, suggesting that a 10 percent increase in fuel price leads to less than a 4 percent decrease in fuel consumption.[15] Many recent studies suggest lower effectiveness of fuel pricing than some of the older studies. For example, Gately (1993) estimated a long-run fuel price elasticity of -0.21 for fuel price increases.[16] Some analysts postulate that consumers are now less responsive to fuel prices since fuel prices account for a much smaller portion of travel costs per mile than in the past, due in part to historical improvements in vehicle fuel economy and falling real gasoline prices.[17]

Some economists suggest that price increases on the order of 5 to 10 percent are ineffective, since fuel prices can vary by that much at different gas stations within an area as small as a few blocks or over a time period as short as a year.[18] However, even if the elasticity of VMT with respect to gasoline prices is small, the impact of gasoline taxes may be significant relative to other policy instruments, since the emission reduction benefits are realized across the entire motor vehicle fleet.

Timing

An increase in fuel taxes should have an immediate effect on traveler behavior, encouraging a shift to higher occupancy vehicles and alternative transport modes. This option can be implemented relatively quickly since existing legal mechanisms and institutional authorities exist, and there is experience with this strategy.

Implementation Issues

Increasing fuel taxes would not require the introduction of a new pricing mechanism, only a readjustment in the rate of the current system. As a result, a fuel-tax increase would be easy to administer and collect. However, setting the appropriate rate of taxation to achieve a specific result is significantly more difficult. A pay-at-the-pump insurance program could be more complicated to design since it involves reimbursing insurance companies. Both the federal and state governments have experience with fuel taxes.

Although the federal government and all states levy gas taxes, the idea of increasing gas taxes may draw considerable political opposition. The contentious political debate surrounding the increase in the federal gas tax of $0.04 per gallon in 1996 suggests that large gas tax increases necessary to significantly reduce greenhouse gas emissions may be difficult. Some analysts have suggested that prices would have to be raised by more than $1.00 per gallon to have a large effect on national emissions.[19] Other researchers have estimated that to reduce CO_2 emissions from light-duty vehicles to 1989 levels by 2000, the federal gas tax would need to increase from $0.09 to $0.40 per gallon by 2000 and $0.50 by 2010 (in 1989 dollars).[20] An analysis of gas taxes by DRI (1991) indicated that to hold emissions level, the gas tax would need to rise by $0.28 per gallon in 2000 and by $0.48 per gallon in 2010.[21] Such large increases present a major political challenge. Furthermore, price increases designed to affect behavior may be viewed more negatively than those designed to finance infrastructure.[22]

In addition to political pressures, increasing fuel taxes can create border issues. If the higher costs are levied over a small region, residents of that region will tend to drive to other areas to purchase less expensive fuel, undermining the goals of the measure. Even when a tax is levied on a large region or a state, border communities will still face this possibility. Unless the measure is applied at the federal level, some consideration would have to be given to potential border problems.

Equity concerns can also be an important barrier to implementation of this strategy. Low-income commuters, drivers with no alternative mode available, and those whose work requires significant auto travel would be disproportionately affected by an increase in the gas tax.

Since gas taxes raise travel costs, they could impair economic activity that depends on transport. However, economic theory suggests that taxes that account for externalities can enhance the overall efficiency of the economy. In addition, gas taxes raise revenues that can serve state or national investment needs.

5.2.2 PROVISION FOR ALTERNATIVE MODES

Actions that provide or improve alternatives to single occupancy vehicle (SOV) travel may reduce dependency on personal vehicles and encourage shifts away from vehicle use. Alternatives to SOV travel include transit, bicycling, and ridesharing. Improvements to travel time, reliability, frequency of service, and comfort of these alternatives reduce the relative costs of these modes compared to SOV travel. A national greenhouse gas reduction strategy may include investment in the following:

- TRANSIT;
- BICYCLE-SUPPORT FACILITIES;
- PARK-AND-RIDE FACILITIES; and
- HIGH OCCUPANCY VEHICLE (HOV) LANES.

Decision-making for these investments is local in nature, often reflecting needs determined by states and metropolitan planning organizations. However, there may be a federal role in encouraging investment in alternative modes.

TRANSIT INVESTMENT

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Infrastructure Investment	Mid-term Effect	Federal, State, Local

Description of Strategy

Investment in transit buses and railways may involve a range of projects, including:

- *System/Service Expansion*—Expansion may include the addition of new fixed guideway, express bus, local bus, or paratransit services to extend geographic coverage.
- *System/Service Operational Improvements*—Improvements include splitting routes, transfer improvements, schedule coordination, and increased vehicle frequency. In addition, service can be improved through the addition of passenger amenities, such as the addition of bus

shelters, station improvements, safety and security enhancements, vehicle comfort improvements (air conditioning and seating), signage, and elderly/handicapped access.

Effectiveness Factors

Since transit is a motorized form of transportation, the effectiveness of transit investment at reducing greenhouse gases depends on the following factors:

- The level of improvement in transit frequency, coverage, or amenities;
- The extent to which increased transit investment reduces motor vehicle fuel consumption (which depends on the extent to which transit causes shifts in mode of travel, improvements in traffic flow, and any offsetting increases in travel due to improved traffic flow); and
- The extent to which any increases in transit fuel consumption offset these reductions.

There is some debate about the extent to which transit investment can reduce personal vehicle travel. When developing a new transit system, planners generally assume that ten trips on the new system will eliminate fewer than ten auto trips since some of the transit trips are new trips induced by building the new system and others have been captured from other transit systems or routes. Some warn that mass transit will have little effect at encouraging drivers to change their mode of travel since it is not compatible with most US automobile users' travel needs for flexibility and convenience, nor is it compatible with existing low-density land use patterns. On the other hand, others claim that transit has a "magnifying effect" in reducing auto travel since transit affects land use in ways that reduces the need to travel. An analysis conducted by the Natural Resources Defense Council (NRDC) and the Sierra Club suggests that each new transit mile traveled replaces four to eight miles of auto travel due to changes in land use that might result from transit development.[23] Assumptions about the degree to which transit eliminates vehicle trips affect estimated emissions benefits.

In addition, by encouraging people to switch modes, transit could improve traffic flow in some areas. Improved traffic operations could reduce fuel consumption per mile, but also could encourage additional drivers to take to the road, which would offset some of the VMT reduction.

Since transit is a motorized form of transportation, net reductions in emissions depend on the level to which increased transit fuel consumption offsets reduced energy consumption from personal vehicles. If new transit lines only carry a small number of passengers, the average energy savings from transit may be minimal (or even negative) on specific routes. Data from the US Department of Energy suggest that on a national basis average energy use per passenger mile, and thus net CO_2 emissions, is higher for transit than for the automobile travel, as shown in Exhibit 5-3:

Exhibit 5-3. Comparative Energy Consumption of Autos and Transit

Mode	BTU per passenger mile
Automobiles	3,593
Rail Transit	3,687
Transit Buses	4,374

Source: US Department of Energy. *Transportation Energy Data Book.* 15th Edition, Table 2.15, p.2-25.

These statistics indicate that transit expansions should be planned carefully to target areas with sufficient ridership. The effectiveness of transit is closely related to land use patterns. High-capacity transit is often not cost-effective for suburb-to-suburb trip patterns, which are prevalent in urban travel. The increasing importance of non-work trips also implies that an increasing portion of travel is not part of the traditional transit commuter markets.[24] Improvements in transit routing, publicity, and service to underserved areas may attract ridership without requiring the operation of additional vehicles.

The effectiveness of transit to reduce greenhouse gas emissions may be small at the national level. Transit comprises a small portion of national travel—only 0.9 percent of total passenger miles in the US in 1994.[25] An analysis by Apogee Research, Inc. suggested that transit improvements can reduce VMT by up to 2.6 percent in metropolitan areas, and most likely by only 1.0 percent.[26] Despite these small effects, a significant portion of the literature suggests that transit is an important supporting measure for a variety of transportation control measures (TCMs), including road and fuel pricing. At the national level, emissions effects will depend upon the extent of increases in transit service feasible in urbanized areas. Vanpools, paratransit, and demand-responsive transit may be more appropriate for less urbanized areas.

Timing

Changes in transit bus routing and frequency can be implemented quickly. Infrastructure-intensive development of new fixed-route transit would take many years to reach completion, and changes in land use patterns resulting from transit would occur over a much longer time frame.

Implementation Issues

A key implementation concern with transit is the financial cost involved, particularly for fixed rail systems. In addition, fixed rail systems may expose a variety of planning and environmental concerns, as with any major transportation investment.

On the other hand, local areas may look upon transit favorably due to its potential benefits for congestion relief and improvements in air quality. In addition, transit provides mobility for segments of the population such as the young, the elderly, and the disabled, who are less likely to have access to automobiles. Transit is also seen as a potential tool for reorienting metropolitan land use patterns and for revitalizing urban central areas that have lost population and employment.

Bicycle Support Facilities

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Infrastructure Investment	Near-term Effect	Local

Description of Strategy

Strategies that enhance the environment for bicycles and bicycling as an alternative to single occupancy vehicles (SOVs) include:

- Development of bicycle routes, lanes, or paths;
- Provision of lockers, racks, other storage facilities, and ancillary facilities (such as showers, and clothing lockers);
- Integration with transit, either at stations or on vehicles;

- Educational, media, and promotional campaigns, including provision of bicycle maps; and
- Hiring of a local government or employer-site bicycle coordinator.

Effectiveness Factors

The potential of bicycle-support strategies to reduce greenhouse gas emissions depends on:

- The extent to which bicycle investment causes shifts in modes of travel;
- The extent to which metropolitan areas adopt bicycle-investment strategies; and
- Improvement in traffic flow (which could encourage some offsetting vehicle traffic).

Most estimates of VMT reduction from bicycle and pedestrian strategies are relatively low.[27] Bicycle trips are generally limited to short trips. In addition, the potential number of trips that individuals may shift to bicycle is constrained by weather conditions, topography, and individual health and fitness. Any improvements in traffic flow due to bicycling could reduce carbon emissions further. However, improved traffic flow could encourage additional vehicle travel, which could offset some of the direct VMT reduction.

Estimates of VMT reductions from bicycle projects suggest that for a metropolitan area, bicycle projects may reduce regional VMT from under 0.01 percent to over 3 percent, with the latter figure assuming capital construction of facilities and an already existing favorable land-use configuration.[xvi]

Timing

Design and construction of bicycle facilities such as bicycle trails and provision for bicycle lanes can take a number of years, whereas supporting measures, like provision of bicycle racks may be implemented immediately. Effects on travel should be near-term or almost immediate.

Implementation Issues

Bicycle projects are generally implemented at the local level, often with some funding from state and/or federal sources. Local governments, developers, or individual employers may invest in bicycle-support strategies. Funding constraints may be a key issue given a variety of funding needs for various types of transportation investments. In addition, land issues, such as taking right-of-way corridors that could be used by other modes, could be barriers to implementation.

Improved bicycle facilities may provide additional recreational opportunities and improve mobility for those without access to motorized vehicles. In addition, bicycling is an entirely "clean" form of transportation that emits no pollution. For the individual, bicycling may result in improved physical fitness and personal satisfaction.

[xvi] According to Harvey and Deakin's 1991 study for the San Francisco Bay area, a bicycle support strategy could result in a 0.01 to 0.02 percent reduction in regional VMT. An estimate of traffic calming and bicycle investment in the Washington, DC region by Replogle suggested that it could result in a 0.9 percent reduction in VMT in 2000 and a 3.5 percent reduction by 2010.

PARK-AND-RIDE FACILITIES

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Infrastructure Investment	Near-term Effect	State, Local

Description of Strategy

Park-and-ride lots serve as a collection point for individuals in carpools, vanpools, and various types of shuttle services, and may serve bus or rail transit. The goal of investment in park-and-ride facilities is to encourage use of these modes rather than single occupancy vehicles (SOVs). Park-and-ride lots may be connected to high occupancy vehicle (HOV) lanes or express transit service.

Effectiveness Factors

Factors that influence national effectiveness include:

- Degree to which park-and-ride facilities reduce vehicle travel;
- Scope of program (i.e., number of facilities constructed); and
- Improvement in traffic flow (which could encourage some offsetting vehicle traffic).

The emissions-reduction potential of park-and-ride facilities is limited because they reduce only the length of vehicle trips, not vehicle trip-making (individuals must drive to the parking facility). In addition, they are primarily suited to reduce long-distance commute travel in urbanized areas, which is only a portion of VMT. Increases in carpooling could also come at the expense of transit ridership. Secondary improvements in traffic flow due to reduced VMT could reduce carbon emissions further. However, improved traffic flow could encourage additional vehicle travel and offset some of the direct VMT reduction from carpooling and transit use.

A review of the literature by Apogee Research, Inc. (1994) found that park-and-ride lots might be effective at reducing regional VMT in metropolitan areas by between 0.1 and 0.5 percent.[28] This estimate is within the range of many other conventional TCMs. On a national basis, the percent reduction in VMT may be somewhat smaller since park-and-ride lots are most appropriate for mid- to large-size metropolitan areas and would not be as effective in rural areas or small towns.

Timing

Park-and-ride lots should yield near-term effects, which may increase somewhat over time as individuals develop arrangements to carpool or vanpool. Construction may take a number of years.

Implementation Issues

Primary concerns with developing park-and-ride facilities include financial costs, as well as environmental issues related to planning and design, such as the need for additional right-of-way and noise barriers. However, park-and-ride lots may receive relatively little public opposition. By encouraging ridesharing and transit use, park-and-ride lots may reduce traffic congestion and alleviate regional air quality problems.

HIGH OCCUPANCY VEHICLE (HOV) LANES

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Infrastructure Investment	Mid-term Effect	State, Local

Description of Strategy

High occupancy vehicle (HOV) lanes are specific lanes designated for use only by vehicles carrying two or more individuals (HOV-2) or three or more individuals (HOV-3). HOV lanes encourage carpooling and vanpooling by reducing travel time and reversing the time penalty generally incurred in picking up passengers. HOV lanes also reduce travel time for transit buses. They may be developed on freeway or arterial facilities. Lane restrictions are often limited to peak-hour driving periods.

Effectiveness Factors

The effectiveness of HOV lanes depends on the following factors:

- Extent to which HOV lanes reduce vehicle travel (encourage carpooling at the expense of SOV travel);
- Improvement in traffic flow;
- Indirect effect of reduced highway congestion to induce additional vehicle travel; and
- Scope of program (i.e., number of facilities constructed).

By improving travel times on congested routes, HOV lanes can be a significant incentive to rideshare. However, the benefits of HOV lanes may be diminished if they encourage carpooling at the expense of transit. Some individuals may divert from transit to carpools with the addition of lanes.

A number of analyses suggest that the net benefits of HOVs are positive. A study of HOV lanes on Interstate 5 in Seattle determined that adjusting for the growth in households and income, the increase in vehicles from 1978 to 1989 was less than had been projected originally without the HOV lanes for each year after the HOV lanes became available. It projected that the benefits increased over time, with a 6 percent reduction of VMT in 1984 to a 35 percent reduction in 1989.[29]

HOV lanes are mainly effective at reducing peak-period travel on highly congested freeways and arterials. The regional effect of HOV lanes is generally smaller than the reduction in any one corridor. Apogee Research, Inc. estimated that HOV lanes could reduce regional VMT by up to 1.4 percent in major metropolitan areas.[30] National effects would likely be somewhat smaller since HOV lanes would not be implemented in small towns and rural areas.

Timing

HOV facilities should yield short-term results, which may build somewhat over time as individuals develop arrangements to carpool or vanpool. Construction may take a number of years.

Implementation Issues

Primary concerns with developing HOV lanes include financial costs, as well as environmental issues related to planning and design (such as the need for additional rights-of-way and noise barriers). In addition, there may be issues involving setting the proper HOV restrictions, and there may be some public discontent if HOV status is placed on lanes that were once open to all traffic. On the other hand, by encouraging ridesharing and transit use, HOV lanes may reduce traffic congestion and alleviate regional air quality problems.

5.2.3 Parking Management

Parking is an essential component of vehicle travel. One must be able to find a space and be willing to pay the price to park in order to use a vehicle. Parking management strategies attempt to reduce vehicle travel by increasing the user costs associated with parking, in terms of monetary price, travel time, or convenience. Parking management may involve increasing the monetary price of parking or limiting supply such that individuals need to search longer for parking or park further from their destinations. It may also involve preferential treatment for carpools.

Parking management strategies include:

- Parking Pricing;
- Mandatory Parking Cash-Out; and
- Parking Supply Limits.

Parking Pricing

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Economic Incentive	Near-term Effect	Local

Description of Strategy

A parking pricing strategy would increase the user costs of driving by increasing the level or extent of parking pricing. Measures include increasing fees at municipal facilities or adding parking meters to previously free on-street spaces. Taxing private-parking operators can also raise the market price of all parking facilities within a region.

Effectiveness Factors

The effectiveness of parking pricing as a greenhouse gas strategy depends upon:

- The response of drivers to parking prices (reflected by price elasticities);
- The level of pricing increase; and
- The extent of pricing.

Case studies of employer-based programs that involved raising employee parking fees to market rates have shown significant decreases in vehicle use, in the range of a 26 to 81 percent decrease in solo driving. Case studies of differential parking rates for SOVs and HOVs also show significant reductions in vehicle travel. A 1996 study examined eight employer programs in California, where parking measures have received considerable attention. The study found that, on average, the employers reduced VMT by 12 percent per employee per year as a result of the program.[31]

Some economists have found that parking charges may have a greater effect on travel behavior than other costs since parking charges are often incurred on a trip-by-trip basis (a separate money transaction must be undertaken with each trip), unlike fuel purchases and other operating costs which are made periodically. A review of parking studies by Feeney (1988) suggests that there is great variation in the parking price elasticities quoted but that a number of studies provide estimates from -0.20 to -0.32.[32] However, some case studies of parking pricing have shown mixed results at reducing VMT since commuters merely shifted parking location to unpriced spaces.[33]

Adding parking meters to on-street spaces and increasing municipal parking charges may be effective in places where drivers depend on these facilities. Most employment sites and commercial establishments, however, provide free parking to their employees and customers. As a result, individual drivers may not be aware of the increase in parking prices in cases where parking is subsidized. The national effect of parking pricing depends upon the extent of local adoption of this strategy.

Timing

Parking pricing would have an immediate effect on travel behavior. Most pricing measures could be implemented relatively quickly.

Implementation Issues

Businesses may be hesitant to implement parking pricing for fear that it will drive away customers or reduce employee satisfaction. Drivers view parking charges with disfavor and may seek out alternative spaces for parking if pricing is not imposed uniformly. Some analysts encourage the implementation of parking pricing policies on a region-wide basis rather than by individual employer in order to prevent overflow parking on residential streets or surrounding lots. However, few areas have made such efforts.

Municipalities may wish to expand parking pricing since it provides revenues to local government, which can be used for a variety of needs. It also can reduce congestion, air pollution, and other externalities associated with vehicle travel. Case studies suggest that parking pricing strategies are most effective in areas where transit is already available. The option of alternative modes to vehicle travel increases the extent of modal shift. Similarly, van- and carpool creation can be increased when supporting services such as rideshare and park-and-ride are offered.[34]

MANDATORY PARKING CASH-OUT

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Economic Incentive	Near-term Effect	Federal, State, Local

Description of Strategy

About 95 percent of those who commute to work by automobile in the US use free parking provided by their employers, and nearly all vehicle trips for non-commute purposes also include free parking.[35] Part of the reason for this high rate is that the US tax code has subsidized employer-provided parking by exempting employer parking costs from federal and most state income and payroll taxes as a fringe benefit, provided the employer does not offer cash salary in lieu of the parking space. The Tax Relief Act of 1997 removed the restriction against offering taxable cash in lieu of tax-exempt parking benefits. A "mandatory parking cash-out" policy would make mandatory what the new tax law made possible. It would require employers who provide subsidized parking to also offer their employees the option of receiving taxable income instead of parking. Since employees would be given the choice between a parking space and taxable income, they would perceive the opportunity cost of driving to work in terms of the income forgone.

Effectiveness Factors

Although documented experience with the parking cash-out concept is limited, its effectiveness in reducing auto use can be estimated based on experience with parking charges. Factors that affect national emissions include:

- Current cost of driving per mile;
- The response of drivers to increases in the opportunity cost of driving (reflected by price elasticities); and
- The degree to which employers adopt cash-out policies (strategy could be limited to large employers).

A number of studies have suggested that a national mandatory parking cash-out policy may result in significant reductions in travel and fuel consumption. An evaluation of a mandatory parking cash-out program in California used an elasticity of VMT to the out-of-pocket variable costs of travel of -0.16 based on parking pricing studies. Using this elasticity assumption, a mandatory cash-out program in California was estimated to reduce VMT and gasoline consumption by about 10 percent from Los Angeles Central-Business-District commuters.[36] Assuming elasticities of home to work VMT with respect to cost of 0.1 to 0.2, the Climate Change Action Plan estimated that reforming the federal tax subsidy would reduce light-duty VMT by approximately 25 billion miles, or 1.1 percent, in the year 2000.[37]

The national effect on greenhouse gas emissions depends upon the extent to which employers actually offer the cash-out to their employees and the alternative transportation options available to employees.

Timing

Effect on behavior should be in the very near term.

Implementation Issues

Implementing a parking cash-out policy may be simpler than congestion pricing or other efforts to raise the price of travel, since it does not require technically complex forms of paying for road use or congestion. A parking cash-out program might garner less political resistance from the public than other market-based programs since it does not directly increase costs for employees. States may wish to implement a mandatory cash-out policy as a measure to reduce congestion and improve air quality. Eliminating the tax subsidy would also generate tax revenue, as a result of some employees accepting taxable income in lieu of parking, which could be used for transportation or other programs.

Still, some implementation problems may be significant. The state of California passed a mandatory parking cash-out measure for large employers, but it has been largely unenforced. There have been difficulties in assessing the value of parking in many cases where parking is bundled with the building lease. In other cases, a firm may own both the building and the parking facility or have committed to a multi-year lease.

PARKING SUPPLY LIMITS

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Regulation or Incentives	Long-term Effect	Local

Description of Strategy

A number of policy instruments are available for government to attempt to limit the supply of parking for SOVs, including:

- Maximum parking-supply ratios in zoning;
- Reduced or eliminated minimum-parking ratios in zoning;
- Area-wide parking caps; and
- Restriction of access to parking at certain times of the day, for certain durations, or to certain classes of users (i.e., preferential parking for HOVs).

Parking supply measures that involve zoning are regulatory in approach, but no more restrictive than zoning codes that are common for development. In fact, eliminating or reducing minimum parking ratios reduces restrictions and allows the market more control over parking supply. Ordinances may also provide incentives to developers, such as allowing increases in development density in return for reduced parking supply.

Effectiveness Factors

The effectiveness of parking supply measures depends on:

- How required parking supply relates to parking demand (parking supply restrictions will have little effect if they are set too high);
- Rates of growth in development; and
- The extent of local adoption nationwide.

Experience with a number of parking supply management techniques shows mixed effectiveness. For example, case studies of preferential parking for HOVs at Arkansas State Government in Little Rock, Hallmark Cards in Kansas City, Government Employees Insurance Company in Bethesda, and the US Pentagon showed increases averaging about 100 percent in carpool rates. However, preferential parking at numerous employment sites in downtown Seattle and Sunnyvale, CA showed little use of preferential spaces. Most evaluations are based on specific local examples.[38]

Similarly, an analysis of parking supply ratio programs shows mixed effectiveness. A 1995 analysis of maximum parking supply ratios in downtown Portland by Apogee Research, Inc. found that this policy may have reduced parking supply and VMT.[39] Since 1975, when the policy was adopted, Class A office space has more than doubled and the number of employees working downtown increased by more than 30 percent, while the number of parking spaces increased by only 12 percent, and the average number of off-street parking spaces per worker has dropped from 0.44 to 0.38. The US EPA reported a successful parking supply program in Bellevue, Washington in the early 1980s. The city reduced its minimum-parking requirement from three to five spaces to two spaces per 1,000 square feet of office space, and instituted a flexible minimum. In some cases, developers requested parking supplies less than the minimum, suggesting that they were willing to reduce parking supply.[40]

However, a recent case study of zoning restrictions on parking supply in Atlanta, Georgia, found that such policies can be ineffective. To attract new development and to improve transit ridership around Midtown rail transit stations, Atlanta has used for two decades Special Public Interest Districts (SPIDs), which offer developers no minimum parking supply ratios. The researchers found that there was no significant difference in parking ratios between buildings constructed inside or outside of SPIDs. In fact, the average ratio inside SPIDs (2.1 spaces per 1,000 square feet) was slightly higher than outside SPIDs (2.0 spaces per 1,000 square feet). The authors postulated that competitive market conditions and financier considerations led to approximately equal parking ratios. In addition, there was a proliferation of parking throughout Midtown, as owners of vacant land built surface lots. Since the SPID policy does not manage total parking supply, the authors concluded that without areawide parking supply efforts, policies patterned after Atlanta's SPID program will have limited success in improving transit ridership.[41]

Clearly, the relationship of parking supply to demand and the extent and level of parking supply restrictions will affect a policy's success. Area-wide parking caps that are set above levels of parking demand will have little effect on reducing travel. In addition, parking supply ratios in zoning are limited because they only affect new development. If maximum parking supply ratios are too restrictive, they may encourage development to shift to areas that are not within the bounds of the restriction.

Timing

Parking supply restrictions may require a long time frame to demonstrate a significant effect on national emissions. While restrictions may have a great impact on a particular building or development, even greatly restricted parking supply for new developments could have a minor effect on altering patterns regionally, since existing developments and their parking facilities are already in place.

Implementation Issues

Generally, parking supply restrictions must be implemented at the local level; there is a minimal role for federal or state involvement. Despite potential benefits to air quality and congestion, localities may be averse to adopting parking supply strategies. There have been relatively few documented cases of localities restricting parking supply in commercial areas as a VMT reduction strategy. Parking and auto access tend to be viewed as positive amenities by developers and businesses. Local business districts are often leery to implement programs that reduce vehicle demand—even if conditions are highly congested—due to concerns about business demand. Limited parking could reduce business, as individuals will chose to shop in stores and eat in restaurants that have ample parking. In addition, homeowners feel that demand for parking from commercial areas could spill over to residential areas if adequate parking levels are not supplied.

The direct monetary cost of most parking supply restrictions is negligible if it involves changes in zoning requirements. However, enforcement against meter feeding and parking over time limits in timed zones may be an important element in implementation. For developers, reduced parking supply minimums could result in reduced construction costs. For example, an evaluation of the costs and benefits of reduced parking requirements in King County, Washington, estimated savings in construction costs for structural lots at $4,200 per space and annual operation and maintenance at $200 per year.[42]

5.2.4 LAND-USE PLANNING

The goal of land use planning as a greenhouse gas reduction strategy is to shape development patterns to encourage less vehicle travel and fuel consumption. Land use measures may be examined at both the neighborhood (micro) level and the regional (macro) level.

The layout and development patterns of neighborhoods and sites can take various forms. For example, the physical layout of a neighborhood may include a mix of land uses or separation of uses. A community may be designed to create an environment conducive to travel by transit, bicycles, and walking or one conducive to vehicle travel. Micro-level measures that might reduce fuel consumption from transportation include:

- Increasing density and mix of uses to provide opportunities for pedestrian trips, trip-chaining, and transit access;
- Orienting higher-density development around commercial centers, transit lines, and community facilities to encourage non-motorized trips; and
- Supporting pedestrian and bicycling activity through facilities for non-motorized modes such as sidewalks and bike lanes, urban design improvements, and traffic calming.

Neighborhoods that exhibit many of these characteristics are often referred to as "pedestrian-oriented development" or "transit-oriented development." "Neotraditional design" refers to a development pattern that replicates the design of older urban areas before the advent of the automobile, and often involves grid-street networks, mixed use development, and pedestrian amenities.

Regional development can also take various forms. Regional development can be either concentrated or decentralized. It may contain a few large employment centers or multiple small activity centers. It may be oriented toward transit corridors or dispersed throughout a broad area. Since most individuals do not work within their own neighborhoods, levels of vehicle travel are affected by the regional dispersion of employment and residential development, and the existence of regional travel options. Macro-level measures that might reduce fuel consumption include:

- Increasing the compactness of metropolitan areas;
- Focusing regional development around transit networks; and
- Providing a sub-regional balance of jobs and housing, so that individuals do not need to commute long distances.

Specific tools outlined in the literature include the following:

- Site-based tools—developer incentives, zoning requirements, development standards (density standards, requirements for mixed uses, grid street requirements; area or sector plans); and
- Regional planning tools—urban growth boundaries, concurrency requirements, and location efficient mortgages (LEMs).

Quantitative relationships among land use, travel, and fuel consumption have been examined by various researchers. Although land use patterns may account for 40 to 50 percent of urban-travel variations across cities, there are many challenges to altering land use patterns, and some researchers suggest that even significant changes in urban spatial structure may bring about travel reductions of no more than 12 percent.[43] At least one simulation of comprehensive land use measures and travel pricing in Portland, Oregon, has suggested greenhouse gas reductions of nearly 8 percent relative to what they would have been without these measures. Although these estimated reductions are significant and exceed many estimates of the potential of conventional transportation demand management (TDM) measures, various conclusions have been drawn about the effectiveness of strategies that attempt to alter land use patterns.[44] It is difficult to isolate the effect of individual land use strategies since they often occur in combination, and they may have synergistic effects. Land use strategies are discussed below under the following headings:

- STRATEGIES TO INCREASE DENSE, MIXED USE, AND TRANSIT-ORIENTED DEVELOPMENT; and
- ENHANCEMENTS TO THE PEDESTRIAN ENVIRONMENT.

STRATEGIES TO INCREASE DENSE, MIXED USE, TRANSIT-ORIENTED DEVELOPMENT

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Regulation or Incentives	Long-term Effect	Local

Description of Strategy

Increasing land use mixing involves locating land uses with complementary functions close enough to one another such that travel distances are minimized. Focusing dense development on transit stations and corridors provides the density necessary for efficient mass transit service and encourages transit use. In combination, these land use patterns may reduce vehicle travel by allowing individuals to walk or take transit among housing, shopping, and employment; to reduce vehicle trip lengths; and to combine trips rather than taking separate vehicle trips. A regional land use strategy might target new development to specific transit corridors or encourage infill development in existing communities and raise transit ridership sufficiently to realize a net reduction in greenhouse gases.

A variety of policies may be used to achieve land use goals. Policies may be either regional in scope, such as urban growth boundaries and concurrency requirements, or more localized in nature, such as developer incentives and zoning.

Effectiveness Factors

The effectiveness of strategies that attempt to alter development densities, mixes, and orientation depend on:

- Expected growth and development patterns;
- The effectiveness of policies to alter development patterns;
- Behavioral and attitudinal forces (whether people demand mixed use, dense development); and
- The effect of land use patterns on vehicle travel and speeds.

Most of the land use literature has focused on the last factor. A number of regional analyses of alternative development patterns and transportation investments have suggested that more compact, transit-focused development patterns result in less vehicle travel than dispersed development patterns.[45] For example, a study of alternative patterns of future residential development in the Baltimore region found that under a centralized pattern (in which a significant portion of anticipated residential growth was allocated to areas within the region's "development envelope"), daily vehicle miles of travel (VMT) were reduced by 0.9 percent and severely congested VMT was reduced by 1.7 percent compared to the adopted base plan. A decentralized pattern resulted in an increase in daily VMT of 1.8 percent and an increase in severely congested VMT of 1.6 percent compared to the base case.[46] The benefits of compact development may have been understated since the benefits were estimated using traditional transportation demand models that do not assume vehicle trip generation rates are affected by land use and also do not account for pedestrian and bicycle trips.

Work in the Portland, Oregon, region is noteworthy because of its sophisticated travel demand model systems that include sensitivity to land uses and extensive use of land use data. In the Region 2040 process, alternative land use patterns were examined. In the base case, the urban areas expanded by more than half their current size. In the Growing Up alternative, all urban growth was maintained inside the current urban growth boundary. The results of simulations suggest that the Growing Up scenario doubled the amount of regional transit travel from 3 to 6 percent, and reduced regional VMT by 16.7 percent compared to the base scenario.[47]

In addition to simulation studies, empirical comparisons of various neighborhoods have been used to suggest that higher density, mixed use, and transit-oriented communities are associated with increased shares of transit and pedestrian travel and reduced VMT. For example, a 1994 study of the San Francisco Bay Area households found that households in newer suburban communities had substantially higher vehicle trip generation rates, a higher proportion of drive alone trips, and a lower percentage of public transportation trips than households in traditional communities.[48] Similarly, a 1996 study that examined travel diaries of residents in three Seattle mixed-use neighborhoods concluded that the pedestrian share of work trips was 11.3 percent in mixed-use communities, as opposed to 3.6 percent in King County as a whole.[49] An analysis of odometer readings from 27 California communities suggested that residential density and access to public transportation were the two urban form factors that most reliably predicted household auto travel behavior, and that doubling residential density reduced annual auto mileage per capita by 20 percent.[50] Similarly, an analysis of trips reported in the 1990 National Personal Transportation Survey (NPTS) found that each doubling in density reduced VMT per capita by 28 percent over the entire urban range of densities.[51]

Despite significant consensus that traditional and transit-oriented communities are associated with less vehicle travel than planned unit (suburban) development, there is disagreement on the total energy use implications of increasing density since denser areas are also often associated with reduced average travel speeds.[52] In addition, nearly all of the empirical studies on land use and travel are cross-sectional. These studies show how variations in land use are associated with variations in VMT but do not prove a causal relationship or show how changes in one variable would result in changes in another. Resident self-selection may explain much of the observed correlation, since people who do not like to drive or cannot drive might tend to seek out high density neighborhoods with good transit access. Thus, some researchers assert that some studies do not support conclusions about how changes in structure will affect travel patterns.[53]

Finally, there is some uncertainty about the effectiveness of planning strategies to alter land use. The amount of development that can be shaped by land use strategies depends on growth in population and employment and on preferences for various types of development styles. The effect of a strategy depends on the extent to which it changes development decisions. For example, an urban growth boundary that is large may not do much to encourage infill development. Developer incentives for higher-density development may not be effective if developers do not feel the market will support such plans.

Timing

Since most land-use strategies primarily affect new development, there may be considerable time lags between the implementation of land use strategies and effects on vehicle travel.

Implementation Issues

Most land-use planning in the US occurs at the local level. Implementation of effective land-use strategies generally requires regional coordination, which may be difficult to achieve. Among the political issues that might arise is what jurisdiction could assume responsibility for establishing and enforcing an urban growth boundary. An equally sensitive issue is who would ensure that municipal zoning conforms with regional development goals. Land-use initiatives often suffer from both not-in-my-backyard (NIMBY) resistance at the local level and a lack of common vision on the ideal metropolis.[54] For example, infill development, the addition of mixed use developments, and high densities are often opposed by home-owners of established single-family neighborhoods, who are afraid that multi-family housing in their vicinity will have an adverse effect on property values.[55] On the other hand, communities may wish to implement land use strategies to meet a variety of goals, including preservation of open spaces, downtowns, and older communities; reduction of traffic congestion; and enhancement of accessibility.

ENHANCEMENTS TO THE PEDESTRIAN ENVIRONMENT

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Regulation; Infrastructure Investment	Mid-term Effect	Local

Description of Strategy

Efforts to enhance the safety and pleasantness of the pedestrian environment include the provision of sidewalks, clearly marked crosswalks, walk signals, and median strips. Pedestrian enhancements can also be a component of a larger scale design plan and may include the addition of lighting, benches, shade trees, and streetscapes designed with a pedestrian focus. Design elements may involve placing porches and home entrances in the foreground and garages and driveways further back on residential properties. In commercial areas, they may involve focusing stores to the street with window displays, reduced building setbacks, and incorporating pedestrian entrances rather than requiring individuals to walk through parking lots or garages. In addition, slowing vehicle traffic through traffic-calming measures can improve pedestrian safety.

Effectiveness Factors

People often drive short distances because pedestrian connections are often lacking. The effectiveness of pedestrian strategies to reduce emissions depends on:

- The extent to which pedestrian improvements cause shifts from vehicle trips to pedestrian trips; and
- The length of trips.

Modeling done in Portland, Oregon suggested that the pedestrian environment may be a significant factor in determining automobile ownership. In addition, it may also influence daily auto VMT and vehicle trips per person.[56] In the LUTRAQ study, a pedestrian environment factor (PEF) was developed that measures ease of street crossing, sidewalk continuity, street connectivity, and topography, with a qualitative assessment on a scale of four to twelve. Each unit increase in PEF resulted in a reduction in 0.7 vehicle miles traveled daily per household.[57] Similarly, the Maryland National Capital Parks and Planning Commission (M-NCPPC) has shown that pedestrian and bicycle friendliness is a significant factor in determining work trip mode choice.[58]

Empirical analyses have come to similar conclusions. For example, a comparison of employment sites in Southern California found that areas perceived as safe and aesthetically pleasing had lower levels of drive-alone commute trips and higher proportions of transit, bicycle, and walk trips than sites perceived as less pedestrian-friendly.[59] A recent study compared two Puget Sound area neighborhoods that were similar in terms of gross residential density and intensity of commercial development. It found that the neighborhood with a high level of pedestrian network connectivity had almost three times as much pedestrian activity as the one with a low level of pedestrian connectivity.[60]

Unlike transit and carpooling, walking is a non-motorized form of transportation, so none of the emissions reduced from less vehicle travel are offset by additional pedestrian activity. The potential VMT reduction from shifting vehicle trips to walking is somewhat limited because the maximum walking trip is generally short.

Timing

Pedestrian-oriented measures can have an immediate effect in encouraging pedestrian activity and reducing vehicle travel through the addition of sidewalks, traffic calming measures, and sidewalk lighting. Other measures that focus on new development may involve significant time lags from strategy implementation to full effect.

Implementation Issues

Improving the pedestrian-environment is primarily limited to policies by local government that influence developers and individual property-owners. Other benefits of an enhanced pedestrian environment include improved quality of life, public safety (pedestrian traffic may deter crime), and physical fitness.

5.2.5 Other Vehicle Travel Reduction Measures

Other strategies to reduce vehicle travel demand typically rely on voluntary measures by individuals, employers, or communities. Some of these measures focus on commute travel and involve employer/employee relations. Government policy may include incentives, education, and information to encourage voluntary measures. Specific strategies include encouraging:

- Telecommuting;
- Compressed work Hours (or other alternative work arrangements); and
- Restrictions on vehicle use.

TELECOMMUTING

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Education and Information	Near-term Effect	Employer-Based

Description of Strategy

Telecommuting has been defined as the partial or complete substitution of telecommunications services for transportation to a conventional workplace.[61] Telecommuters utilize computer and telecommunications equipment to work from home or a local telecenter close to home. By telecommuting, employees may either eliminate work trips entirely or shorten their length significantly.

The goal of a telecommuting strategy is to increase employer and employee awareness of and remove barriers to telecommuting in order to increase use. Since telecommuting involves individual places of employment, public policy tends to be limited to education, encouragement, and promotion. These tend to be voluntary programs, and government may develop incentives to increase use. Thus far, telecommuting policies have been limited to the following:[62]

- Adoption of telecommuting by public agencies;
- Consideration of telecommuting programs as a transportation control measure for purposes of certifying compliance with air-quality regulations; and
- Fostering of these voluntary actions through research on benefits and information about how to set up work rules.

The promotion of greater use of telecommuting is Action #21 in the *US Climate Change Action Plan.*

Effectiveness Factors

The effectiveness of a telecommuting strategy depends on three factors:

- The degree to which telecommuting reduces vehicle travel and improves traffic flow;
- Indirect increases in travel from improved traffic flow and increased dispersion of development; and
- The degree to which public efforts increase the rate of adoption by employers.

Although telecommuting can reduce vehicle travel for those that participate, its effect is limited for a number of reasons. In particular, telecommuting only targets commute travel, which is only about one quarter of total vehicle miles traveled.[xvii] Telecommuting is feasible for only a portion of all workers—primarily information workers—and those that participate will often only eliminate one to three days of commute per week. In addition, some of those that participate may have taken transit or carpools in the past. Trips previously chained with the work trip will still need to be made.

[xvii] Personal travel accounts for about 75 percent of total highway vehicle travel (Energy Information Administration, 1990), and the journey to work accounts for about 32 percent of personal vehicle travel (Nationwide Personal Travel Survey).

Indirect effects offset some of the reduction in commute travel. Reduced congestion may induce additional vehicles to use highways. In addition, telecommuting may exacerbate trends toward increased geographic dispersion of residences and places of employment, which would increase driving distances for non-commute trips. Despite these countervailing effects, a scenario analysis conducted by the US DOE suggests that the net benefits of telecommuting are positive. The countervailing effects of latent demand and increased urban sprawl reduced the potential effect on fuel consumption by 55 percent. However, fuel consumption would be reduced by over 1.5 billion gallons and carbon dioxide emissions would be reduced by 11.6 million metric tons.[64]

The *Climate Change Action Plan* estimated that a national strategy to promote telecommuting, including the implementation of a Federal telecommuting pilot project, could reduce 3.3 billion VMT and save 170 million gallons of motor fuel by the year 2000.[63] These figures were estimated by assuming a relatively modest increase in telecommuting rates due to the program; however, they did not account for induced travel or increased travel due to increased sprawl associated with telecommuting.

Telecommuting is projected to increase even in the absence of any coordinated government actions. It is unclear to what extent public efforts can encourage additional adoption of telecommuting by private employers.

Timing

Public efforts to encourage telecommuting could have a near- to mid-term effect on emissions. Some time lags will occur between implementation of the public incentive and actual participation in telecommuting programs because employers may be somewhat slow to acquire necessary telecommunications equipment or it may take some time for a community to develop a neighborhood telecenter and attract corporate participation.

Implementation Issues

Implementation of a telecommuting program requires expenditures for computers and telecommuting equipment, which may be incurred by the employee or employer. A program that utilizes a neighborhood telecenter may be more expensive than home-based commuting, and may involve government financing. Generally, however, public costs are small.

The exact nature of the social effects of widespread telecommuting are not well understood because telecommuting is a recent phenomenon.[65] However, it is believed that telecommuting may yield benefits in terms of increased employee effectiveness and productivity, higher morale and job satisfaction, decreased absenteeism and sick time, and decreased overhead costs (since less office space may be needed).[66] Utilization of more advanced technology can stimulate economic growth and contribute to productivity throughout the economy. Increased telecommuting is likely to reinforce trends toward the dispersal of economic activities and population, and may raise important issues concerning disparities between workers with the option of telecommuting and those for whom telecommuting is not feasible.

COMPRESSED WORK HOURS

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Education and Information	Near-term Effect	Employer-Based

Description of Strategy

Compressed work hours is a program that allows individuals to work more hours per day and fewer days per week. A typical program involves working 10 hours, 4 days a week, rather than 8 hours, 5 days a week. For each employee working under this schedule, this strategy eliminates one round-trip to work each week. In addition, the change in daily work hours can often reduce peak-period travel. Like telecommuting, the strategy has been limited to education and encouragement or pilot programs at government worksites.

Effectiveness Factors

The effectiveness of efforts to encourage compressed work hours depends on the following factors:

- The degree to which compressed work hours reduces commute vehicle travel for those who participate;
- Effects on traffic flow;
- Increases in trip-making on days off from work;
- Indirect increases in travel from improved traffic flow; and
- The degree to which public efforts increase the rate of adoption by employers.

Compressed work hours programs have many of the same limitations of telecommuting programs—commute travel is only a small portion of total transportation emissions, it only reduces travel one day per week or every two weeks, not all employees will be able to participate, and there may be some offsetting increases in travel. It also is not clear to what extent government efforts will induce adoption by private employers.

According to EPA's Transportation Control Measures Information Documents, there is only one example in the literature where the transportation impacts of a coordinated compressed work-hours program have been systematically documented. Denver participated in a federal employee compressed work-week experiment from 1978-1981. Findings were favorable. Among employees participating, there was a 15 percent reduction in commute VMT, and a shifting of peak arrival and departure times. There was little change in modal share. Overall, participants reduced household VMT by almost 16 percent. Although there was some increase in non-work trips during the employees' day off, this was offset by a drop in weekend VMT.[67]

Timing

Public efforts to encourage compressed work hours and flexible work schedules would have a near-term effect on emissions. In most cases, employers could implement such programs relatively quickly. The effectiveness of these programs might increase over time as employers become more familiar with the programs.

Implementation Issues

Costs of implementing compressed work hours are relatively low for employers and government. Government at all levels may participate in education and incentives to promote alternative work arrangements.

Substantial levels of use of alternative work arrangements could reduce congestion. Alternative work arrangements may also reduce the need for highway capacity expansion, thereby saving capital and maintenance costs, urban land, and travel time for individuals.

VOLUNTARY RESTRICTIONS ON VEHICLE USE (NO DRIVE DAYS)

Primary Target	Approach	Timing	Level of Implementation
Reduce Vehicle Travel	Education and Information	Near-term Effect	Local

Description of Strategy

No-drive days refer to programs aimed at restricting the use of vehicles on specific days of the week. Although several foreign cities, such as Athens, Mexico City, and Santiago, as well as the Republic of Singapore have established mandatory no-drive days or severe restriction on driving during certain time periods, all US programs to date have been voluntary and in many cases encourage alternatives to single-occupancy vehicles.[68] These programs may either tie the no-drive day to license plate numbers or to days during which air quality is forecast to be particularly poor.

Effectiveness Factors

The effectiveness of programs to restrict vehicle use depends on:

- The approach taken—whether restrictions are mandatory, voluntary, or utilize incentives;
- The degree to which voluntary programs or incentives affect driving behavior; and
- The extent of adoption of programs nationwide.

According to EPA, it is difficult to measure the effectiveness of no-drive day programs. The voluntary nature of no-drive days inherently limits their potential effectiveness.[69] EPA notes that voluntary programs have the most participation during "challenge" periods in which participants receive recognition and prizes for successfully participating. These programs use incentives as an approach; in addition, education about problems associated with travel, such as smog and associated health costs, may spur individual action.

Timing

Restrictions on vehicle use and education and incentives to encourage travelers to voluntarily reduce vehicle use should have an immediate effect on traveler behavior.

Implementation Issues

No-drive days, whether voluntary or mandatory, are generally implemented at the regional level. Because they are typically voluntary in nature, they avoid costs of monitoring and enforcement. However, these programs tend to function most effectively with some incentives to induce participation, which may require some minor costs. In addition, media participation can be important. Often, the media and employers will volunteer to participate in promotion efforts.

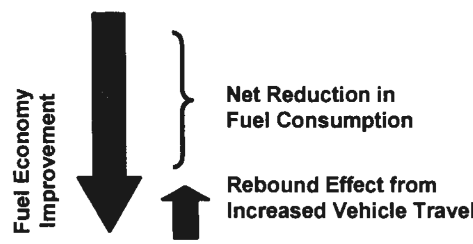
Primary benefits of no-drive days include air quality improvement and congestion relief. According to EPA's Transportation Control Measures Information Documents, an additional benefit is that the programs can draw communities together and improve education about pollution that helps in the effectiveness of other programs.

5.3 Fuel-Economy-Focused Strategies

In addition to reducing vehicle travel, a second target that can achieve reductions in greenhouse gas emissions from transportation is the improvement in the fuel economy of vehicles. Since emissions of CO_2 are directly proportional to the amount of fuel burned, any improvements in fuel efficiency reduce greenhouse gas emissions per mile proportionately. Fuel economy is generally expressed in terms of miles per gallon (mpg). Since demand for vehicle travel is expected to grow as a result of rising population and income, it would not be possible to stabilize fuel consumption from motor vehicles without improving fuel economy. Fuel economy can be improved by improving traffic flow and by improving vehicle technologies. Strategies can either "push" vehicle manufacturers to produce more efficient vehicles or "pull" them by encouraging individuals to demand more fuel-efficient vehicles.

Although fuel economy improvements reduce fuel consumption, these improvements can lead to a "rebound effect" as shown in Exhibit 5-4. An increase in mpg reduces the fuel cost-per-mile of travel. Lower variable costs of travel lead to increases in VMT. Some estimates suggest that this "rebound effect" may be 10 to 15 percent of the emissions reduction resulting from the improved fuel economy.[70] Some studies provide higher estimates of the elasticity of VMT with respect to fuel efficiency improvements in the range of 0.2 to 0.3, meaning that for every percentage gain in fuel efficiency, consumers increase vehicle use by 0.2 to 0.3 percent.[71] Differences in elasticity assumptions can have significant implications on the relative effectiveness of fuel economy strategies versus fuel and travel pricing strategies.

Exhibit 5-4. Fuel Consumption Rebound Effect



5.3.1 Improving Traffic Operations

For a given vehicle, on-road fuel economy is a function of average speed and acceleration. At low speeds, a greater proportion of energy to the engine goes to internal engine friction and to operating accessories such as power steering and transmission, oil and water pumps, and air conditioners. Braking directly translates the vehicle's momentum into heat energy.[72] Since characteristics of highway congestion—low travel speeds, increased braking and accelerations, idling—are associated with increased fuel use, strategies to reduce congestion and improve traffic flow can reduce greenhouse gas emissions.

At speeds above 55–60 mph, increasing aerodynamic drag causes fuel economy to decline. Oak Ridge National Laboratory is currently conducting tests of light-duty vehicles to characterize their fuel consumption over most of their operating ranges, to represent fuel economy as functions of vehicle speed and acceleration. Preliminary tests showed over 20 percent of fuel economy loss occurs between 55 and

75 mph.[73] This fuel economy loss is similar to losses estimated from earlier studies in the 1970s and 1980s.[xviii] Thus, policies to limit speeds to 55 mph may be used to reduce greenhouse gas emissions.

The effect of travel characteristics on fuel economy is reflected in the shortfall between vehicle sticker fuel economy and actual on-road fuel economy. Strategies that attempt to reduce fuel consumption and emissions by affecting traffic conditions may include:

- TRAFFIC FLOW IMPROVEMENTS;
- LIMIT FREEWAY SPEEDS TO 55 MPH; and
- DRIVER EDUCATION.

TRAFFIC FLOW IMPROVEMENTS

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Infrastructure Investment	Near-term Effect	State, Local

Description of Strategy

Traffic flow improvements encompass a wide range of programs to smooth traffic flow, reduce idling, and eliminate bottlenecks:

- *Signalization improvements* can reduce intersection delay on arterials and other routes in urbanized areas.
- *Incident management* and advanced traffic sensing technologies allow faster response time to remove breakdowns and accidents from the road.
- *Intelligent Transportation Systems (ITS)* encompass a range of technologies that develop more intelligent vehicles and transportation infrastructure, including use of real-time information on traffic conditions, directions to unfamiliar places, and identification of alternate routes.

Effectiveness Factors

The effectiveness of signalization and other traffic flow improvements depends on the following factors:

- Existing levels of congestion/current traffic speeds and operational conditions;
- Technical ability of traffic signals, incident management, and ITS to alleviate congestion;
- Extent of increase in vehicle travel; and
- Extent of investment in and adoption of traffic flow improvement measures.

Although traffic flow improvements can lead to significant reductions in delay on particular routes and at particular times, fuel savings will be reduced by a smaller percentage since delay only consumes a portion of vehicle fuel over the course of a trip. For example, a new traffic control signal system in Los Angeles was estimated to reduce signal delays by 44 percent, vehicle stops by 41 percent, and fuel

[xviii] However, two previous studies by the Federal Highway Administration indicated maximum fuel efficiency was achieved at speeds of 35 to 45 mph. Preliminary data from the ORNL study suggest that maximum efficiency may occur at higher speeds, near 55 mph.

consumption by 13 percent. A study of retiming several Virginia signal systems estimated that it would reduce stops by 25 percent, travel time by 10 percent, and fuel consumption by 4 percent.[74] California's Fuel Efficient Traffic Signal Management program, which optimized 3,172 traffic signals through 1988, documented an average reduction in vehicle stops of 16 percent and in fuel use of 8.6 percent in the affected areas.[75] Since one-fifth of total VMT in California is traveled on streets controlled by traffic signals, statewide implementation with comparable success would potentially save 1.7 percent of total highway fuel consumption. Effectiveness might be limited, however, since improving traffic flow lowers the "time" costs of travel, which might encourage additional vehicle travel.

The national effect of signalization and other traffic flow improvements depends on the extent of adoption by local areas. There appears to be large potential for implementation of traffic signalization improvement projects and other traffic flow improvements, given increasing highway congestion. The Institute of Transportation Engineers estimated in 1989 that 74 percent of the approximately 240,000 signalized intersections in the nation's urban areas needed upgraded physical equipment or improved signal timing. A 1990 review of 24 signal systems by the Federal Highway Administration found that 21 systems did not meet the minimum standards of performance.[76]

Timing

Signalization can be improved quickly through technology, which should have an immediate effect on traffic conditions. Many regions are currently investigating and are in the initial phases of deploying mechanisms to integrate traffic control systems and ITS technologies.

Implementation Issues

States and localities may support investment in signalization and other traffic flow improvements for potential congestion benefits. For example, an analysis of a new signal system implemented at 365 intersections in Orlando, Florida showed a 56 percent reduction in vehicle stops and delays.[77] Implementation concerns that have surfaced include institutional barriers regarding integrating signal timing plans across jurisdictions and technological needs such as fiberoptic networks to relay real-time traffic information.

LIMIT FREEWAY SPEEDS TO 55 MPH

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Regulation	Near-term Effect	Federal, State

Description of Strategy

Beyond 55 miles per hour, fuel economy is generally a decreasing function of speed for both cars and trucks. The national 55 mph speed limit, repealed in 1995, was originally passed by Congress in 1974 as an energy conservation measure. A greenhouse gas reduction strategy would be to re-apply the national 55 mph speed limit or encourage states to voluntarily limit speeds on interstates and freeways to 55 mph.

Effectiveness Factors

The effectiveness of speed limits as a national carbon dioxide emissions reduction strategy depend on:

- The differential in fuel economy at different speeds;

- The number of highways where speed limits are maintained or limited to 55 mph; and
- Stringency of speed enforcement.

EPA estimates that traveling at 65 mph as compared to 55 mph lowers fuel economy over 15 percent.[78] Preliminary testing of vehicles at Oak Ridge National Laboratory for US DOT suggest that an increase in speed from 55 to 65 mph may reduce fuel economy by over 11 percent and that increasing from 55 to 70 mph may reduce fuel economy by over 23 percent.[79]

In addition to the technical efficiency of vehicles, the effectiveness of a national speed limit depends upon enforcement and compliance with the maximum speed. According to FHWA statistics for Fiscal Year 1993, the average speed on urban interstates with a posted 55 mph speed limit was 58.5 mph, with 70.0 percent of traffic exceeding 55 mph. On rural interstates with a posted speed limit of 55 mph, the average travel speed was 66.9 mph, with 78.1 percent of vehicles exceeding 55 mph.[80]

Various estimates of energy savings from the national 55 mph limit indicate that despite imperfect compliance, it may reduce national fuel consumption on highways by about 1 to 3 percent.[81] A 1984 study by the National Research Council (NRC) concluded that in 1983, the national speed limit reduced highway fuel consumption by about 2.2 percent.[82]

Timing

Re-application of the national speed limit in the near term may be unlikely given that it was repealed in 1995 as part of the law designating the National Highway System. However, states may choose individually to limit highway speeds to 55 mph. Speed limits have an immediate effect on travel speeds and emissions levels.

Implementation Issues

Adjusting speed limits is simple for states and imposes minimum public-sector costs. However, for drivers, time is a major cost associated with travel. Lowering speed limits imposes a substantial cost on drivers. On the other hand, there are a number of non-greenhouse gas benefits that could encourage re-introduction of lower speed limits. In particular, a reduced speed limit has been advocated as a traffic safety measure. One study estimated that the 55 mph speed limit saved 3,000 to 5,000 lives annually in the early years after its implementation and 2,000 to 4,000 annually during the early 1980s.[83] There has not been consensus on the safety implications of recent increases in speed limits. Traveling at 55 mph may also be promoted as a means to reduce emissions of some criteria pollutants.

DRIVER EDUCATION

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Education and Information	Near-term Effect	Federal, State, Local

Description of Strategy

An education strategy would involve the development of courses for commercial truck drivers and private motorists or the inclusion of information on fuel-efficient driving practices—such as reduced idling time and quiet accelerations—into driver education programs. A broader education program might involve information to discourage vehicle idling or to promote off-peak travel for discretionary trips (reducing congestion). Education helps the driver to associate an economic incentive with efficient driving, since it shows the driver that improved fuel economy results in decreased fuel expenditures.

Effectiveness Factors

The effectiveness of driver education programs depends upon:

- The number of drivers that are reached by such programs;
- The extent to which these programs yield long-term changes in driver behavior; and
- The extent to which the behavioral changes reduce emissions.

The Department of Energy's Driver Energy Conservation Awareness Training program developed in the late 1970s for commercial truck drivers and private motorists demonstrated potential fuel economy improvements of approximately 10 percent for both groups.[84] These results suggests that there is potential for efficiency improvements through these programs. On the other hand, it may be increasingly difficult for drivers to change driving habits. As the real cost of gasoline has fallen since the late 1970s, drivers may be less responsive to adjusting driving behavior in order to reduce fuel costs. No recent evidence was found on the potential of such a program.

Since energy efficiency training never became incorporated into the official curricula for licensing, the number of people reached by these programs to date has been small. Effectiveness as a national greenhouse gas strategy would depend on the extent of adoption of such programs in driver education curricula.

Timing

Driver education would have an immediate effect on fuel consumption as drivers adjust their driving practices. There is evidence that the effectiveness of training falls as time from training increases; therefore training must be conducted on a periodic basis or be refreshed over time.[85]

Implementation Issues

There are modest up-front costs to develop curricula and training materials. Generally, education programs are accepted by the public if well designed. In addition to reducing greenhouse gas emissions, driver education programs would reduce emissions of criteria pollutants, which also are affected by idling, accelerations, and decelerations.

5.3.2 Vehicle Technology Improvement

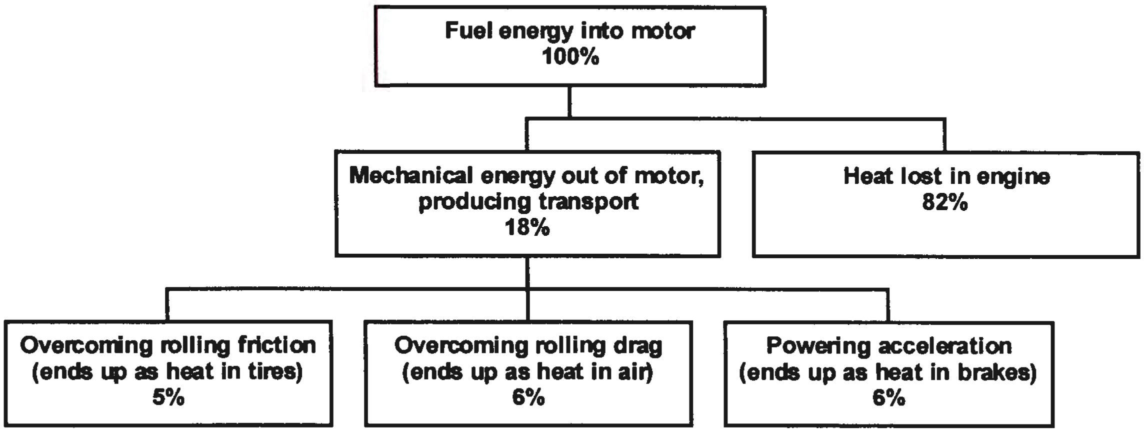
Improving the efficiency of conventional vehicles has been advanced as a means to reduce fuel consumption.[xix] Some vehicles consume less fuel per mile than others under equivalent driving conditions due to physical attributes of the vehicle—size, weight, and technology. However, fuel economy is only one of the many factors that designers consider when developing a vehicle, and only one of the factors that consumers consider when making vehicle purchase decisions. Recent consumer trends have been toward the purchase of more light trucks (e.g. minivans, pick-up trucks, sport utility vehicles), which

[xix] Vehicle technology advances that would use alternative fuels, such as electric vehicles, are discussed in Section 5.4 of this report.

generally get fewer miles per gallon than automobiles.[86] As a result, measures to encourage vehicle manufacturers to develop more fuel-efficient vehicle technologies have been advanced.

A starting point for assessing the potential role of vehicle technologies in reducing greenhouse gases is to examine the degree to which fuel economy improvements are technically feasible and can be commercialized. A number of redesign options have been identified to increase the fuel economy of the conventional internal combustion engine (ICE) vehicle. Exhibit 5-5 illustrates the consumption of energy from gasoline in an average of highway and urban driving cycles, ignoring the secondary factors of bearings and accessories.

Exhibit 5-5. Energy Consumption by Gasoline-Powered Vehicles (Average of Highway and Urban Driving Cycles)



Under high power, the engine efficiency may rise to 30 percent, but under typical driving, efficiency is closer to 15 percent than the 18 percent shown. About one-third of the mechanical energy goes into rolling friction, one-third into air drag (closer to three-fourths at steady highway speeds), and one-third into heating the brakes to decelerate the car (more in urban driving).

Vehicle redesign to improve fuel economy must address the components of energy use and loss. Vehicles would use less fuel if engine efficiency increased, if lower weight and better tires gave less tire drag, if vehicle aerodynamics were improved, and if lower weight or regenerative braking saved some braking loss. Some key technology improvements being considered for introduction or wider application in US markets include the following:[xx]

Engine Technologies—Engine improvements would improve mechanical efficiency. Some improvements that could enhance the efficiency of all types of engines include:

- *Boosting*—Boosting refers to the use of a turbocharger or supercharger to pressurize cylinder intake air, allowing more fuel to be burned and greater power to be delivered by an

[xx] Note that the state-of-the-art in technology is constantly advancing. This report summarizes recent literature that identifies various technological improvements but may fail to represent some of the emerging or more speculative technologies that are less well documented.

engine of a given displacement. Although typically applied to enhance power performance, boosting can increase fuel economy if engine displacement is reduced while maintaining fixed vehicle performance.

- *Idle off*—Idle off allows the engine to be turned off when no power is demanded, such as when a vehicle is stopped, braking, or coasting.

The use and improvement of different types of engines holds the potential for fuel savings.

- *2-stroke engines*—Two-stroke engines offer potential fuel economy improvements of 15 to 20 percent over four-stroke engines of comparable power since power from a cylinder is delivered on every revolution of the crankshaft, in contrast to once every two revolutions for a four-stroke engine.[87] This results in higher efficiency and superior specific output and power-to-weight ratios. A technical challenge for two-stroke engines is meeting NO_X emissions requirements.

- *Improvements to efficiency of 4-stroke gasoline engines*—Energy savings are possible in conventional four-stroke gasoline engines through a variety of technological improvements, such as overhead camshafts, variable engine control, and reduced engine friction.[88] A *four-valve engine* (four valves per cylinder) permits an engine to be replaced by a smaller engine with equivalent performance (e.g. a 4- or 6-cylinder engine could replace a 6- or 8-cylinder engine of equivalent performance). Higher peak-power output means that power needs can be met with an engine of smaller displacement, which also lowers total engine friction. Multi-valve engines are nearly universal in Japan and widespread in Europe, but still relatively uncommon in the US.[89] *Variable engine control* may involve variable displacement or variable valve control (VVC), which permits valve positions to be controlled depending on operating conditions, permitting a more optimal management of induction and exhaust processes. A *four-stroke direct-injection stratified charge (DISC) gasoline engine* reduces fuel flow at part load by injecting fuel directly into each cylinder at high pressures in such a way that the fuel/air mixture is stratified, with high fuel concentrations near the spark plug to maintain stable combustion. The combination of zero throttling losses, low fuel use at light loads because of very lean fuel mixture, and more precise control of combustion yields substantial fuel efficiency improvements.

- *Diesel engines*—Diesel direct-injection engines offer a 25 to 40 percent fuel-economy improvement over similar displacement spark-ignition engines because of their much higher compression ratios, high part-load efficiency, inherently lean operation, and amenability to turbocharging.[90] However, this translates into a smaller carbon emissions reduction (about 10 to 20 percent) since diesel fuel has a higher carbon content per gallon than motor gasoline. European automakers have advanced many of the diesel engine's traditional disadvantages, such as noise, smoke, poor acceleration, and cold start problems. However, the most important obstacle is exhaust emissions, especially NO_X and particulate matter.

Transmissions—Transmission improvements would improve fuel economy since an optimal synchronization of the transmission with the engine is required to maximize the amount of time an engine operates near peak efficiency.

- *Continuously variable transmission (CVT)*—CVT allow engines to operate at the maximum efficiency under a given load and rev the engine when more power is needed.

- *Optimal transmission control*—Transmission optimization could be implemented through electronic control, termed Aggressive Transmission Management (ATM).

- *Adding gears*—A five or six-speed automatic would keep the engine operating at as low RPM as possible, subject to smoothness and driveability constraints.

Load Reduction—Load includes air and tire resistance, inertia and braking (related to vehicle mass), plus accessories such as heating, air conditioning, and power steering. Reducing load reduces the engine's power-producing requirements and the transmission's power-transmitting requirements.

- *Weight reduction*—Extensive use of aluminum and other light-weight materials in suspension and other components, as well as redesigns to seats, bumpers, and other components could potentially reduce vehicle weight significantly.[xxi] A 30 percent reduction in weight may be feasible without compromising passenger comfort, safety, or performance.[91]

- *Reduced rolling resistance*—Rolling resistance can be reduced through improved design of differential gears in axles, steerable rear wheels and better wheel design. In addition, high-pressure and narrower tires can contribute to lower rolling resistance but may negatively affect vehicle handling. There is potential to reduce rolling resistance by about 30 percent without compromising passenger comfort, safety, or performance.[92]

- *Improved aerodynamics*—Reductions in aerodynamic drag coefficients of vehicles can be achieved by styling, reducing the area of air intakes for engines and air conditioning, reducing protrusions, making windows flush with body panels, and covering the underside of the vehicle with smooth sheet material. For most vehicle types, there is potential to reduce vehicle wind resistance by 30 percent without radically altering shape or affecting passenger comfort.[93]

- *Reduced accessory loads*—A number of concepts have been proposed as a means to reduce accessory loads, in particular, to improve air conditioner efficiency. Such concepts may play an increasing role in improving vehicle fuel economy as the rest of the vehicle becomes more fuel-efficient.

Regenerative Braking—Regenerative braking would allow the vehicle to recapture energy that would otherwise dissipate as heat.

An estimate of the fuel economy potential of vehicle technology improvements is summarized in Exhibit 5-6. Note that percent improvement in fuel economy does not equal percent reduction in fuel use or CO_2 emissions.[xxii]

[xxi] An advanced car (like Ford's PNGV prototype, the P-2000), will weigh about 2000 lbs, compared to a typical car weight of about 3300 lbs (US EPA. "Light-Duty Automotive Technology and Fuel Economy Trends through 1996."), which is a 39 percent weight reduction. However, these prototypes use very expensive materials like carbon fiber composites and magnesium, which may not be commercially acceptable due to high cost.

[xxii] The percent increase in fuel economy tends to be larger than the percent reduction in fuel use and carbon emissions. For example, an increase from 20 mpg to 25 mpg is a 25% increase in fuel economy. This change yields a 20% decrease in fuel consumption (to travel 100 miles requires 5 gallons in the first case and 4 gallons in the second case). The higher the starting mpg, the less fuel is saved per equivalent increment of fuel economy gain. Percent reduction in carbon dioxide emissions also differs if fuel with a different carbon-content is used, such as diesel.

Exhibit 5-6. Fuel Economy Improvement Potential of Conventional Vehicle Technologies

Technology	Fuel Economy Improvement Potential[xxiii]
2-stroke engines	15% to 20% (compared to 4-stroke engines of similar power output)
4-stroke direct injection stratified charge engines	18% to 23%
Direct-injection diesel engines	25% to 40% (compared to similar displacement gasoline engines)
Continuously variable transmissions (CVTs)	3% to 10%
Lightweight materials: aluminum, magnesium, plastics, composites, powdered metals	10% to 20% (assuming weight reductions of 30% without compromising safety, comfort, or performance)
Reduced rolling resistance	5% to 8% (assuming 30% reduction in rolling resistance)
Improved aerodynamics	5% to 15% (based on reduction in wind resistance of up to 30% without radically changing vehicle shape or restricting comfort)

Source: US Department of Energy, Office of Energy Efficiency and Renewable Energy. *Scenarios of US Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond.* Prepared by Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies. September 22, 1997.

Other advanced alternatives, including use of hybrid-electric or fuel cell power trains, potentially offer an efficiency advantage over conventional internal combustion engine (ICE) drivetrains. These alternatives are discussed in Section 5.4 of this report. Recent efforts by automobile manufacturers to develop and begin marketing hybrid-electric vehicles in Japan and the US by the end of this millenium show promising potential. In particular, hybrid-electric vehicles, which use two drivetrains (an internal combustion engine running on gasoline or alternative fuels and a battery-driven electric drivetrain), have shown considerable gains in mile-per-gallon ratings.

A few studies have examined the potential of these various technologies in an attempt to assess the "technological potential" for fuel economy improvements for the future model-year vehicle fleets. These estimates range from conservative to optimistic. From the conservative perspective, SRI International (1991) estimated that further increases in fleet fuel economy are likely to be less than 3 mpg within 10 years since major gains have already been achieved, safety and emissions standards will degrade fuel economy, and consumers prefer vehicle characteristics that conflict with fuel economy.[94] From the optimistic perspective, large increases in fleet fuel economy, 45 mpg and higher, have been estimated to be readily obtainable by existing or soon-to-be-available technology.[95] Several studies provide assessments of the fuel economy improvements achievable through technologies. Exhibit 5-7, on the following page, summarizes six studies.

In 1995, sales-weighted fuel economy estimates were 28.2 mpg for new passenger cars and 20.4 mpg for new light-duty trucks. These studies suggest that major fuel economy improvements of up to 80 percent by 2005-2010 are possible using currently available technologies.[xxiv] The Partnership for a New Generation of Vehicles (PNGV) has set even higher goals toward improvements in fuel economy.

[xxiii] Some of the potential technologies listed may have additive or cumulative effects toward gains in fuel economy improvement in conventional vehicles, the extent of which is not yet fully known.

[xxiv] Note that these studies are a number of years old, so the year of achievement may need to be adjusted to reflect intervening years. Conversely, new technological developments may signify that greater fuel economy gains are feasible. Not all of the estimates are independently derived.

Exhibit 5-7. Estimated Potential for Fuel Economy Improvements

Source	Year Achievable	Scenario	Fuel Economy (mpg)
Difiglio, Duleep and Greene (1990)[96]	2000	Cost Effective Maximum Technically Achievable	36.4 39.4
National Research Council (1992)[97]	2001	Technically Achievable Automobiles Light-trucks	 31–33 24–25
	2006	Technically Achievable Automobiles Subcompact Large Light-trucks	 35–37 39–44 30–33 26–28
DiCicco and Ross (1993)[98]	2002-2005	High technological certainty Medium technological certainty (incorporates measures ready for commercialization) Low technological certainty (assumes use of technologies in advanced stage of development)	40–43 47–50 53–56
Office of Technology Assessment (1994)[99]	2001	No new regulations, rising oil prices With higher CAFE standards Maximum Current technology	32.9 35.5 38.2
	2005	With higher CAFE standards	37.1
	2010	Advanced technologies	45–55
Office of Technology Assessment (1995)[100]	2005	Mid-size car (best-in-class): Average estimate of technology benefit Optimistic estimate of technology benefit	 38.8* 41.7*
	2015	Mid-size car (best-in-class): Average estimate of technology benefit Optimistic estimate of technology benefit	 53.2-59.0* 63.5*
National Research Council (1998)[101]	2004	Attainment of PNGV targets for preproduction prototypes	80*

*Note: The Office of Technology Assessment (1995) estimates are for "best-in-class" vehicles; the National Research Council (1998) estimate is for preproduction prototypes. Other estimates are for the new car fleet, unless otherwise noted.

The PNGV goal is by 2004 to produce a mid-size family sedan prototype with up to three times the fuel efficiency of comparable 1994 vehicles (implying a fuel economy of approximately 80 miles-per-gallon) that meets customer needs for quality, performance, and utility. While the National Research Council's 4th Annual Independent Review of PNGV found that some of the year 2000 concept vehicle attributes will probably fall short of established targets, the preproduction prototypes are expected to meet the targets by 2004.[102]

Although fuel economy improvements reduce greenhouse gas emissions per VMT, there are several factors that can offset these emission reductions:

- Higher fuel economy can raise vehicle prices, which could reduce fleet turnover causing less fuel-efficient vehicles to remain on the road longer.
- Improved fuel economy lowers the fuel cost of driving per mile, which could encourage additional vehicle travel (rebound effect).

A major change in design would most easily gain public acceptance if the new designs do not significantly degrade amenities in terms of space (interior volume), performance, safety, reliability, and convenience in refueling, and if they can be made available at competitive prices.

Public policies may either "push" vehicle manufacturers to improve technologies or "pull" them by influencing consumer behavior and preferences. Two primary strategies to push vehicle technology include:

- VEHICLE FUEL ECONOMY MANDATES, SUCH AS CORPORATE AVERAGE FUEL ECONOMY STANDARDS (CAFE); and
- SUPPORT FOR RESEARCH AND DEVELOPMENT (R&D) ON VEHICLE TECHNOLOGIES.

These strategies are described below.

MANDATES ON NEW VEHICLE FUEL ECONOMY (CAFE STANDARDS)

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Regulation	Mid-term Effect	Federal

Description of Strategy

The Corporate Average Fuel Economy (CAFE) standards require each automobile manufacturer to meet a minimum fuel efficiency standard for all cars and light trucks sold by that manufacturer in the US in a model year. There are separate CAFE standards for automobiles and light trucks. Established under the 1975 Energy Policy and Conservation Act, CAFE standards required the fuel economy of new cars to increase from about 14 mpg in the early 1970s to 27.5 mpg by 1985, which is the current standard. New light truck fuel economy standards have increased from 17.2 mpg in 1979 to 20.7 mpg in 1997.[103] Although a number of OECD countries with domestic automobile industries have adopted voluntary fuel economy standards, only the US standards provide legal sanctions for failing to meet the standards.[104]

Raising CAFE standards has been advanced as a policy to spur vehicle manufacturers to increase vehicle fuel economy. Regulation is justified on the basis of a market failure, since consumers do not take into account the full costs of fuel use when purchasing a vehicle. In addition to the existing system of CAFE standards where all manufacturers are required to meet the same minimum standard, a number of options for raising CAFE standards have been identified, including:

- Require automakers to raise their fuel economy by a uniform percentage over that attained in a base year;
- Base company standards on the attributes of each company's fleet at the time standards are to be met (i.e., a volume average fuel economy (VAFE) standard would base standards on the interior volume of vehicles);
- Change the light truck/car definition; and
- Increase the CAFE light truck weight limit.

Effectiveness Factors

The effectiveness of increasing CAFE standards depends on a number of factors. In particular, effectiveness depends on the extent to which the standards do the following:

- Increase new vehicle fuel economy compared to their levels without the standards;

- Reduce the rate of turnover in the vehicle fleet (by increasing prices);
- Cause shifts between cars and light trucks (by altering relative prices); and
- Cause an increase in vehicle miles traveled (rebound effect).

Manufacturers weigh fuel economy against other factors in vehicle design. While there is agreement that the years in which the CAFE standards took effect coincided with a large increase in the fuel economy of the US new-car fleet—from 17.2 mpg in 1976 to 27.9 mpg in 1986—one must examine how automakers would have reacted in the absence of standards. This comparison is difficult since real gasoline prices tripled between 1973 and 1980, but have since declined, and a number of other factors have affected consumer vehicle purchasing decisions.[105]

Some industry analysts have concluded that the CAFE standards implemented in the late 1970s and early 1980s increased fuel economy only about 1.0 to 1.5 mpg beyond the level that would have been achieved without them, while others conclude that the standards improved economy by 4 to 5 mpg or more.[106] Although some have claimed that increases in the price of gasoline in the late 1970s were largely responsible for fuel economy improvements, statistical analysis of manufacturer's CAFE achievements shows strong evidence that the standards were a constraint for many manufacturers and were significantly more important than gasoline prices.[107] Graphs of actual versus required levels of corporate fuel economy show that Ford, General Motors, and to a lesser extent Chrysler, increased their fleet fuel economy in virtual lockstep with the levels required. On the other hand, the levels of the Japanese and other foreign manufacturers producing small, high-fuel-economy cars (those not affected significantly by the standard but more by gasoline prices) vacillated and sometimes fell during the same period.[108] In addition, the increase in fuel economy in that period was more rapid than that for fuel price.

During the 1990s, as the real price of fuel has fallen, fleet fuel economy for cars and light trucks has consistently hovered near the CAFE levels, suggesting that the standards have been an important constraint against lower fuel economy.[xxv] Since fuel prices are low and the American public has shown relatively little interest in fuel economy in recent years, increased CAFE standards have been identified as a measure to push vehicle fuel economy improvements that the marketplace would not otherwise provide.

> The majority report by the Presidential advisory committee on reducing greenhouse gas emissions from motor vehicles estimated that increasing the CAFE standards starting in 1998 would result in the most significant reductions in greenhouse gas emissions. Under their recommended policy, CAFE standards would reach 45 mpg for new cars and 34 mpg for new light trucks by 2007. These targets correspond to standards increasing annually by 1.5 mpg per year. Their analysis suggested that CAFE standards (in combination with feebates) could reduce greenhouse gas emissions by 36 million metric tons of carbon in 2005 and 117 million metric tons in 2015.

There are several factors that can offset emission reductions. There is evidence that CAFE standards result in higher vehicle prices.[109] If CAFE standards are inconsistently applied to cars and light trucks, then higher prices could shift sales of autos to light trucks. While light duty vehicle trucks made up 17 percent of new vehicle sales in 1972, this shares has grown to 41 percent in 1997.[110] Since the standard for light trucks is much lower than that for automobiles, the shift to trucks has reduced fuel savings.[xxvi] In addition, price increases could reduce fleet turnover causing less fuel efficient vehicles to remain on the road longer, although this is less of a

[xxv] CAFE standards have been constant for autos since 1990. From 1990 to 1995, new sales-weighted fuel economy for autos has been basically flat.

[xxvi] This issue could be addressed by increasing light truck CAFE standards.

consideration today since average vehicle fuel economy has been relatively flat since the mid-1980s. An offsetting rebound effect for VMT may be of more concern.

Timing

Development of a new vehicle model typically takes three to four years. As a result, manufacturers need to be given a few years of lead time in order to meet new standards, or they would need to abandon or redesign platforms before the end of life cycles.[111] Although the standards would have an immediate effect on new vehicles' fuel economy, the full effect of CAFE standards is not seen for many years until substantial portions of the whole fleet turns over.

Implementation Issues

A number of issues have been raised regarding the implementation of new CAFE standards. In particular, issues of safety and economic impact have been important. Many have argued that increased CAFE standards will encourage smaller vehicles that might be less safe than larger vehicles. According to the Office of Technology Assessment (OTA), although small cars need not be unsafe, the bulk of statistical evidence argues that, given current design, the car fleet could be less safe if all vehicles were somewhat smaller than they are today.[112] Still, new safety technologies might be implemented to ensure maintenance of passenger safety.

Due to concerns about effects of CAFE standards on US auto manufacturers and incentives created by the regulations, a variety of options for raising these standards have been identified, including measures that would challenge all auto manufactures to increase fuel economy or base standards on vehicle attributes. A uniform minimum CAFE standard on all manufacturers does not force makers of primarily small cars to improve significantly, and the US auto industry has argued a minimum standard would be harmful to American manufacturers. Although the American Automobile Manufacturers Association (AAMA) estimated over 210,000 jobs would be lost in the auto industry by 2001 due to new CAFE standards, the American Council for an Energy Efficient Economy (ACEEE) estimated that new standards would increase employment by 244,000, including 47,000 in the auto industry, by 2010 from enhanced efficiency in the economy.

Despite concerns by the auto industry, to some extent the regulatory approach of CAFE has been viewed as politically more acceptable than raising fuel taxes as a means of reducing fuel consumption since it appears to "place the burden of compliance on manufacturers and not on the consumer."[113] Although some argue that fuel-efficiency standards entail changes in vehicle characteristics that consumers do not like, fuel-economy regulations to date have been well-received by consumers, since they have been achieved largely without major changes in size and power of vehicles.[114]

Research and Development to Improve Fuel Economy

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Incentive for Manufacturers	Long-term Effect	Federal, Private Sector

Description of Strategy

The goal of research and development (R&D) is to support the development and implementation of new technologies that could improve fuel economy and reduce greenhouse gas emissions. The economic argument for national investment in R&D is that vehicle manufacturers would under-invest in fuel economy technologies due to a market failure in which consumers under-value fuel economy. R&D holds the potential to advance numerous innovations. A number of current efforts focuses on use of alternative fuels for highway vehicles, such as battery-powered electric vehicles, which are discussed in the next section on alternative fuels.

Passenger cars and light trucks are the prime focus of most current R&D efforts. The Partnership for a New Generation of Vehicles (PNGV) is the cornerstone of US research and development for light-duty vehicles. A joint venture of the US Government and the US Council for Automotive Research (a research consortium formed by General Motors, Ford, and Chrysler), the PNGV has a long-range goal to develop technologies that will assist the development of vehicles with up to three times the fuel efficiency of today's mid-size family sedan (implying fuel economy of about 80 mpg), at an equivalent life-cycle cost (vehicle purchase plus operating costs) that meets customer needs for quality, performance, and utility.[xxvii] Major improvements in aerodynamics, friction reduction, and lightweight materials will be essential to this effort. PNGV is examining conventional, hybrid electric, and fuel cell technologies. As work progresses, priorities will be established among various technologies.

The US DOT and DOE are currently supporting heavy-duty vehicle engine research with a goal to achieve a 50-percent improvement in fuel efficiency.[115]

Effectiveness Factors

The effectiveness of R&D as a means to reduce national emissions depends upon the extent to which:

- Technology is pushed beyond levels that would have been achieved without the investment;
- Market penetration of these technologies is achieved by private-sector commercialization;
- Policies are included to ensure that new fuel efficient technology is applied to improving fuel economy rather than increasing power and size; and
- Vehicle miles traveled increase through a "rebound effect."

A vehicle that is three times as fuel efficient as today's vehicles would significantly reduce greenhouse gas emissions from transportation, even after accounting for a rebound effect.

Timing

If PNGV's goal of developing production prototypes by 2004 is reached, production of "new generation" vehicles could begin by 2006-2007. With adequate commercialization, enough vehicles could be on the road by 2010 to have a measurable effect on national emissions.[116] However, the current portfolio of R&D programs is heavily weighted toward longer-term technologies, apparently reflecting US policy that government's R&D role should be weighted toward long-term opportunities.[117]

Implementation Issues

Public investment in R&D raises issues about the appropriate role of government in researching, and designing vehicles. It also raises issues about potential shifts in market power among or away from traditional vehicle manufacturers and changes in employment patterns and national economic activity.

[xxvii] Two other goals are to improve the competitiveness of US vehicle manufacturing and to rapidly deploy cost-effective incremental technology improvements.

The public is generally receptive or neutral toward investment in R&D since R&D does not directly or immediately increase the price of travel or attempt to change behavior and attitudes.

Deployment of the vehicle technologies and fuels under consideration in the PNGV program could both require and precipitate a very wide range of infrastructure changes, some of which could emerge as major barriers to implementation. Prominent examples could include supply and procession of raw materials, manufacturing of vehicle components, vehicle assembly, vehicle maintenance and repair, emergency response, vehicle recycling and disposal, and fuel production and distribution. In addition, research into the structural performance of lightweight vehicles will need to be supplemented with research focused on the safety performance of some powertrain components if overall vehicle safety is to be well-understood prior to deployment.

5.3.3 Changing Vehicle Purchase/Retirement Decisions

These strategies attempt to influence the types of vehicles individuals purchase and use, but without providing a direct push to vehicle manufacturers to improve vehicle technology. Rather, these strategies affect individual vehicle purchase and retirement decisions, and attempt to pull along technological improvements as vehicle manufacturers respond to consumer desires. Examples include:

- Dissemination of fuel economy information;
- Vehicle Efficiency taxes or feebates;
- Fuel economy- (or emissions-) based vehicle registration fees; and
- Vehicle buyback programs.

Disseminate Fuel Economy Information

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Education and Information	Mid-term Effect	Federal, Private Sector

Description of Strategy

The goal of disseminating fuel economy information is to influence consumer-purchasing decisions on vehicles and tires. By making buyers aware of the differences in fuel economy among vehicles and tires, they will be more likely to take fuel economy into account in their purchase selection since better fuel economy means lower fuel costs over the long-run of owning a vehicle.

The Energy Policy and Conservation Act of 1975 established a fuel economy information program for passenger cars and light trucks that requires the estimated city and highway fuel economy to be prominently displayed on a window sticker for all new cars. It also required that a *Gas Mileage Guide*, listing fuel economy ratings of all makes and models be prominently displayed and available in new car dealer showrooms. Strategies that would build upon this existing program include developing:

- A fuel economy information program for heavy duty vehicles; and
- A tire labeling program.

A fuel economy information program for heavy-duty vehicles would provide information to allow freight carriers as well as governments (fleets of garbage trucks and buses) to incorporate fuel cost considerations into their vehicle purchase decision. There currently is no standard basis for comparing fuel economy across makes, models, and configurations of heavy trucks. A tire labeling program would help consumers identify tires that have low rolling resistance and, therefore, provide better fuel economy. Under the *Climate Change Action Plan*, the US has committed that the US DOT would develop a tire-labeling program mandatory for most light-duty vehicle tires and, if possible, establish a voluntary labeling program for heavy-duty truck tires.

Effectiveness Factors

The effectiveness of a fuel-economy information program depends on:

- The number of vehicle/tire purchases annually;
- The extent to which education affects purchasing behavior; and
- The extent to which selected vehicles/tires yield fuel economy improvements.

No data have been found that estimate the carbon reduction impact of a fuel economy program for heavy- duty vehicles. Since heavy-duty vehicles make up a small portion of the total highway fleet, the potential may be somewhat limited. In addition, it is not known to what extent the program would actually influence vehicle purchasing decisions, since other considerations, such as size and performance, may dominate the selection decision, and purchasers of heavy trucks may be more aware of fuel economy differences among vehicles than consumers of light-duty trucks.

For light-duty vehicles, consumers often purchase replacement tires that have 20 percent more rolling resistance than original-equipment tires, reducing their vehicles' fuel economy by up to 4 percent.[119]

> The Climate Change Action Plan estimated that a tire labeling program would result in the purchase of 20 million additional fuel-efficient tires, out of a total replacement market of about 120 million tires, in the year 2000. Assuming market penetration of 7.5 percent for light-duty vehicles and 11.0 percent for heavy-duty vehicles, and an increase in on-road fuel economy of 4.0 percent for light-duty vehicles and 7.0 percent for heavy-duty vehicles, this strategy would reduce carbon emissions by 1.5 million metric tons (mmtCe) in the year 2000.[118]

Although the response of consumers to fuel economy information is not precisely known, evidence suggests that information programs may have a small effect on consumer behavior. An assessment of the light-duty vehicle labeling program suggests that many consumers are not aware of fuel economy even with the program. One study found that only 26 percent of 1988 and 1989 new vehicle purchasers were aware of the *Gas Mileage Guide*, and only 4 percent consulted it before making a purchase.[120] Two-thirds knew of the fuel economy label, and half got information from it. Evaluation shows that consumers who are aware of fuel-economy information purchase cars that are about 2 mpg more efficient than those who are not, but it is not known to what extent this is a result of the program and to what extent this may be self-selection bias.[121] In recent years, fuel economy does not appear to be a prime consideration in vehicle selection. Gas costs per mile have fallen significantly, and the cost advantage of choosing higher fuel economy is relatively small in the context of the total costs of owning and operating a car, especially when one discounts future fuel savings.[122]

Timing

There will be a time lag for consumer education programs to reach full effectiveness since they only affect new vehicle and replacement tire purchases, not the entire in-use vehicle fleet.

Implementation Issues

Implementation of these programs would involve a mandate on dealerships and manufacturers to provide the fuel-economy labels and information. Generally, education programs do not suffer from problems of political acceptance and are not very costly.

VEHICLE EFFICIENCY TAXES AND FEEBATES

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Economic Incentive	Mid-term Effect	Unknown

Description of Strategy

The idea of an efficiency tax is to provide an incentive for manufacturers to produce and for customers to purchase fuel-efficient vehicles. Two pricing mechanisms have been identified to achieve this objective:

- A tax on fuel-inefficient vehicles (e.g., a "gas-guzzler" tax), and
- A "feebate" program that both taxes fuel-inefficient vehicles and offers rebates that lower the purchase price of fuel-efficient vehicles.

Although taxes and feebates have generally been discussed in the context of vehicle purchases, the application of these concepts to the purchase of tires has also been identified as a policy option.[xxviii] Since low rolling resistance tires tend to be more expensive than other tires, a rebate for purchases of tires that have rolling resistance below a set point and fees for rolling resistance levels above the set point would encourage sales of low rolling resistance tires. A plan can be designed to be revenue-neutral or revenue-generating.

Feebates for vehicles can be structured in a variety of ways. They can be scaled to fuel economy or fuel consumption, or a measure of one or the other normalized to a measure of vehicle size, such as interior volume, wheelbase, or according to EPA size classes. The purpose of normalizing is to provide a pull to improve technology and design within each size class and to avoid disadvantaging domestic manufacturers whose model lines are concentrated on larger vehicles. However, a limitation of grouping vehicles into categories is that it provides a strong incentive for manufacturers to grow vehicles at the upper range of a group into the next group, which would have a lower average fuel economy. Gas-guzzler taxes are already being imposed in the United States and affect roughly 1.4 percent of automobile sales.[123]

Effectiveness Factors

The effectiveness of taxes and feebates on greenhouse gas emissions depends on:

- The level of taxes and feebates;
- Responsiveness of vehicle manufacturers to the tax or feebate;
- Responsiveness of consumer vehicle/tire choice decisions to vehicle/tire price;
- Number of new vehicle sales annually/change in the rate of turnover in the vehicle fleet;

[xxviii] The Majority Report of the Policy Dialogue Advisory Committee proposed a feebate policy for purchase of tires based on rolling resistance.

- Shifts between vehicles of different sizes or between cars and light trucks; and
- Increases in vehicle miles traveled (due to reduced fuel costs per mile).

Estimates of the effectiveness of feebate programs are unclear due to uncertainties in the response of consumers and manufacturers to the incentives. ACEEE estimated a small consumer response—on the order of 1 mpg fleet improvement—to a $300/mpg feebate, assuming no long-term effects on manufacturers.[124] On the other hand, some analyses suggest that over 90 percent of the fuel economy improvement from vehicle purchase price strategies would come from changes in vehicle designs and offering by manufacturers and only 10 percent from direct consumer reactions.[125] Lawrence Berkeley Laboratory (LBL) estimated that a relatively moderate feebate (e.g., one that awarded a $500 differential between a 20- and a 25-mpg car) can achieve substantial fuel economy improvements (e.g., a 15 percent improvement in new car fuel economy by 2010 over levels expected without feebates).[126]

> The majority report of the advisory committee on emissions from motor vehicles estimated greenhouse gas reductions from a feebate on replacement tires based on rolling resistance would be 3 mmtCe by 2000, 4 mmtCe by 2010, and 5 mmtCe by 2025.

OTA suggested that effectiveness is not well understood since models of manufacturers' reactions include treatment of the auto manufacturers as one large entity rather than as multiple companies. In addition, models do not account for manufacturers' desire to optimize long term investments rather than to immediately capture as many feebate dollars as possible. While these uncertainties also apply to analysis of fuel economy regulations, the analysis of feebates attempts to understand how companies will behave in a market situation in the absence of regulatory constraints that mandate specific fuel economy averages.[127]

If gasoline prices are stable or rise only slowly, and the feebate causes fuel economy to rise more than fuel price, then the cost per mile of driving will fall. The resulting "rebound" effect of increased VMT would offset some of the emissions savings.

Timing

Feebates/rebates could be implemented quickly. However, since feebates/rebates affect only new vehicle sales, it would take a number of years for a full impact to be observed as the vehicle fleet turns over. Consumers have an immediate effect through their selection of vehicles. It would take somewhat longer for vehicle manufacturers to adjust their product.

Implementation Issues

Efficiency taxes/rebates can be structured to be revenue-neutral or revenue-generating for governments such that administrative costs are covered. Any form of taxes/rebates may distort consumer behavior, and potentially reduce welfare in ways that cannot be easily measured. However, these programs may lead also to fuel savings and cost reductions for drivers. For example, the majority report of the Policy Dialogue Committee estimated that fuel savings from a revenue-neutral feebate on tires would produce fuel cost reductions of $7 billion for drivers over the four-year tire life.[128]

Finally, the impact of efficiency taxes/rebates on automobile manufacturers is likely to be significant, changing the structure, conduct, and performance of this important industry. To avoid disadvantaging domestic manufacturers, feebate structures can incorporate vehicle size and separate cars from light trucks.[129]

FUEL ECONOMY BASED VEHICLE REGISTRATION FEES

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Economic Incentive	Mid-term Effect	State

Description of Strategy

Fuel economy based registration fees involve a surcharge on vehicle registration fees or license fees based on vehicle fuel economy. A similar measure, such as registration fees that vary on vehicle age may accelerate the rate of vehicle turnover, resulting in use of more fuel-efficient vehicles. Currently, registration fees are collected by states in constant rates that do not vary by type of light-duty vehicle or vehicle age. Sometimes referred to as emissions taxes, the concept involves variable registration fees that reflect the emissions rate of a particular vehicle or may attempt to reflect actual yearly emissions. In the latter case, the program must account for miles of travel, as with a VMT fee. Although emissions-based fees have generally been discussed in connection with criteria air pollutants, a charge based on fuel consumption may be feasible. These charges could be assessed on an annual or semi-annual basis.

Effectiveness Factors

Effectiveness depends on:

- The level and frequency at which the emissions fees are charged;
- Responsiveness of consumer vehicle decisions to life-cycle vehicle price;
- Number of new vehicle sales annually/change in the rate of turnover in the vehicle fleet;
- Shifts between vehicles of different sizes or between cars and light trucks; and
- Increases in VMT (due to reduced fuel costs per mile).

Consumer responses to an increase in vehicle registration fees are likely to be smaller than responses to a direct increase in the purchase price of a vehicle (e.g., a feebate) since consumers discount future payments (e.g., value them less than current payments). In addition, vehicle registration fees have a less direct effect on vehicle manufacturers compared to vehicle purchase price measures. In order for these fees to be effective at influencing consumer decisions, the fees may need to be significant.

Timing

Although emissions fees may be assessed annually, they only have an effect on greenhouse gas emissions to the extent that they alter vehicle purchase decisions. As a result, it will take many years to achieve the full effects since the average lifetime of an auto is nearly 14 years.[130]

Implementation Issues

These fees could involve significant increases in government revenues, which may encourage their adoption by states. On the other hand, like other pricing measures, increased vehicle registration fees raise concern regarding political feasibility and issues of equity.

VEHICLE RETIREMENT/BUYBACK PROGRAMS

Primary Target	Approach	Timing	Level of Implementation
Improve Fuel Economy	Economic Incentive	Near-term Effect	State, Local, Private Sector

Description of Strategy

Since newer vehicles tend to be more efficient than older vehicles, the retirement of older vehicles and sales of new vehicles will increase average fleet fuel economy. Retirement or scrappage of older vehicles can be encouraged through buyback programs that offer a financial inducement to voluntarily remove a vehicle from use. The idea of encouraging retirement of older vehicles was first proposed as a strategy to reduce air pollution because a small portion of old vehicles produce a disproportionate share of emissions.[131]

Effectiveness Factors

The effectiveness as a greenhouse gas strategy depends on the following factors:

- Number of vehicles retired annually due to the program;
- Usage characteristics of older vehicles; and
- Average fuel economy of retired vehicles compared to replacement vehicles.

There are significant limitations to the potential of vehicle retirement programs as a greenhouse gas emissions strategy. Although fuel economy doubled from 1974 to 1985, the fuel economy of new passenger cars in the US has not improved significantly since the mid-1980s.[132] In addition, fuel economy does not deteriorate rapidly as vehicles age. Fuel economy is likely to deteriorate by only about 10 percent over a period of 15 years.[133] Since there is a small differential between the fuel economy of newer and older vehicles, removing older vehicles from the road will result in very small improvements in average fleet-vehicle fuel economy.

In addition, vehicle use tends to decline with vehicle age so that a typical automobile 10 years and older will be driven only half as many miles as a new vehicle.[134] If demand for driving is sensitive to driving costs, then people with newer, more fuel efficient replacement vehicles will drive them more than the cars they sold.

Timing

A vehicle buyback program would have an immediate greenhouse gas effect through the removal of older, less fuel-efficient vehicles.

Implementation Issues

Urban areas may wish to consider vehicle retirement programs as part of a strategy to reduce criteria pollutant emissions since new vehicles produce significantly less pollution than cars manufactured 20 years ago. The 1990 Clean Air Act Amendments specify programs to encourage voluntary retirement of pre-1980 light-duty vehicles as a transportation control measure that can help urban areas to reach attainment of national ambient air quality standards. Old autos are high criteria pollutant emitters since they were manufactured with no or much less stringent emissions controls compared to new vehicles. Retirement of older vehicles may be a useful supporting strategy to increase the rate of fleet turn-over, which can support other policies to improve new-vehicle fuel economy, such as CAFE standards, feebates, and gas taxes.

5.4 Reduced Carbon Content (Alternative Fuel) Strategies

A third target to reduce greenhouse gas emissions is to switch to fuels that have a lower life-cycle carbon content than conventional gasoline. All fuels have unique carbon contents that reflect the amount of carbon emitted per unit of energy consumed during combustion. Greenhouse gas emissions are also produced during upstream activities associated with transportation, such as fuel production, fuel distribution, feedstock transport, methane leaks, and production and assembly of vehicles. In addition to carbon dioxide, fuel use and upstream processes generate other greenhouse gases, such as methane.[xxix]

The use of low life-cycle carbon fuels offers an opportunity to reduce greenhouse gas emissions without relying on substantial reductions in transportation demand. The Energy Policy Act of 1992 (EPACT) lists a variety of fuels not derived from crude oil that are considered alternative or replacement fuels: methanol, natural gas, liquid petroleum gas, ethanol, hydrogen, and electricity. In addition, reformulated gasoline is conventional gasoline that has been reblended to reduce criteria pollutant emissions. Although many of these fuels have lower carbon-contents than conventional gasoline, on a life-cycle basis, not all alternative fuels reduce greenhouse gas emissions.[xxx]

DOE recently estimated the full fuel cycle carbon dioxide emissions of conventional gasoline and four alternative fuels. Of the five fuels examined, compressed natural gas (CNG) produced the lowest level of CO_2 emissions, followed by liquefied petroleum gas (LPG) and ethanol from corn, as shown in Exhibit 5-8.[135]

Exhibit 5-8. DOE's Estimated Fuel Cycle Carbon Dioxide Emissions per Vehicle Mile Traveled (grams/mile)

Fuel	Vehicle Use	Upstream	Total Emissions
Gasoline	272.4	74.9	347.3
Methanol from Natural Gas	270.4	112.7	383.1
Ethanol from corn	301.1	24.4	325.5
Compressed natural gas	204.7	43.5	248.2
LPG from oil and gas	235.4	28.1	263.5

Note: This table presents results only for carbon dioxide, not other greenhouse gases.

Source: US Department of Energy. Energy Information Administration. Alternatives to Traditional Transportation Fuels 1994: Volume 2, Greenhouse Gas Emissions. August 1996. p.16.

The same study found that although compressed natural gas (CNG) produced less carbon dioxide than conventional gasoline, it produced significantly more methane, a much more powerful greenhouse gas.[136] Of the five fuels examined, ethanol from corn produced the largest nitrous oxide emissions across the total fuel cycle. DOE's methodology for estimating full fuel cycle emissions paralleled a framework

[xxix] These emissions can be converted into carbon equivalent using global warming potentials.

[xxx] For policy development and target setting, it is important to note that national inventories of greenhouse gas emissions only include emissions from travel in the transportation sector's inventory. Fuel processing and other upstream effects are counted as industrial sources.

established earlier by Delucchi, who examined full fuel cycle emissions for over twenty different fuels and fuel sources (i.e., ethanol from corn, ethanol from wood).[137]

Upstream emissions are an important component of carbon dioxide emissions from transportation. Battery-powered vehicles produce no greenhouse gas emissions during vehicle use. However, greenhouse gases can be emitted from the energy source used to produce the electricity stored in the vehicle's batteries. If electric vehicles are recharged from power supplied by coal-fired power plants, total fuel cycle CO_2 emissions are higher than for gasoline vehicles. Battery-powered electric vehicles emit less on a full fuel cycle basis if they use hydroelectric, natural gas, nuclear, or solar power for generation of electricity.[138]

In theory, fuels from biomass (e.g., ethanol and methanol from wood, ethanol from corn) have zero life-cycle carbon emissions since carbon is absorbed in the growth of raw materials and then released during combustion. However, cultivation and conversion of biomass into fuel also require energy consumption. Other renewable resources (e.g., solar, hydroelectric) theoretically have zero life cycle emissions.

When examined over the full fuel cycle, the greenhouse gas emission benefits of many alternative fuels are minimal. Upstream emissions, however, are uncertain and would change depending on the scale of adoption of alternative fuels. Economies of scale in fuel processing and distribution could reduce emissions per mile as the market for alternative fuels expands.[139] The efficiency of alternative fuel vehicles (AFVs) also may differ from that of conventional vehicles, which would affect carbon emissions. A strategy to reduce carbon emissions by switching fuel sources would need to focus on the development and use of low life cycle carbon fuels.

The use of some alternative fuels requires major vehicle redesign. Alternatives to the conventional combustion engine vehicle include:

- *Battery electric vehicles*—These vehicles use high-energy-density batteries as their sole power source.
- *Hybrid vehicles*—These vehicles combine two power sources: a high-energy-density battery or ultracapacitor, and a small internal combustion engine or generator. The small internal combustion engine could be used to continually charge the battery and address the range limitations of batteries.
- *Fuel cell vehicles*—These vehicles use a fuel cell, which is a device that converts chemical energy directly into electrical energy without combustion. It is a simple electrochemical device with no moving parts that generates electricity by harnessing the reaction of hydrogen and oxygen to make water. The vehicle holds a storage tank containing hydrogen or a hydrogen-carrying substance, such as methanol. Since hydrogen can be made from solar or wind energy, a fuel cell operating on hydrogen from these sources has zero greenhouse gas emissions. If the hydrogen is generated from other sources, however, significant levels of greenhouse gases may be produced.

Alternative fuel fleet programs have been designed primarily to reduce reliance on imported oil. Criteria pollutant emissions reductions necessary to meet attainment of national ambient air quality standards (NAAQS) are also a major force pushing regions to use reformulated gasoline and to examine alternative-fueled vehicles. Aside from the considerable weight of the NAAQS in encouraging alternative fuel vehicle use, there are a number of strategies to encourage use of alternative fuels or reformulated gasoline, including:

- LOW CARBON/ALTERNATIVE FUEL VEHICLE (AFV) MANDATES;
- RESEARCH AND DEVELOPMENT ON FUELS/ ALTERNATIVE FUEL VEHICLES; and

- CARBON TAXES AND OTHER MARKET INCENTIVES.

LOW CARBON/ALTERNATIVE FUEL VEHICLE MANDATES

Primary Target	Approach	Timing	Level of Implementation
Reduce Carbon Content	Regulation (including government regulating itself)	Mid-term Effect	Federal, State, Local

Description of Strategy

Mandates can be set either on vehicle manufacturers to produce an alternative-fuel vehicle (AFV) or on certain vehicle customers—specifically government agencies and other large fleets—to purchase AFVs powered by low life-cycle carbon fuels. The purpose of fleet procurement requirements is to create initial market demand to spur development and commercialization of AFV technologies and infrastructure. These mandates would need to be targeted at AFVs with low life-cycle carbon emissions to achieve greenhouse gas reductions.

The Energy Policy Act of 1992 (EPACT) and Presidential Executive Order 12844 require minimum AFV purchases for federal government vehicle fleets. In March 1996, the US DOE published a final rule to implement AFV acquisition requirements for state government and fuel provider fleets, as directed in the EPACT. For states or state agencies, the rulemaking specifies that of the new light-duty vehicles acquired annually, the following percentages must by AFVs (Exhibit 5-9):

Exhibit 5-9. Mandates for Percent of State Vehicle Purchases that Must be AFVs under DOE Rule

1997	1998	1999	2000	After 2000
10%	15%	25%	50%	75%

Source: US Department of Energy. Energy Information Administration. *Alternatives to Traditional Transportation Fuels 1995.* December 1996. p. 29.

California's pilot-test program, the Low Emission Vehicle (LEV) Program, requires minimum sales of zero emission vehicles (ZEVs) and average emission standards that must be met through flexibly combined sales of vehicles in different emission categories. This program could reduce carbon emissions if vehicles are powered by low carbon sources.

Effectiveness Factors

The effectiveness of alternative-fuel vehicle mandates depends on the following factors:

- Scope and extent of the mandate (which should correspond with feasibility, given constraints on technology and cost);
- Number of new vehicle sales annually/vehicle fleet turn over rate;
- Consumer acceptance of new technologies and fuels; and
- Differential between greenhouse gas emissions of alternative fuels and conventional gasoline.

Alternative-fuels programs appear to have substantially increased the number of AFVs in operation in the US. The Energy Information Administration reports that the number of AFVs in use in the US has increased by over 32 percent from 1992 to 1995, from about 251,350 to 333,049. The number of AFVs in use is expected to increase at an annual rate of 7.6 percent between 1995 and 1997 primarily due to minimum AFV purchase requirements for Federal government vehicle fleets and for state and local fleets.[140] These vehicles still comprise a very small portion of the total vehicles in use.

Ultimately, the effectiveness at reducing greenhouse gases depends on the type of vehicles and fuels used. Alternative fuel mandates have primarily been designed to reduce reliance on imported oil and LEV mandates have been identified as a means to improve air quality. Greenhouse gas reduction depends on use of low life-cycle carbon fuels.

Timing

Use of wide-scale alternative fuels is constrained by time lags associated with investment requirements. For example, the research and development necessary to bring alternative-fuel production capacity on-line is time-intensive, as well as the appropriate infrastructure that must be in place to enable the use of alternative fuels. Moreover, the economic feasibility and marketability of such fuels adds to the time it would take to achieve the wide-scale usage of alternative fuels.[141]

Implementation issues

Replacing gasoline with alternative fuels involves a number of transitional barriers and costs associated with immature technologies. In particular, impediments to AFV use include supplier and consumer unfamiliarity, new operational complexities, training needs, less frequent realization of economies of scale in production, and lack of necessary infrastructure.[142]

RESEARCH AND DEVELOPMENT ON FUELS AND ALTERNATIVE-FUEL VEHICLES

Primary Target	Approach	Timing	Level of Implementation
Reduce Carbon Content	Incentive for Manufacturer	Long-term Effect	Federal, Private Sector

Description of Strategy

The goal of research and development (R&D) is to provide a "push" to support the development and implementation of new vehicle technologies using low carbon fuels. Some of these efforts have focused on battery powered and fuel-cell powered vehicles. R&D could also focus on reducing upstream emissions from processing of alternative fuels.

A number of efforts are supporting R&D, including the Partnership for a New Generation of Vehicles (PNGV), described in Section 5.3.2. The US Advanced Battery Consortium (USABC), established in January 1991, has been developed to concentrate efforts on battery development for electric vehicles. The USABC consists of the Big Three US auto manufacturers (Chrysler, Ford, General Motors), the Electric Power Research Institute, the US DOE, and five major US electric utilities. The mid-term Advanced Battery Technology goals were to double the range and performance of electric vehicles compared to that of current battery technology in the mid-term, and develop a battery competitive with internal combustion engine vehicles in the long-term.[143] Approximately $260 million were committed to the Consortium from 1991 to 1996.

Effectiveness Factors

Like R&D efforts to improve conventional vehicle fuel economy, the effectiveness of R&D efforts aimed at AFVs depends on the extent to which it:

- Pushes technology beyond levels that would have been achieved without the investment; and
- Supports market penetration of these technologies.

Timing

There are some near-term goals for improvements in battery and fuel cell technology that may be achievable. However, the widespread acceptance and use of electric, fuel-cell, and hybrid vehicles would most likely be a long-term response. There are multiple constraints that currently limit potential commercialization, including cost, limited range, time for recharging current-generation batteries, durability, limited speed, safety concerns, and the need for an entirely new infrastructure in the form of charging stations and equipment. These concerns are being addressed under existing research efforts but may take significant time to resolve.

Implementation Issues

Public investment in R&D raises issues about the appropriate role of government in researching and designing vehicles. It also raises issues about potential shifts in market power among or away from traditional vehicle manufacturers and changes in employment patterns and national economic activity. The public is generally receptive or neutral toward investment in R&D, since it does not directly or immediately increase the price of travel or attempt to change behavior and attitudes.

CARBON TAXES AND DIFFERENTIAL TAXES FOR ALTERNATIVE FUELS

Primary Target	Approach	Timing	Level of Implementation
Reduce Carbon Content, Improve Fuel Economy, Reduce Vehicle Travel	Economic Incentive	Near-term Effect and Long-term Effect	Federal, State

Description of Strategy

A carbon tax is a levy on fuel that ties the tax level directly to the carbon content of the fuel. A carbon tax would be broad-based, so that it would affect fuels used in all sectors. A related fuel tax strategy is to reduce existing taxes for "clean" or alternative fuels. Until the year 2000, a 5.4¢ exemption of federal gasoline taxes exists for fuels containing at least 10 percent ethanol. In theory, differential tax rates provide an incentive for commuters to switch to alternative-fuel vehicles.

Effectiveness Factors

A carbon tax reduces carbon dioxide emissions in multiple ways. By increasing fossil fuel prices generally, it encourages more efficient use of energy and reduced vehicle travel. By changing relative prices of fuels, it encourages a shift in consumption from high-carbon fuels to low carbon-content fuels. Since carbon taxes address all components that contribute to carbon emissions, they are more efficient than simple fuel taxes at reducing carbon emissions.[144]

Effectiveness in reducing national emissions depends upon:

- The level of the tax; and
- Responses to the price of various fuels (in terms of travel demand, fuel economy, and type of fuel).

A number of economic models have examined the relationship between tax rates and emission levels, and a range of estimates has been suggested for the appropriate level of a carbon tax. Within the transportation sector, carbon taxes will function like conventional gasoline taxes except to the extent that they encourage switching to lower carbon fuels. While the availability of alternative fuels and vehicles is increasing, limited availability may present a significant barrier to using lower carbon fuels. The response to the tax could be amplified by using revenues to fund alternative technologies and energy-efficient infrastructure. One study found that a significantly lower tax rate would be required to achieve emissions reductions if the revenues were earmarked for carbon abatement measures rather than general revenues.[145]

Timing

A carbon tax would have a near-term effect on emissions stemming from near-term reductions in vehicle travel. Improvements in vehicle fuel economy and shifts to alternative fuels would take significantly longer.

Implementation Issues

Ideally, by raising fuel prices to account for negative externalities, a carbon tax will yield a more efficient economy. However, by raising prices on all energy consumption, they could reduce economic productivity. A carbon tax would have most negative effect on industries highly dependent on fossil fuels. Carbon taxes could also be viewed as a fiscal benefit to governments, since such a broad-based tax can raise substantial revenues. The Congressional Budget Office estimated that a national carbon tax of $70 per ton would raise net revenues of $72.5 billion annually.[146]

The idea of a carbon tax has surfaced in national political debate over the past decade. The Bush Administration's National Energy Strategy considered but rejected a tax of $135 per ton of carbon.[147] Early in Clinton's first term, the Administration indicated that it was considering a broad-based energy tax, but this was not included in the budget package. A number of states have implemented tax incentives for alternative fuels, and interest in new revenue sources suggests that there is potential for state adoption of carbon taxes.[148]

5.5 Summary Assessment

Recent policy debate on energy consumption from the use of light-duty vehicles is often characterized as a choice between those who favor higher fuel taxes and those who place greater emphasis on regulating vehicle fuel economy. This report suggests that decision-makers are not limited to one-or-the-other policy responses. A variety of different strategies are available to reduce carbon dioxide and other greenhouse gases from highway vehicles, which need to be closely examined in terms of their effectiveness and implementation feasibility. Strategies can have different targets, be implemented at various levels of government, and be devised with various levels of stringency. Some strategies may work in a complementary fashion and have multiple benefits, which should be considered.

Although this section does not recommend specific strategies for implementation, it highlights some of the concerns that decision-makers may wish to examine when selecting strategies. This literature review suggests a number of conclusions:

- *Decision-makers will be faced with many uncertainties when selecting strategies.* There is considerable uncertainty about the full costs and benefits of various strategies, as well as about the political and practical limits to a given strategy. In addition, economic and behavioral relationships that determine strategy effectiveness are not precisely known. An assumption that gasoline demand and fuel economy are very sensitive to fuel prices leads to the conclusion that fuel taxes may be relatively more effective than fuel economy standards. On the other hand, assuming that travel is relatively insensitive to travel costs leads to the conclusion that fuel economy standards may be more effective than pricing strategies. Economists disagree on these elasticity values, yet they are critical to the estimation of strategy effectiveness. Using different elasticity estimates from the literature can entirely reverse the ranking of policies by CO_2 and other greenhouse gas emissions impacts.[149] Decision-makers should expect to operate under uncertainty and recognize the range of effects that might be achieved by various strategies.

- *Some factors that affect strategy effectiveness may themselves be affected by policy development.* The effectiveness of strategies depends on a variety of factors. Some factors cannot be changed directly, such as individual responses to travel pricing and vehicle pricing. Other factors are at the discretion of policy makers, such as the level of price increases, infrastructure investment, and mandates. The number of variables that influence strategy effectiveness suggests that scenario analysis is necessary to identify ranges of potential emissions reductions that are practical.

- *Different strategies can be effective over different time periods.* Since different strategies are suited to emissions reductions over various time periods, decision-makers should recognize the timing of strategy effects when setting targets and developing policies. In general, strategies that focus on driver behavior will tend to have a near-term effect. Strategies focused on vehicle technologies will have an intermediate effect since it will take a number of years for improved technologies to be developed and then be brought into the vehicle fleet in significant numbers. Finally, land-use changes yield significant results only over a longer time frame.

A variety of groups have tried to identify and assess strategies for reducing greenhouse gas emissions from highway transportation, including policies and initiatives already underway. However, consensus on national policy has been difficult to attain, and further research is needed regarding uncertainties about the full costs and benefits strategies and their subsequent implications. For example, the Policy Dialogue Advisory Committee established by President Clinton to examine measures to reduce greenhouse gas emissions from personal motor vehicles could not develop consensus on the most appropriate package of measures. This report has acknowledged throughout that there are many difficulties in ranking strategies and developing consensus on policy. Selection of strategies involves decisions that could have political, economic, and lifestyle ramifications. Many strategies also offer potential multiple benefits beyond greenhouse gas reduction. Uncertainty about possible strategies in the US may also make it difficult to reach conclusions about the relative effectiveness of various policies for other countries.[150] By identifying the issues that decision-makers will need to consider, this report can serve as a basis for continuing policy dialogue to confront the threat of potential global climate change.

Exhibit 5-10 summarizes the previous discussion of strategies and their components:

Exhibit 5-10. Summary of Strategies and their Characteristics

Strategy		Primary Target	Approach	Timing	Level of Implementation
Travel Pricing	Road Pricing	Reduce Vehicle Travel	Economic Incentive	Near-term Effect	State, Local
	VMT Fees				Unknown
	Fuel Pricing	Reduce Vehicle Travel Increase Fuel Economy			Federal, State, Local
Provision of Alternative Modes	Transit Investment	Reduce Vehicle Travel	Infrastructure Investment	Mid-term Effect	Federal, State, Local
	Bicycle Support Facilities			Near-term Effect	Local
	Park & Ride Facilities				State, Local
	HOV Lanes			Mid-term Effect	State, Local
Parking Management	Parking Pricing	Reduce Vehicle Travel	Economic Incentive	Near-term Effect	Local
	Mandatory Parking Cash-out				Federal, State, Local
	Parking Supply Limits		Regulation or Incentives	Long-term Effect	Local
Land Use Planning	Dense, Transit-Oriented Development	Reduce Vehicle Travel	Regulation or Incentives	Long-term Effect	Local
	Enhance Pedestrian Environment		Regulation; Infrastructure Investment	Mid-term Effect	Local
Other VMT-reduction Measures	Telecommuting	Reduce Vehicle Travel	Education and Information	Near-term Effect	Employer-Based
	Compressed Work Hours				Employer-Based
	No-Drive Days				Local
Improving Traffic Operations	Traffic Flow Improvements	Improve Fuel Economy	Infrastructure Investment	Near-term Effect	State, Local
	Limit Freeway Speeds to 55-mph		Regulation		Federal, State
	Driver Education		Education and Information		Federal, State, Local
Vehicle Technology Improvement	CAFE Standards	Improve Fuel Economy	Regulation	Mid-term Effect	Federal
	R&D to Improve Vehicle Fuel Economy		Incentive for Manufacturer	Long-term Effect	Federal, Private Sector
Changing Vehicle Purchase/ Retirement Decisions	Disseminate Fuel Economy Information	Improve Fuel Economy	Education and Information	Mid-term Effect	Federal, Private Sector
	Vehicle Efficiency Taxes and Feebates		Economic Incentive		Unknown
	Fuel Economy based Vehicle Registration Fees				State
	Vehicle Retirement/ Buyback Programs			Near-term Effect	State, Local, Private Sector
Reduced Carbon Content (Alternative Fuels)	Alternative Fuel Vehicle (AFV) Mandates	Reduce Carbon Content	Regulation	Mid-term Effect	Federal, State, Local
	R&D on Fuels and AFVs		Incentive for Manufacturer	Long-term Effect	Federal, Private Sector
	Carbon Taxes and Differential Taxes for Alternative Fuels	Reduce Carbon Content Improve Fuel Economy Reduce Vehicle Travel	Economic Incentive	Near-term Effect Long-term Effect	Federal, State

[1] *Majority Report to the President by the Policy Dialogue Advisory Committee to Recommend Options for Reducing Greenhouse Gas Emissions from Personal Motor Vehicles.*

[2] The following reports and studies examine travel price elasticities (note that many of these studies examine fuel price elasticities, which can be converted into travel price elasticities):

Dahl, Carol, and Thomas Sterner. "Analysing Gasoline Demand Elasticities: A Survey." *Energy Economics.* July 1991, pp. 203-210.

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APPENDIX A: CALCULATING CARBON DIOXIDE EMISSIONS FROM FUEL CONSUMPTION

METHODOLOGY

Carbon dioxide emissions from fuel consumption are estimated according to the following simple formula:

$$Emission(mmtCE) = Fuel\ consumption\ (Btus)\ x\ Carbon\ coefficient\ (\frac{mmtCE}{Btu})\ x\ \%Fuel\ Combusted$$

As the formula suggests, three pieces of information are necessary to calculate CO_2 emissions:

- Fuel consumption (in BTUs)—This data is available from a variety of sources; US national inventories of CO2, as reported by DOE and EPA, have been calculated using the Energy Information Administration's State Energy Data Report.
- Carbon coefficients—Each fuel has a different carbon coefficient, which identifies the amount of carbon released when the fuel is burned. The carbon coefficient depends on the density, carbon content, and gross heat combustion of the fuel (these are reported in DOE/EIA, Emissions of Greenhouse Gases in the United States 1987-1994, Table A1).
- Fraction of Fuel Combusted—Some portion of fossil fuel consumption is not combusted. Some energy may be consumed for nonfuel use (for example, 50 percent of lubricants are assumed to be consumed for nonfuel use). For fuels that are combusted, the IPCC assumes that oxidation is 99 percent complete and that one percent of the carbon remains sequestered.

CARBON EMISSION COEFFICIENTS OF PETROLEUM AT FULL COMBUSTION, 1994

(MILLION METRIC TONS OF CARBON PER QUADRILLION BTU)

Petroleum	Carbon Coefficients
Residual Fuel	21.49
Lubricants	20.24
Distillate Fuel	19.95
Special Naphtha	19.86
Motor Gasoline	19.43
Jet Fuel	19.34
Aviation Gas	18.87
LPG	17.02

Source: EIA 1994-*Energy Information Administration, Emissions of Greenhouse Gases in the United States*, Washington, DC, September 1995.

Since carbon coefficients differ for each fuel, emissions are calculated for each fuel and then summed to determine total sector emissions.

In addition, carbon dioxide is emitted from other sources associated with transportation but unrelated to travel. Mark Delucchi has estimated full fuel cycle emissions related to transportation.[1]

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1 DeLuchi, M.A. *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity.* Argonne National Laboratory, November 1991.

DIFFERENCES IN DATA SOURCES

There is relatively little debate about carbon coefficients and fraction combusted for each fuel. However, the fuel consumption estimates, which are the source of carbon dioxide emissions estimates, do vary among different sources.

EIA's fuel consumption estimates are used to compute inventories of carbon dioxide emissions for national and international reporting, and estimates using these data are reported in the *Climate Change Action Plan*, as well as the *US Climate Change Report* submitted under the United Nations Framework Convention on Climate Change.

Fuel consumption data for transportation is available from the following sources:

- US Department of Energy, Energy Information Administration, *Supplement to the Annual Energy Outlook*
- US Department of Energy, Energy Information Administration.
- US Department of Energy, Oak Ridge National Laboratory. *Transportation Energy Data Book*
- US Department of Transportation, *National Transportation Statistics.*

If different sources of energy consumption data are used, transportation sector carbon dioxide emissions estimates may vary considerably. For example, the following modal carbon dioxide emissions estimates were calculated using the same methodology, based on different fuel consumption data both reported by the US Department of Energy.

1993 Carbon Dioxide Emissions Estimates from Various Sources

	DOE/EIA, Supplement to Annual Energy Outlook 1995		DOE Transportation Energy Databook: Edition 15	
Transportation Mode	CO_2 Emissions	% of Transportation Sector Emissions	CO_2 Emissions	% of Transportation Sector Emissions
Highway[2]	320.1	73.0	338.8	75.2
Rail	12.4	2.8	9.5	2.1
Aviation	44.9	10.2	38.3	8.5
Water-based	33.7	7.7	30.4	6.7
Military Use	16.7	3.8	16.7	3.7
Pipeline Fuel	9.0	2.1	15.5	3.4
Lubricants	1.6	0.4	1.6	0.3
TOTAL: ALL MODES	438.5[3]	100.0	450.7	100.0

Note: These estimates include bunker fuels.

2 Total highway mode emissions do not equal the sum of components listed since the light-duty vehicles and freight trucks categories overlap.

3 This estimate of 1993 transportation sector emissions differs slightly from the estimate of 436.7 mmtCE reported by EIA. This difference is less than 0.5 percent and stems from slight differences in fuel consumption reported in the *Supplement to the Annual Energy Outlook 1995* (used to calculate estimates here) and the *State Energy Data Report 1993: Consumption Estimates* (used to calculate estimates in the EIA report).

The variation in emissions estimates is important since it suggests that accurately measuring progress toward targets contains a high degree of uncertainty. The variation stems from the approach used to estimate fuel consumption. EIA uses a modeling approach, whereas the DOE's Transportation Energy Databook estimates consumption from various sources, including FHWA's *Highway Statistics*, APTA's *Transit Fact Book*, and DOE sources.

UNCERTAINTY IN FORECASTING FUTURE EMISSIONS

Uncertainty regarding future levels of energy-related emissions arises from a number of sources:

- The relationships between economic activity, energy prices, and energy use are not completely understood (these assumptions are embodied in the Department of Energy's Annual Energy Outlook modeling process)

- Future conditions may diverge from assumptions made regarding economic growth rates, world oil prices, US energy resources, and the costs and performance of technologies used on the supply and demand sides of the energy market.

APPENDIX B: GLOBAL CLIMATE CHANGE INTERNET SITES

The discussion and debate surrounding global climate change theory evolves quickly, and often the most recent information is available on the World Wide Web. The following information was collected primarily from web sites operated by the US Environmental Protection Agency and other organizations.

American Council for an Energy Efficient Economy (ACEEE)

The American Council for an Energy-Efficient Economy (ACEEE) is a nonprofit organization dedicated to advancing energy efficiency as a means of promoting both economic prosperity and environmental protection. Their web site contains a list of their publications, some of which address transportation's contribution to global climate change.

http://crest.org/aceee

American Petroleum Institute

The American Petroleum Institute is the primary United States national trade association serving all components of the petroleum industry. This web site contains a number of issue papers on energy, the environment, and global climate change.

http://www.api.org/

California Air Resources Board

The California Air Resources Board mission is to promote and protect public health, welfare, and ecological resources through effective reduction of air pollutants while recognizing and considering the effects on the economy of the state. The site contains events calendar, related links, new releases, and software. Additionally, it contains reports on the zero emission vehicle program in California.

http://www.arbis.arb.ca.gov/homepage.htm

California Energy Commission

The California Energy Commission is the state's primary energy policy and planning agency, charged with ensuring a reliable and affordable energy supply. Their site contains a list of their publications, a few of which focus on global climate change.

http://www.energy.ca.gov/energy

Carbon Dioxide Information Analysis Center (CDIAC)

The Carbon Dioxide Information Analysis Center (CDIAC) provides information to help international researchers, policy makers, and educators evaluate complex environmental issues, including potential climate change, associated with elevated levels of atmospheric carbon dioxide and other radioactive trace gases.

http://cdiac.esd.ornl.gov/cdiac/

Center for Clean Air Policy

Founded in 1985 by a bipartisan group of state governors, the Center for Clean Air Policy seeks to promote and implement innovative solutions to major environmental and energy problems which balance both environmental and economic interests. The Center's work is guided by the belief that market-based approaches to environmental problems offer the greatest potential to reach common ground between these often conflicting interests. The site contains a number of reports on emissions trading concepts.

http://www.ccap.org

Center for Climatic Research, University of Delaware

Members of the Synoptic Climatology Lab group located at the University of Delaware perform research in a variety of applied climatological issues that affect humans and other organisms around the world. As synoptic climatologists they attempt to characterize an entire weather situation that exists in a given area at a given time, in hopes of being able to better understand the atmospheric environment and its effects on the organisms.

http://www.udel.edu/SynClim/scl.html

Center for Global Change (CGC) at the University of Maryland

The Center for Global Change, based at the University of Maryland, seeks innovative solutions to global environmental problems and studies their relationships to energy use, economic development and equity. The Center evaluates and recommends policies, technologies and institutional reforms to promote sustainable development and reduce the risks of environmental degradation, particularly those posed by climate change and ozone depletion.

http://www.bsos.umd.edu/cgc

Center for Integrated Study of the Human Dimensions of Global Change, Carnegie Mellon University

The Center is a group of more than 30 scientists worldwide who study how people affect the environment. Its goals include merging social and scientific knowledge to understand the patterns of human activity and environmental change and to communicate findings through educational materials, brochures and government briefings. The site contains a link to a brochure prepared by researchers at Carnegie Mellon University explaining the issue of global warming and climate change.

http://hdgc.epp.cmu.edu/main.html

Center for Renewable Energy and Sustainable Technology (CREST)

The Center for Renewable Energy and Sustainable Technology (CREST), located in downtown Washington, DC, is dedicated to the promotion of renewable energy, energy efficiency, the environment, and sustainable development. One of CREST's primary functions is to explore and demonstrate the use of advanced information and communication technologies in these fields.

http://solstice.crest.org/

CFCs: What they are and what they do

Chlorofluorcarbons (CFCs) and other halocarbons are greenhouse gases (GHGs) that may be causing severe damage to the Ozone Layer. This factsheet looks to provide the reader with accurate information on what CFCs are and how they may or may not be contributors to the breakdown of the Ozone Layer. The net effect of CFCs are unknown because even though they are a GHG they also destroy ozone, another GHG. Alternatives to CFCs are being developed.

http://www.unep.ch/iucc/fs031.html

CFCs and the Montreal Protocol

International legal efforts to protect the ozone layer also have important implications for climate change. The 1985 Vienna Convention for the Protection of the Ozone Layer and the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer do not directly address the issue of climate change. However, they do seek to phase out chlorofluorocarbons (CFCs) and halons, an important group of greenhouse gases.

http://www.unep.ch/iucc/fs224.html

Climate Action Network (CAN) Newsletter

The Climate Action Network (CAN) consists of over 160 Non-Governmental Organizations (NGO) that produce, write, and electronically distribute a newsletter. The newsletter seeks to give its readers access to negotiations on climatic issues and what they mean. Past editions are available for download.

http://www.igc.apc.org/climate/Eco.html

Climate Change and Weather: What's the Connection?

This is a report outlining how unusual weather experienced in the US during the last few years has led to assertions that global warming was the cause for the extreme weather. The weather may not be necessarily attributable to climate change but just normal features of the climate. Defensible statements based on observations and what is known about the earth's weather and climate are provided. The site is run by The Center for Ocean-Land-Atmosphere Studies located in Calverton, Maryland.

http://grads.iges.org/nncc

Climate Change Causes, Impacts, and Responses

The 90-plus fact sheets at this site are organized into three series: Causes, Impacts, and International Response.

http://www.unep.ch/iucc/fs250.html

Climate Institute

The Climate Institute seeks "to protect the balance between climate and life on earth." The Institute has become one of the leading international NGO focused on climate change. Through worldwide conferences and programs the Climate Institute promotes awareness and responsible action that will hopefully lead to a balanced climate.

http://www.his.com/~climate/

Committee for the National Institute for the Environment

The Committee for the National Institute for the Environment is a national, non-profit organization working to improve the scientific basis for making decisions on environmental issues through creation of a new, non-regulatory environmental science and education agency (the National Institute for the Environment).

http://www.cnie.org/

Department of Energy (DOE)

The Department of Energy, in partnership with our customers, is entrusted to contribute to the welfare of the Nation by providing the technical information and scientific and educational foundation for technology and policy.

http://www.ercn.doe.gov

DOE's Clean Cities Program (Alternative Fuels Data Center)

The Alternative Fuels Data Center (AFDC) is operated by the National Renewable Energy Laboratory (NREL) with funding and direction from the Office of Alternative Fuels within the Office of Transportation Technologies at the US Department of Energy (DOE). The AFDC collects operating information from vehicles (in programs sponsored by the Alternative Motor Fuels Act) running on alternative fuels, analyzes those data, and makes them available to the public.

http://www.afdc.nrel.gov/

The Econet Homepage

Econet serves organizations and individuals working for environmental preservation and sustainability. Econet builds coalitions and partnerships with individuals, activist organizations and non-profit organizations to develop their use of the electronic communications medium.

http://www.igc.apc.org/econet

Edison Electric Institute

The Edison Electric Institute is the association of shareholder-owned electric companies. EEI acts as a representative for its members on subjects of public interest and as a facilitator of information exchange among its members. EEI members generate more than three-quarters of the electricity in the US.

http://www.eei.org/

Energy and Environmental Analysis, Inc.

Energy and Environmental Analysis, Inc. (EEA) is a consulting firm founded in 1974 to perform economic, engineering, and policy analysis in the energy and environmental fields. The site lists publications on global climate change strategies, especially regarding the role of technology in reducing emissions. The site information on how to obtain copies of their publications.

http://www.eea-inc.com/

Environmental Alliance for Senior Involvement (EASI)

The Environmental Alliance for Senior Involvement (EASI) presents a springboard for senior citizens to be actively involved in focusing the direction in which their community, their nation, and their world will be headed in the future.

http://www.easi.org/

EPA's Green Lights and Energy Star Programs

The Environmental Protection Agency has individual web sites to explain two of its popular programs: Green Lights and Energy Star. The programs encourage energy-efficiency to reduce electricity, which in turns reduces harmful air pollutants, such as greenhouse gases.

http://www.epa.gov/GCDOAR/EnergyStar.html
http://www.epa.gov/greenlights.html

EPA's Global Warming Web Site

The Environmental Protection Agency has extensive information pertaining to global climate change at its Global Warming Web Site. The site contains a brief explanation of global climate change and a user survey. There are reports and other sources of information on the science and impacts of warming; policies and programs to address warming; ways of obtaining more information; latest developments in climate change; quick facts; and links to related sites.

http://www.epa.gov/globalwarming/home.htm

Electric Power Research Institute (EPRI)

The mission of the Electric Power Research Institute (EPRI) is to discover, develop, and deliver high value technological advances through networking and partnership with the electricity industry. The EPRI web site provides information on a variety of impacts commonly associated with global climate change.

http://www.epri.com/

http://www.epri.com/mecca/Crops.html

http://www.epri.com/mecca/Cyclones.html

http://www.epri.com/mecca/Droughts.html

http://www.epri.com/mecca/Ecology.html

http://www.epri.com/mecca/Hazards.html

http://www.epri.com/Impacts.html

Framework Convention on Climate Change: Full Text

Framework Convention on Climate Change (1992). This site contains the full text of the Climate Change Convention.

http://www.unep.ch/unfccc/fca6e.html

Framework Convention on Climate Change: Summary

The United Nations Framework Convention on Climate Change is the first binding international legal instrument that deals directly with climate change. The Convention was adopted on May 9, 1992 after 15 months of negotiations by the UN-sponsored Intergovernmental Negotiating Committee for a Framework Convention on Climate Change.

http://www.unep.ch/iucc/fs250.html

Global Change Data Center (GCDC)

The Global Change Data Center (GCDC) Home Page is part of the NASA/Goddard Space Flight Center's Earth Sciences Directorate, Greenbelt, MD, US. The mission of the Global Change Data Center is to develop and operate data systems, generate science products, and provide archival and distribution services for earth science data in support of the US Global Change Program and the NASA Mission to Planet Earth.

http://ame.gsfc.nasa.gov/gcdc/gcdc.html

Global Climate Change Information Programme

The Global Climate Change Information Programme (GCCIP) was established in October 1991 with the express purpose of providing the necessary information link between scientists (both natural and social), politicians, economists and the general public. GCCIP was formed as a part of the Atmospheric Research and Information Centre (ARIC) based at the Manchester Metropolitan University. The major aim of the Programme is to provide up-to-date information, in a number of user friendly options, on climate change to the general public, school pupils, students, teachers, lecturers, researchers, industry, and decision makers.

http://www.doc.mmu.ac.uk/aric/gcciphm.html

Global Change Master Directory (GCMD)

The Global Change Master Directory (GCMD) is a comprehensive source of information about Earth science, environmental, biosphere, climate, and global change data holdings available to the scientific community throughout the world.

http://gcmd.gsfc.nasa.gov/

Global Change Research Information Office (GCRIO)

The GCRIO site provides you with access to global change and environmental data and information from around the world.

http://www.gcrio.org/

Global Change Research Program (USGCRP)

This site provides extensive documents and data on global climate, as well as many useful links to other sources.

http://www.uscgrp.gov/

Global Warming and Mortality

This site provides information on how global warming might potentially lead to higher mortality rates. Potential increase in mortality due to global warming require an understanding of how changes in the climate will affect different population groups and their sensitivities. This section leads to thematic guides on modeling potential increases in mortality to how and where climatic parameters are expected to vary due to global warming. The site is maintained by CIESIN a non-profit, non-governmental organization looking to help all better understand their changing world.

http://www.ciesin.org/TG/HH/morthmpg.html

Global Warming Update

The National Climatic Data Center (NCDC) is the world's largest archive of weather data. The center also produces climate publications and responds to data requests. The NCDC is part of the National Oceanic and Atmospheric Administration under the US Department of Commerce.

http://www.ncdc.noaa.gov/

Information Unit on the Framework Convention on Climate Change (IUCC)

This section of the Web is managed by the UNEP/WMO Information Unit on Climate Change (IUCC) and the secretariat for the United Nations Framework Convention on Climate Change (UNFCCC). It contains official documents from the Conference of the Parties (COP) as well as the archives of official documents from the Intergovernmental Negotiating Committee (INC), which negotiated the Convention.

http://www.unep.ch/iucc.html

Institute for the Study of Planet Earth

The Institute for the Study of Planet Earth (ISPE) located at The University of Arizona provides an interdisciplinary framework for addressing global environmental questions through active education and research. ISPE coordinates seminars and conferences in order to address society's most pressing concerns regarding the rates and patterns of environmental change.

http://www.ispe.arizona.edu.ispe.html

Integrated Assessment Models

The Model Visualization and Analysis service (MVA), developed by the Socioeconomic Data and Applications Center (SEDAC), provides background information on the use of integrated assessment to examine the relationship between human activities and global climate change, descriptions of integrated assessment models (IAMs), and access to model-generated output. Integrated assessment modeling tries to provide a systematic way of integrating knowledge across disciplines, styles, resolutions, and degrees of certainty.

http://sedac.ciesin.org/sedac-2.3/iamcc.tg/TGsec3-1-3.html

Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the available scientific, technical, and socio-economic information in the field of climate change. The IPCC is organized into three working groups: Working Group I concentrates on the climate system, Working Group II on impacts and response options, and Working Group III on economic and social dimensions. The IPCC released its Second Assessment Report in 1995 and continues to produce technical papers and develop methodologies (e.g. national greenhouse gas inventories) for use by Parties to the Climate Change Convention.

http://www.ipcc.ch/

International Council for Local Environmental Initiatives (ICLEI)

The Cities For Climate Protection Campaign We are a campaign of the International Council for Local Environmental Initiatives (ICLEI), which encourages cities to reduce local emissions of carbon dioxide, other greenhouse gases which contribute to global warming (climate change), and related air pollutants.

http://www.iclei.org/co2

International Institute for Energy Conservation

This site is sponsored by CREST, the Center for Renewable Energy and Sustainable Technology located in Washington, DC and San Francisco, CA. Solstice is a CREST sponsored program providing internet accessible information on energy efficiency, renewable energy, and sustainable technology.

http://solstice.crest.org/clients/iiec/iiec.html

Interstate Renewable Energy Council (IREC)

IREC works to accelerate the sustainable utilization of renewable energy sources and technologies in and through state and local government activities.

http://www.eren.doe.gov/irec

Joint Implementation

The US Initiative on Joint Implementation (USIJI) was launched in October 1993 as part of President Clinton's Climate Change Action Plan. USIJI is the largest and most developed of several pilot programs being created worldwide to explore the potential of "joint implementation." Joint Implementation (JI) refers to arrangements between entities in two or more countries, leading to the implementation of projects that reduce, avoid, or sequester greenhouse gas (GHG) emissions.

http://www.ji.org/

George C. Marshall Institute

The Marshall Institute contains much information regarding the uncertainty of global warming theory and the models used to predict global climate change.

http://www.marshall.org/

National Association of State Energy Officials (NASEO)

The National Association of State Energy Officials exists to contribute to the success of the State and Territories as they pursue an economically, environmentally and socially sustainable energy future. The site contains NASEOs strategic plan to pursue their mission.

http://www.naseo.org

National Center for Policy Analysis (NCPA)

NCPA is a nonpartisan think tank addressing national policy concerns. The site contains some reports done by the organization on global climate change.

http://www.public-policy.org/~ncpa/pi/enviro/envdex.html#q

National Weather Service

The National Weather Services (NWS) is a part of the National Oceanic and Atmospheric Administration (NOAA). The NWS issues warnings and forecasts for severe weather conditions that may threaten the United States population. The site contains current weather information, climate and historical data and information of weather topics.

http://www.nws.noaa.gov/

NICE3 Program: Building Energy Efficiency

The US Department of Energy (DOE) sponsors an innovative, cost-sharing program to promote energy efficiency, clean production, and economic competitiveness in industry. The grant program, known as NICE3, provides funding to state/industry partnerships for projects that develop and demonstrate advances in energy efficiency and clean production technologies.

http://www.oit.doe.gov/access/nice3/

Partnership for a New Generation of Vehicles (PNGV)

The PNGV website contains information on this initiative, including program goals and accomplishments, federal agency participants, background information, how to participate in PNGV, future technology needs, current status reports, and related events and articles on the PNGV news front. The PNGV website is maintained by the US Department of Commerce.

http://www.ta.doc.gov/pngv/

Resources for the Future (RFF)

RFF is an independent, nonprofit organization that does research and policy analysis of natural resource and environmental issues. The Energy and Natural Resources Division explores world oil markets and energy security; regulatory issues in natural gas and electricity; connections between energy and the environment; and improved management practices in agriculture, water, and forestry. The site contains a list of recent RFF Discussion Papers presented at their weekly seminars. Most of the papers are downloadable, and there are some recent reports on global climate change.

http://www.rff.org/

Science and Environmental Policy Project (SEPP)

A research organization founded by an atmospheric physicist, Dr. S. Fred Singer, a Professor of Environmental Sciences at U-VA at the time. The purpose of the SEPP is to ensure that sound science is the basis for environmental decision-making. There is a considerable amount of reading material at this site devoted to the uncertainty and skepticism regarding global climate change within the scientific community.

http://www.his.com/~seep/glwarm/glwarm.htm

Sierra Club Global Warming News

Global Warming News is an update set out by the Sierra Club Global Warming Team (Dan Becker, Ellen McBarnette, David Danzig, and Patty Glick) on what's new in Global Warming issues.

http://www.sierraclub.org./news/global-warming/

Trees For The Future

Trees for the Future is a non-profit member organization. The organization helps people plant useful, fast-growing trees to replace the ones they keep cutting down for fuel.

http://wwwa.com/trees

Union of Concerned Scientists (UCS)

This group of concerned scientist promote ideas and solutions to agriculture, arms control, energy, global resources, and transportation. Their Sound Science Initiative focuses on biodiversity, climate change, ozone depletion, and population growth. The site also contains a junk science quiz for those interested.

http://www.ucsusa.org/

The World Climate Report

World Climate Report is edited and written by a team headed by Environmental Scientist Dr. Patrick J. Michaels of the University of Virginia. The site contains reports and discussion on global climate change.

http://www.wcrpt.com/

World Meteorological Organization

The World Meteorological Organization (WMO) is a specialized agency of the United Nations located in Geneva, Switzerland. Their site provides a wealth of information on the various climate programs they institute throughout the world. The nations of the world coordinate through WMO in an effort to monitor, understand, predict, and protect the global environment in the interest of all humanity.

http://www.wmo.ch/

World Health Organization

The World Health Organization (WHO) seeks to promote the greater well being and health of earth's people. WHO is an agency of the United Nations administering programs around the globe to battle disease, famine and any other health hazard affecting the population. The WHO site contains publications and statistical information on the health of the world.

http://www.who.ch/

APPENDIX C: ANNOTATED BIBLIOGRAPHY

Due to the fact that much of the interesting discussions concerning the complexity or conflicting opinions of global climate change occur outside the realm of peer-review, both peer-reviewed documents and those which are not peer-reviewed are included in this annotated bibliography. Whenever it is fully known that a document was peer-reviewed, it is indicated at the end of the summary. Some of the literature that is not indicated as such may still have been peer-reviewed, but a confirmation of peer-review was perhaps unobtainable or uncertain.

INVENTORIES OF EMISSIONS AND CONCENTRATIONS

Energy Information Administration, Office of Integrated Analysis and Forecasting. *Emissions of Greenhouse Gases in the United States, 1995.* Pittsburgh, PA: US Government Printing Office, October 1996.

This report presents updated estimates of US anthropogenic emissions of greenhouse gases for the years 1987-1994 along with preliminary estimates of 1995 levels of emissions. EIA finds that updated energy data resulted in slightly higher estimates of emissions for the years before 1995 than had been found in the past. This report offers updated global warming potential, based on the further revised estimates of the IPCC. It incorporates reformulated gasoline into the 1995 emission coefficient for motor gasoline. Other new or updated information included in the document is as follows: revised historical estimates for methane emissions; revised methods for estimating methane emissions from the solid waste of domesticated animals and wastewater treatment; new carbon sequestration estimates; and new maps of the historical extent of forest land in the United States.

Energy Information Administration, Office of Integrated Analysis and Forecasting. *Emissions of Greenhouse Gases in the United States, 1987-1994.* Pittsburgh, PA: US Government Printing Office, October 1995.

This report presents estimates of US anthropogenic emissions of greenhouse gases for the years 1987-1993. Estimates of 1994 levels of halocarbons and carbon dioxide are also given. The study finds a somewhat higher effect of methane and nitrous oxide relative to that of carbon dioxide, which differs from past years. The report offers revised information on annual emissions of gasoline, liquefied petroleum gas, jet fuel and crude oil; revised flare gas estimation methods; revised historical estimates for methane emissions from coal mines and landfills; expanded coverage of nitrous oxide combustion emissions; new data on methane and nitrous oxide emissions from agricultural burning; and reviewed 1993 energy data.

Policy Dialogue Advisory Committee. *Majority Report to the President to Recommend Options for Reducing Greenhouse Gases from Personal Motor Vehicles.* December 1996.

This report represents the view of majority of the Policy Dialogue Advisory Committee. The Committee was charged by President Clinton to make recommendations for the implementation of three sets of policies to reduce greenhouse gas emissions to 1990 levels by 2005, 2015, and 2025, without subsequently increasing. Using figures from the *Annual Energy Outlook* for 1995, the Committee displayed the 1990 level of carbon emissions from the transportation sector, as well as the projected level of emissions in 2010. The Analytic Support Group (ASG) of the Interagency Steering Committee developed information used in this report to specify a feasible path for GHG emissions and a model to compare the amount of greenhouse gas reductions that would result from any specific policy.

Executive Office of the President. *The Climate Change Action Plan.* President William J. Clinton and Vice-President Albert Gore, Jr., October 1993.

The Climate Change Action Plan (CCAP) is the basis for the US response to the international *Framework Convention on Climate Change*. The CCAP outlines nearly 50 new or expanded initiatives in all sectors of the US economy—commercial, residential, industrial, and transportation—that are expected to return US greenhouse gas emissions to 1990 levels by the year 2000. The Plan broadly describes the major policy initiatives, implementation, projected greenhouse gas impacts, and costs.

Organization for Economic Cooperation and Development and the International Energy Agency. *Cars and Climate Change.* Washington: OECD Publications and Information Centre, 1993.

The book evaluates the contribution of automobile emissions to global warming, primarily focusing on Japan, the United States, and OECD Europe. The study gives thorough consideration to greenhouse gas emissions from highway vehicles, including emissions during construction of the vehicles and emissions during the generation of the final power source. Statistics on transportation-generated greenhouse gases are compared for several countries. The technological and economic feasibility of reducing transportation-generated greenhouse gases is considered in the context of both policy and market mechanisms for reducing emissions.

The Osbourne Group, in association with DesRosiers Automotive Consultants Inc. and Pilorusso Research & Consulting Inc. *Reducing Greenhouse Gas Emissions From the Ontario Automotive Sector.* May 26, 1995.

The report explores measures to reduce greenhouse gas emissions from the automotive sector in Ontario over the next ten years. It provides a statistical description of the passenger car and light truck fleet with projections of its growth in size and use; estimates emissions factors for greenhouse gases under different reduction options; assesses the technological feasibility and implementability of various reduction options; and offers insight into the barriers to implementation that are unique to Ontario.

Submissions of the United States of America Under the United Nations Framework Convention on Climate Change. *Climate Action Report.* Washington, DC: US Government Printing Office, 1994?

The document describes the current program as required under the Framework Convention on Climate Change in the *Climate Change Action Plan.* It is intended to identify current policies dealing with climate change and aid in the conception of ideas for future actions. The report gives a brief overview of recent scientific estimates on the state of the climate and the need for CCAP. The rest of the report provides a look at the US program, including information on national circumstances, an inventory of greenhouse gas emissions, mitigation programs, adaptation programs, research and education programs, international activities, and the future direction of US planning for climate change.

United States Congress, Office of Technology Assessment. ***Changing by Degrees: Steps to Reduce Greenhouse Gases.*** **Washington, DC: US Government Printing Office, 1991.**

OTA addresses whether the United States could effectively reduce carbon dioxide emissions in the near term, a question posed by six congressional committees. The OTA project staff examines the feasibility of emissions reductions in the next 25 years in six key sectors of the US economy, including transportation; and whenever possible the report quantifies the potential for emissions reductions in each sector. In doing so, OTA considers energy efficiency gains, product substitution, conservation, and technological options to reduce the level of greenhouse gas emissions. Policy options are proposed and organized into three scenarios: no reduction, moderate reduction, and extreme reduction. [peer-reviewed]

United States Congress, Office of Technology Assessment. ***Saving Energy in US Transportation.*** **Washington, DC: US Government Printing Office, July 1994.**

This report was the final part of an OTA assessment on *US Energy Efficiency: Past Trends and Future Opportunities*. The report analyzes energy use in US transportation. It analyzes the widely varied opinions about the ability of proposed measures to reduce energy consumption of the transportation sector, which currently uses over 60 percent of all the oil consumed in the US. OTA addresses the various opinions of consumption reduction measures and applies them to the current status of the system. Additionally, OTA evaluates current transportation-related problems, forecasts future energy use in transportation, and describes a variety of alternatives for saving energy. [peer-reviewed]

US Department of Energy. ***The Climate Change Action Plan: Technical Supplement.*** **March 1994.**

The CCAP Technical Supplement documents the assumptions and parameters used in developing the analysis for the CCAP. This Annex provides more detail about the analytical underpinning and assumptions of the CCAP and the events necessary to transpire for the projected emissions reductions to occur. It describes the administration baseline assumptions and calculations of the emissions impacts of each action. In addition, the Annex provides an overview of the IDEAS model used to determine the integrted energy impacts of the Plan and provides contacts for the various actions.

POTENTIAL IMPACTS OF GLOBAL CLIMATE CHANGE

Barnola, J.M., et. al., "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2", ***Journal of Geophysical Research 92: 14722-14780 (1987).***

This article summarizes results from ice cores, which provide fairly reliable historical records of gas concentrations. The article was peer-reviewed and has been widely cited. [peer-reviewed]

Baliunas, Sallie. *Uncertainties in Climate Modeling: Solar Variability and Other Factors.* Testimony presented on September 17, 1996 to the Senate Committee on Energy and Natural Resources.

Baliunas, Senior Scientist at the George C. Marshall institute, explores the scientific factors in support of the claim that global warming due to human activities will be significant or problematic. Baliunas argues the need to test computer simulated models of climate change against the record of climate change in the last 100 years. Baliunas concludes that there is no evidence that dangerous levels of warming have been or will result from human activities.

Black, William, "Global Warming: Impacts on the Transportation Infrastructure", in *TR News*, Vol. 150, pp. 2-8 (Sept. - Oct. 1990).

This article overviews the potential impacts of global warming on transportation infrastructure. Some impacts could be positive, such a decrease in the need for snow removal and longer shipping seasons in northern ports. However, the majority of impacts would require resources to adapt infrastructure. For example, transportation would need to adapt to changes in the flow of goods and people caused by regional economic changes in existing patterns of production and consumption. Roads and railroads in low-lying coastal areas would need to be relocated in the event of significant sea level rise. Drops in lakes and rivers in some regions could disrupt shipping.

George C. Marshall Institute, *Are Human Activities Causing Global Warming?* (April 1996).

This report expresses significant skepticism that human activities are affecting global warming. As climate models improve, the report says, the predictions get closer to a small gradual warming indistinguishable from the natural warming we have been experiencing for the last several hundred years. Instead, the report concludes that natural climate change is the most probable link to moderate temperature increases.

Greene, David L., and Santini, Danilo J., eds. *Transportation and Global Climate Change.* Washington, DC and Berkeley, CA: American Council for an Energy-Efficient Economy, 1993.

The book responds to the 1991 Asilomar Conference on Transportation and Global Climate Change, attended by leading transportation experts from around the world. The conference addressed the transportation sector's contribution to greenhouse gas emissions and role in global warming. A long-term strategy to deal with growing global demand, energy efficiency, and the use of alternative energy sources was discussed at the conference and is continued in this book. The text contrasts the problems of the US transportation system to the rest of the world. A range of mitigation options, such as technological advances, government policies, and use of renewable energy, are examined in a thorough manner.

IBI Group. *Transportation and Climate Change Collaborative: Urban Planning, Public Transit and Related Initiatives for More Sustainable Urban Transportation.* March, 1995.

This report presents a discussion of urban transportation conditions and future challenges in Canada, with an extensive description of some of the attempts being made to achieve more sustainable urban travel. It provides an analysis of the potential of these attempts for reducing greenhouse gas emissions. Barriers to implementation are also discussed, and two strategies for achieving sustainable urban transportation in Canada in both the short and long run are recommended.

Innes, Robert, and Kane, Sally, "Agricultural Impacts of Global Warming: Discussion", in *American Journal of Agricultural Economics,* Vol. 77, pp. 747-750 (Aug. 1995)

This article provides an overview of ongoing discussions about the impacts of global warming upon agriculture. One significant area of uncertainty is the extent of potential warming, because of the uncertainty of global climate models. However, a shift in global agricultural patterns seems likely. The authors conclude that free trade among nations and regions can help to mitigate the adverse impacts to human populations of such a shift in agriculture.

Intergovernmental Panel on Climate Change, *Second Scientific Assessment of Climate Change, Summary and Report,* World Meteorological Organization / UN Environment Program (Cambridge, MA: Cambridge University Press, 1995).

This recent IPCC report explores potential impacts of climate change on hydrological systems, sea level, agricultural productivity, human health, and other factors. Relatively few references are made to transportation, other than to note that the sensitivity of the transportation sector is relatively low compared to agricultural or natural ecosystems, and the capacity for adaptation through management and normal capital replacement is expected to be high. The report's findings were formally accepted by the Second Conference of Parties to the Framework Convention on Climate Change. As such, the IPCC report represents an "official" international scientific consensus. The IPCC report is explicit about those conclusions it reaches with certainty, and those about which it is confident but unable to state with certainty given available scientific evidence. See also the description under "Developments in Global Climate Change Policy. [peer-reviewed]

Mendelsohn, Robert, and Rosenberg, Norman, "Framework for Integrated Assessments of Global Warming Impacts", *Climatic Change,* Vol. 28, pp. 15-44 (1994).

This article provides a framework for integrated assessment of the impacts of climate change on natural resources, and for assessing the potential for specific policies for mitigating adverse impacts. The paper also includes a 'primer' on the current understanding of the science underlying climate change.

Moore, T.G., "Health and Amenity Effects of Global Warming" *Working Papers in Economics,* E-96-1 (The Hoover Institution: 1996)

This paper examines statistics on mortality and climate variables for 89 metropolitan counties in the United States. It finds a statistically significant inverse relationship between temperature and mortality—warmer weather is correlated with fewer deaths. If the United States were to warm by 2.5^{o}C, the paper predicts mortality would be reduced by 41,000 per year.

Poiani, Karen, and W. Carter Johnson, "Global Warming and Prairie Wetlands," *Bioscience.* Vol. 41, No. 9, Oct. 1991, pp. 611-618.

This article reviews the effect of potential global warming on inland prairie wetland ecosystems. These wetlands are the single most important breeding area for waterfowl. While not directly related to potential transportation impacts, the article presents a short summary of likely impacts on ecosystems and water resources.

Singer, S. Fred. ***Shaky Science Behind the Greenhouse Effect*****, SFS 8/23/90.**

This article was taken from the Science and Environmental Policy Project home page on the internet: http://www.his.com/~sepp/glwarm/ghw-ipcc.htm. Dr. Singer argues that the IPCC conclusions are drawn hastily from inadequate models that are based on our limited understanding of the physical processes of the atmosphere. He recommends discretion in formulating policies under the pressure of uncertainty when they will affect economic growth and the welfare of billions of people.

Titus, J., and Narayanan, V., "The Risk of Sea Level Rise: A Delphic Monte Carlo Analysis in Which Twenty Researchers Specify Subjective Probability Distributions for Model Coefficients Within Their Respective Areas of Expertise", ***Climactic Change.*** **Vol. 33, pp. 151-212, 1996.**

This paper estimates a probability distribution for sea level rise, using existing models and subjective assessments of reviewers. The models and assumptions used in the paper suggest that greenhouse gases have contributed 0.5mm per year to sea level over the last century. Its projections suggest that there is a 65 percent chance that sea level will rise 1mm per year in the next thirty years, more rapidly than it has been rising in the past century. Assuming that nonclimatic factors do not change, the paper estimates a 50 percent chance that global sea level will rise 45 cm, and a 1-percent chance of a 112 cm rise by the year 2100.

Titus, J., ***et. al.,*** **"Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea",** ***Coastal Management.*** **Vol. 19, p. 172 , 1991.**

This article assesses the impacts of sea level rise from global warming on the United States. A one-meter rise in sea level would inundate 14,000 square miles of drylands and wetlands, if no protective measures were taken. Cost impacts of sea level rise include (1) the cost of protecting ocean resort communities by maintaining protective barrier islands and beaches, (2) cost of protecting developed areas along sheltered waters through the use of levees and bulkheads, and (3) the loss of coastal wetlands and undeveloped lowlands. The estimated total cost for a one-meter rise would be between $270 and $475 billion, ignoring future development. [peer-[reviewed]

Titus, J., "Strategies for Adapting to the Greenhouse Effect," ***APA Journal.*** **Summer 1990, pp. 311-323.**

This article discusses opportunities for preparing for consequences of predicted levels of global warming, focusing on options "that are rational even if one is skeptical about global warming". The article discusses questions to ask when setting policy priorities for addressing global warming. Among options discussed are the rerouting of the Mississippi River to save coastal Louisiana, changing coastal land use conventions to enable ecosystems to migrate inland as sea level rises, and phasing out federal water subsidies in the west.

Titus, James G. and Greene Michael. US Environmental Protection Agency. ***An Overview of the Nationwide Impacts of Rising Sea Level*****, Peer Review Draft.**

The draft document considers the effects of sea level rise in terms of disruptions to both physical and economic processes. The authors examine four studies to analyze the nationwide impact of a rise in sea level of 50-200 centimeters by the year 2100. They find that a large amount of land could be lost to the sea from a one meter rise if shores are not protected. They argue that the coastal areas and wetlands could be protected in a cost-effective manner using what they term as a "conditional" policy approach, which they explain in detail. [peer-reviewed]

Toman, Michael, et. al, "Climate Change and Its Consequences", ***Resources.*** **Issue 124, Summer 1996, pp. 10-13.**

The article succinctly summarizes the IPCC's *Second Scientific Assessment*, and places its conclusions in a broader scientific context. The authors argue that the current state of scientific certainty about global climate change argues strongly for aggressive policies to reduce greenhouse gases.

US Congress Office of Technology Assessment, ***Preparing for an Uncertain Climate, Vol. I,II*** **(Washington, D.C.: US Government Printing Office, 1993).**

This study provides an in-depth discussion of policies which might enhance the ability of human and natural systems to adapt to changes in global climate. The report assesses how natural systems may be affected by climate change and evaluates available tools to ease adaptation to a warmer climate. Volume I addresses coastal areas, water resources, and agriculture; volume II includes wetlands, preserved lands, and forests. [peer-reviewed]

US Environmental Protection Agency, ***The Probability of Sea Level Rise.*** **(EPA 230-R-95-008), October 1995.**

EPA's report provides estimates of the impact of greenhouse gas emissions on coastline sea level elevations. The report projects that along the US Atlantic and Gulf of Mexico Coasts, sea level is most likely to rise 26 centimeters by the year 2050 and 55 centimeters by the year 2100. The report discusses elements of its predictive model, which includes the cooling effects of sulfate emissions, stratospheric ozone depletion, possible declines in ocean circulation, and the chlorofluorocarbon phase-out under the Montreal Protocol. [peer-reviewed]

US Environmental Protection Agency. ***The Potential Effects of Global Climate Change on the United States: Appendix A—Water Resources.*** **(EPA-230-05-89-051, June 1989).**

This report contains a series of case studies on the potential effects of climate change on water resources in several areas of North America. Featured areas include the Sacramento-San Joaquin River Basin in California; San Francisco Bay; California generally; water resources in Atlanta, Georgia; Laurential Great Lakes; Lake Michigan; Lake Erie; Tennessee Valley Authority reservoirs; and the Upper Chattahoochee River in Tennessee. [peer-reviewed].

World Health Organization Task Group, "Potential Health Effects of Climate Change" (Geneva: World Health Organization, 1990).

This report explores the potential health effects of climate change, including its impact on vector-borne diseases. The report observes that several vector-borne diseases might be influenced by climate change, including malaria, lymphatic filariasis, dengue and yellow fever. Initial impacts would likely be at the margins of the diseases' current distributions, with distributions expanding as warmer temperatures expand polewards. WHO also predicted that climate change might also affect the altitude at which vector-borne diseases are found. On the positive side, climate change may cause the elimination of some disease vectors and pathogens as the result of very hot dry conditions.

STRATEGIES TO REDUCE GREENHOUSE GAS EMISSIONS FROM TRANSPORTATION SOURCES

Cambridge Systematics. *The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior.* Prepared for US Department of Transportation and US Environmental Protection Agency. November 1994.

This report presents analytical results of a project undertaken to investigate the effects of land use and demand management on traffic congestion and VMT. Activities were designed to test various land use and urban design variables to determine their influence on travel behavior. Some general conclusions include: financial incentives are important as part of a TDM strategy; specific land use/urban design characteristics influence mode choice; a positive interaction exists between land use and financial incentives; and tradeoffs exist between ridesharing. transit, walking, and bicycling.

Cambridge Systematics. *Transportation Control Measure Information Documents.* Prepared for US Environmental Protection Agency. March 1992.

These documents provide information on the formulation and emission reduction potential of transportation control measures related to criteria pollutants and their precursors.

Congressional Research Service, *Global Climate Change* (Issue Brief updated September 6, 1996).

CRS' report reviews the political context of global warming policies, describing various international negotiations and agreements. The report also summarizes sources and trends of information on greenhouse gases. CRS reports are typically widely read by Congress, but are not peer-reviewed.

Deakin, Elizabeth and Greig, Harvey. *Transportation Pricing Strategies for California: An Assessment of Congestion, Emissions, Energy, and Equity Impacts.* Prepared for the California Air Resources Board, June 1995.

This report analyzes the impacts five market-based transportation control measures on air quality, congestion, energy and equity. Those five measures are congestion pricing, parking charges, fuel tax increases, VMT fees, and emissions fees. Each measure is discussed generally in the form of a literature review. The measures are applied to four major California cities, including Los Angeles, Sacramento, San Diego, and San Fransisco.

DeCicco, John M., American Council for an Energy-Efficient Economy. ***The Greenish Machine: On the Road to Reduced CO_2 Emissions via Higher Fuel Economy and Alternative Fuels (Revised Draft).*** **September 24, 1992.**

This report is a revised version of a paper presented to the Urban CO_2 Reduction Project Workshop in Miami, Florida during March of 1992. The report explores ways to quickly reduce the carbon dioxide emissions and petroleum dependence of personal transportation in the US. Vehicle technologies are explored, rather than demand-side management techniques, with a focus on the short-term effects of various strategies. Alternative fuels are considered, particularly methanol and natural gas used in an internal combustion engine and grid electricity used in battery-powered vehicles. Several alternative cars are presented and analyzed for cost and performance. The findings suggest that the pursuit of both efficiency and alternative fuel technologies is desirable, because of the close relation between the development of both approaches. This report provides a good review of recent studies, and is one of few that addresses in detail the various technological strategies for reducing greenhouse gas emissions.

DRI/McGraw-Hill, ***An Analysis of Public Policy Measures to Reduce Carbon Dioxide Emissions from the US Transportation Sector*****, for Office of Policy, Planning, and Evaluation, US Environmental Protection Agency, January 1991.**

This study defines the tax strategies that would stabilize or reduce the amount of CO_2 produced by the combustion of gasoline in cars and small trucks. The underlying result of the study is that changes retail gasoline taxes, which affect the usage and efficiency of motor vehicles, is the policy of choice since it virtually taxes pollution directly. Other policy instruments investigated in the study include gas-guzzler taxes and gas-guzzler/gas-sipper rebates. However, these strategies do not affect driving habits (i.e., travel demand) and thus are less able than gasoline taxes to influence the level of CO_2 emissions. Finally, an oil import fee is analyzed as an alternative to gasoline taxes, but although effective such a policy places an unnecessary burden on the economy.

The study finds that federal taxes on gasoline must rise dramatically to achieve a 20 percent reduction in CO_2 emissions, but only moderately to restrain emissions growth. Specifically, if a 20 percent reduction in CO_2 emissions from the transportation sector was achieved by an increase in the gas tax (of roughly 25 cents each year for the next 20 years), over 85 percent of the reduction in gas consumption would result from lower VMT and the adoption of more fuel-efficient technologies.

DRI/McGraw-Hill in association with Charles River Associates, ***Highway Transportation and Greenhouse Gas Emissions*****. April, 1994.**

DRI/McGraw Hill reviewed and assessed current findings concerning highway transportation's contribution to greenhouse gases in a study for the Federal Highway Administration. After synthesizing relevant information, they considered the costs and effectiveness of emissions reduction options. A literature search was performed and a list of future project ideas was compiled. An annotated bibliography is included, which contains literature written up until 1994 on transportation data, policy options, comparative analyses, and alternative transportation fuels.

Policy Dialogue Advisory Committee. ***Majority Report to the President to Recommend Options for Reducing Greenhouse Gases from Personal Motor Vehicles.*** **December 1996.**

The report represents the view of the majority of the Policy Dialogue Advisory Committee. The Committee was charged by President Clinton to make recommendations for the implementation of three sets of policies to reduce greenhouse gas emissions to 1990 levels by 2005, 2015, and 2025, without subsequently increasing.

The Committee examined three main factors that determine greenhouse gas emissions from personal vehicle use: fuel economy, VMT, and alternative fuels. They also provided an analytical framework for assessing the merits and weaknesses of certain policies. The members of the Committee did not reach a consensus, but the report offers valuable insights regarding the array of options that exist for emissions reduction. The report recommends a balanced set of policies intended to reduce vehicle emissions by: increasing the efficiency of the vehicle fleet; reduce emissions by introducing cleaner burning fuels; and reduce the amount of driving through attractive transit alternatives and prices that more accurately signal the true cost of driving.

Policy Dialogue Advisory Committee. ***Development of Measures to Significantly Reduce Greenhouse Gas Emissions From Personal Motor Vehicles.*** **Interim Report to the President. March 1995.**

This report is a summary of the Advisory Committee's first six months of progress, including a discussion of the assumptions to be used in future estimates of baseline scenarios for greenhouse gas emissions in the next century. It also reviews factors affecting fuel economy, alternative fuel technologies, and vehicle miles traveled. Finally, an outline of 65 potential policy options for further consideration and method for evaluating such options is presented.

Executive Office of the President. ***The Climate Change Action Plan.*** **President William J. Clinton and Vice-President Albert Gore, Jr., October 1993.**

The Climate Change Action Plan (CCAP) is the basis for the US response to the international *Framework Convention on Climate Change*. The CCAP outlines nearly 50 new or expanded initiatives in all sectors of the US economy—commercial, residential, industrial, and transportation—that are expected to return US greenhouse gas emissions to 1990 levels by the year 2000. The Plan broadly describes the major policy initiatives, implementation, projected greenhouse gas impacts, and costs.

Framework Convention on Climate Change (FCCC)

This international treaty was negotiated in 1992, and signed by the United States and 153 other nations. The FCCC calls for a voluntary reduction of greenhouse gases to 1990 levels by the year 2000. The treaty encapsulates the international goal of preventing global climate change caused by human greenhouse gas emissions.

Intergovernmental Panel on Climate Change, *First Scientific Assessment of Climate Change, Summary and Report,* World Meteorological Organization/UN Environment Program (Cambridge, MA: Cambridge University Press, 1990).

This report is the IPCC's initial peer-reviewed summary of scientific knowledge about global climate change. As a widely peer-reviewed document, it represents a reliable snapshot of global climate science in 1990. The report stated with certainty that a natural greenhouse effect already keeps the Earth warmer than it would otherwise be, and that emissions from human activities are substantially increasing atmospheric concentrations of greenhouse gases. The report also concluded that atmospheric concentrations probably adjust only slowly to changes in emissions. The IPCC stressed that all its predictions were subject to many uncertainties with regard to the timing, magnitude, and regional patterns of climate change. [peer-reviewed]

Intergovernmental Panel on Climate Change, *Second Scientific Assessment of Climate Change, Summary and Report,* World Meteorological Organization/UN Environment Program (Cambridge, MA: Cambridge University Press, 1995).

This report is the IPCC's 1995 peer-reviewed summary of scientific knowledge about global climate change. The report asserted clearer linkages between human activity and global warming, saying that a human cause for climate change now observed is "likely", not just possible—a much stronger conclusion than in its *First Scientific Assessment*. The report includes extensive discussions of greenhouse gas inventories, potential impacts of global warming, and areas of scientific uncertainty. The report's findings were formally accepted by the Second Conference of Parties to the Framework Convention on Climate Change. As such, the IPCC report represents an "official" international scientific consensus. [peer-reviewed]

MacKenzie, James J., Roger C. Dower, and Donald D. T. Chen. *The Going Rate: What It Really Costs to Drive.* World Resources Institute, Washington, DC; 1992.

This document is a detailed review of the costs of automobile use. Costs are categorized as direct personal costs such as auto insurance and gasoline, and hidden social costs, such as health and safety-related expenses. The discussion provides significant historical information on factors such as energy use, air pollutant emissions levels, vehicle miles of travel, and transportation costs over the last several decades.

Pilorusso Research & Consulting, Inc. *The Role of Transportation Technologies in Reducing Greenhouse Gas Emissions.* May 25, 1995.

This document was prepared for the Ontario Roundtable on Environment and Economy and offers a thorough look at the major technologies option for reducing greenhouse gas emissions. Technologies to improve fuel efficiencies are considered, including policy initiatives in the United States. Other sections are dedicated to alternative fuels for combustion engines; electric and hybrid vehicles; advanced transit; intelligent transportation systems (ITS); high speed rail; and bicycles. For each of the above options, the feasibility of and barriers to implementation of such measures are considered, as well as both the environmental and economic benefits of such policy options. The findings suggest that technology must be taken in context. That is, technological fixes are attractive, especially to the voting public who would prefer not to modify behavior. However, while technologies have a significant role to play in reducing emissions, they are unlikely to sufficiently achieve emissions reduction targets on their own. This is a useful, detailed presentation of technological options for reducing greenhouse gas emissions.

United States Congress, Office of Technology Assessment. ***Saving Energy in US Transportation.*** **Washington, DC. July 1994.**

This report assesses the US transportation system, its energy use, and its energy use patterns as compared to those of European nations. It then provides a review of a series of transportation policy options designed to reduce energy use, and addresses the interplay among these policies and other transportation problems such as air pollution and congestion.

United States Department of Energy, Office of Policy and International Affairs. ***Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions: Lessons from Recent Literature.*** **July 1996.**

This DOE document provides a review of the recent literature on various policy options intended to reduce greenhouse gas emissions. As such, it reviews various sectors of the economy, including manufacturing, transportation, and electricity generation and their respective contribution to greenhouse gas emissions. The document then addresses economy-wide options to reduce emissions.

US Department of Energy, ***Report to the Congress of the United States: Limiting Net Greenhouse Gas Emissions in the United States,*** **September 1991.**

This two-volume study evaluates policy options for reducing US emissions of carbon dioxide and other greenhouse gases. Volume I, Energy Technologies, identifies and describes the principal performance and cost characteristics for energy and environmental technologies that were expected to play a role during the study period—to 2030. Volume II, Energy Response, includes a national-level policy analysis to determine the effectiveness and costs of various federal policy instruments in reducing projected US emissions.

The study finds that the most cost-effective combination of strategies for meeting the congressional emissions objectives encompassed a wide array of actions, including NES Actions such as emissions reductions of chlorofluorocarbons and hydrogenated chlorofluorocarbons, the planning of large areas of new forests, and a broad energy-related emissions reduction program. Transportation fuel efficiency improvements and alternative fuels comprise the spectrum of policies addressing the transportation sector. The study finds that increases in the fuel economy of conventionally-powered light duty vehicles causes only a small decrease in emissions relative to those achieved by the NES Actions.

US Department of State. ***Draft Protocol.*** **January 17, 1997.**

This draft protocol lays out specific responsibilities for countries to help reduce the threat of global warming, focusing on actions to be taken after the year 2000. The US plan would establish a multi-year "budget" for greenhouse gas emissions, with a specific cap on the amount of greenhouse gas emissions and industrialized country could release during that time. Caps would be a percentage of greenhouse gas emissions each nation released in 1990. If a nation fell under budget, it could transfer its savings to the next period, or sell off its excess emissions allowances. Alternatively, countries emitting over their budget could use part of the next budget period's allocation, but would have to include extra emission cuts in their paybacks—a form of "interest". The US proposal would set up an international trading regime for greenhouse gases. The US proposal also would require all developing countries to take "no-regrets" actions to control their greenhouse gas emissions, and report annually.

The proposal does not specify what the cap might be, or what specific actions must be taken. However, it is expected to act as a basis for discussions among the countries signing the Framework Convention on Climate Change (FCCC) at several meetings held during 1997. The draft protocol is accompanied by a press release and fact sheet describing the proposal.

US Environmental Protection Agency, ***Policy Options for Stabilizing Global Climate: Report to Congress*** **(EPA Report No. 21P-2003.1, December 1990).**

This report examines a range of possible responses to global climate change, and estimates their potential for reducing or limiting emissions of greenhouse gases on a global scale. The report describes the types of gases involved, their physical sources, and the level of emissions by source as well as geographic location. The transportation sector is discussed, both in terms of its contribution to greenhouse gas emissions and potential strategies to reduce those emissions. [peer-reviewed]

A number of sources provide information on VMT-reduction strategies without specifically focusing on greenhouse gas emissions. Much of the literature on transportation control measures (TCMs) focuses on local or regional programs rather than national implementation of strategies. A few sources include:

US Environmental Protection Agency. ***Methodologies for Estimating Emissions and Travel Activity Effects of TCMs.*** **Prepared by Systems Applications International. July 1994.**

This report provides methodologies for estimating the travel activity effects from individual TCMs. It discusses interactions among TCMs, mode choice dependence on multiple attributes, and an approach to evaluating TCM packages.

US Environmental Protection Agency. ***Transportation Control Measure: State Implementation Plan Guidance*** **(450/2-89-020). September 1990.**

This guidance document provides descriptions and examples of the most frequently implemented TCMs; institutional guidance such as assessing feasibility, agency responsibilities, and funding; and techniques for monitoring and enforcing TCMs as a strategy to attain National Ambient Air Quality Standards (NAAQS).

US Environmental Protection Agency. ***Guidance on the Use of Market Mechanisms to Reduce Transportation Emissions.*** **(Final Draft, May 1996.)**

This guidance document provides state and local transportation and air quality officials with assistance in analyzing the emissions reductions potential of market-based approaches for state and local air quality planning purposes.

METRIC CONVERSION TABLE

MASS

	TO (multiply by)			
FROM	Gram	Milligram	Short Ton	Metric Ton
Ounce (troy)	31.103	31,103	5.0×10^{-4}	4.5362×10^{-4}
Pound (troy)	373.24	373,240	1.1023×10^{-3}	1.0×10^{-3}
Short Ton	9.0718×10^{5}	9.0718×10^{8}	1.0	0.90718
Metric Ton	9.999845×10^{5}	$9{,}999845 \times 10^{8}$	1.102317	1.0

LENGTH

	TO (multiply by)			
FROM	Millimeter	Centimeter	Meter	Kilometer
Inch	25.4	2.54	.0254	2.54×10^{-5}
Foot	304.8	30.48	.3048	3.048×10^{-4}
Yard	914.4	91.44	.9144	9.144×10^{-4}
Mile	1,609,400	160,934	1609.34	1.6094

VOLUME

	TO (multiply by)	
FROM	Milliliters	Liters
Fluid Ounce (US)	28.412	.028412
Pint (US, liq)	473.163	.473163
Quart (US, liq)	946.3	.9463
Gallon (US, liq)	3785.3	3.7853

AREA

	TO (multiply by)	
FROM	Square Meters	Square Kilometers
Square Inch	.000645	6.45×10^{-10}
Square Foot	.0929	9.29×10^{-8}
Square Yard	.8361	8.361×10^{-7}
Square Mile	2,589,990	2.58999

TEMPERATURE

	TO (multiply by)
FROM	Celsius
Fahrenheit	5/9 (F° – 32°)