SPECIAL REPORT 251

TOWARD A SUSTAINABLE FUTURE

Addressing the Long-Term Effects of Motor Vehicle Transportation on Climate and Ecology

TRANSPORTATION RESEARCH BOARD
National Research Council

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Committee for a Study on Transportation and a Sustainable Environment

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NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1997

Transportation Research Board Special Report 251

Subscriber Categories
1A planning and administration
1B energy and environment

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Printed in the United States of America

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report was sponsored by the Energy Foundation; the U.S. Department of Energy; the Federal Highway Administration and Federal Transit Administration, U.S. Department of Transportation; and the Cooperative Research Programs and Executive Committee, Transportation Research Board.

Library of Congress Cataloging-in-Publication Data

Toward a sustainable future: addressing the long-term effects of motor vehicle transportation on climate and ecology / Committee for a Study of Transportation and a Sustainable Environment.
p. cm.—(Special report ; 251)
"February 1997."
"Final draft submitted for review."
ISBN 0-309-05969-0
1. Transportation—Environmental aspects—United States.
2. Transportation and state—United States. 3. Air—Pollution—Government policy—United States. 4. Sustainable development—United States. I. National Research Council (U.S.). Transportation Research Board. Committee for a Study of Transportation and a Sustainable Environment. II. Series: Special report (National Research Council (U.S.). Transportation Research Board) ; 251.
HE203.T748 1997
338—dc21 97-19443
CIP

Cover design: Karen White

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Preface

Recognition that humans may be influencing environmental systems and processes on a global and lasting basis has fostered interest in the concept of sustainable development. The basic premise of this concept is that each generation should seek to provide for its own needs in ways that do not compromise the ability of later generations to meet their needs. The concern is that the global and potentially long-term environmental effects of current human activities are endangering the welfare of future generations. International efforts were initiated in the 1980s to control depletion of the stratospheric ozone shield and were followed by the broader United Nations Earth Summit in Rio de Janeiro in 1992. Since these beginnings, many governments, professional societies, industries, and environmental advocates from around the world have been working together to gain a better understanding of the environmental disturbances from human activities that warrant attention as long-term environmental risks.

During the past several years, many segments of society and sectors of the economy—from agriculture to manufacturing—have begun evaluating their activities in light of concerns over these environmental risks in an effort to achieve a more sustainable form of development. Because of the integral role of transportation in society and the economy and its significance as a user of energy and a source of environmental disturbances, interest in sustainable development has come to influence research and policy debates in this sector. As has been the experience in other sectors, it has proved controversial and difficult to apply such a broad and complex concept to a single sector. Nevertheless, the basic trade-off that must be grappled with in the transportation sector—that of striking a balance between the mobility and access needs of people on the one hand and environmental and resource imperatives on the other—is not unlike those that must be addressed in other sectors. Perhaps the most immediate challenge is to build a broader consensus on the key environmental issues that need to be addressed and on the range of options for doing so.

STUDY ORIGIN, MISSION, AND FUNDING

This study had its genesis in discussions initiated by Thomas B. Deen, former Executive Director of the Transportation Research Board (TRB), and members of the TRB Executive Committee. The Executive Committee concluded that the transportation community would be well served by a study that fosters understanding among the professional and public policy communities about the long-term environmental disturbances contributed by transportation and the various opportunities and options for improving their recognition and reducing their risks through research, technological innovation, and changes in transportation practices and policies. In particular, the Executive Committee believed that such an effort could play a valuable role in helping to

- Inform the transportation and public policy communities about the scientific background of several important environmental risks to which transportation is a contributor;
- Inform the scientific and public policy communities about some options available for reducing transportation's contribution to these risks and the technical, political, and economic challenges that must be confronted; and
- Identify the kinds of research that are needed to better understand the risks and inform public policy so that options continue to become available for addressing them.

The Executive Committee recommended that the National Research Council appoint a committee to conduct the study, and TRB provided

initial funding for the project through the Institute for Strategic Transportation Studies, supported by unrestricted grants from the UPS Foundation, Norfolk Southern Corporation, Consolidated Rail Corporation, Inc., and the Association of American Railroads. Additional funding (in order of the date funds were contributed) was provided by the Energy Foundation, Federal Highway Administration, American Association of State Highway and Transportation Officials (through the National Cooperative Highway Research Program), transit agencies (through the Transit Cooperative Research Program), U.S. Department of Energy (through Battelle Northwest Laboratories), and Federal Transit Administration. Each of the sponsors offered informational and technical assistance to the committee.

STUDY APPROACH AND SCOPE

The National Research Council appointed a study committee of 18 experts under the leadership of James D. Ebert. Committee members have expertise in environmental sciences, economics, transportation, and public policy. The committee met eight times to deliberate on the issues and to prepare this report.

In approaching its task, the committee made a number of decisions that affected the subsequent analysis and content of the report. Much of the early deliberations were spent in identifying issues that the committee could agree on as most relevant to transportation and concerns over long-term environmental risks and sustainable development. Clarifying the study scope in this way proved difficult because there is no consensus within the transportation community or generally about the array of environmental risks and other issues germane to the concept of sustainable development. As a guiding tenet, the committee repeatedly returned to the fundamental notion that current generations should not compromise the ability of later generations to meet their needs. On the basis of this concern—and using a rationale described in Chapter 1—the committee refrained from conducting a far-ranging assessment of all of transportation's environmental effects. Instead, it elected to focus its attention on transportation's contribution to those long-term environmental risks that have potentially large and permanent adverse consequences.

Another way in which the committee narrowed the study scope was to focus on the U.S. transportation system, particularly on the highway and motor vehicle component. The committee recognizes that transportation activity is growing worldwide and is best considered within a global context, especially because technologies and practices are often interchangeable worldwide and because transportation systems transcend national boundaries. Yet it is important to acknowledge that the United States is in a position to initiate many important changes on its own, some having broader influence. The U.S. transportation sector is by virtually all measures the largest and most technically advanced in the world, a source of many new transportation services and technologies. In this leadership capacity, it has the potential to be a role model for good policy and practice. Hence, the approach taken in this report is to focus attention on the U.S. transportation sector but to recognize that actions taken within this sector can have global influence.

The decision to concentrate on motor vehicle transportation was one of both practicality and reason. The original prospectus for the study called for an examination of all transportation modes. As a practical matter, the committee found it difficult in the time available to treat all modes in detail. Hence, most of the report focuses on motor vehicle transportation, which accounts for the predominant share of transportation energy consumption, emissions, expenditures, and activity. This limit should not be viewed as a finding that other modes of transportation have minor adverse environmental effects; indeed, the committee was made aware of ongoing scientific inquiries into the effects of aircraft on the protective ozone shield and greenhouse gas balance, issues that another National Research Council panel is presently reviewing.[1] Nevertheless, motor vehicle travel is the largest and most pervasive component of the transportation system. If serious consideration is to be

[1]The Panel on the Atmospheric Effects of Aviation of the Board on Atmospheric Sciences and Climate is reviewing the long-running aviation effects project of the National Aeronautics and Space Administration, which includes studies of the possible climatic effects of the current subsonic and potential supersonic fleets. Because of this parallel project, the committee was dissuaded from further examining environmental issues related to the U.S. aviation sector.

given to transportation's role in sustainable development, this central component will certainly warrant the most attention.

Finally, in considering transportation trends, environmental effects, and policy and technology options, the committee believed it appropriate to do so from a vantage point covering the next half century. Such a long-term outlook is essential given the nature of the issues considered and because the transportation system itself is not amenable to abrupt changes in technology and practice. New vehicle technologies, for instance, can take a decade or more to filter through the fleet, not including the many years of preceding research and development. Even more enduring is the transportation infrastructure system, which is designed and built to last many decades and serves land use patterns that are equally enduring. Although change in the transportation system is measured over decades, the committee did not believe that it was capable of speculating beyond 25 to 50 years. The pace of innovation and change in transportation is often incremental, but tremendous transformations accumulate over time. The last half-century—a period that witnessed the emergence of jet aircraft, the decline and the subsequent revival of marine and railroad freight sectors, and the advent of the Interstate highway system—is replete with examples of such change. It would be presumptuous to assume that equally dramatic changes will not occur during the next half-century. Yet it is important to take a longer-term perspective in recognition that tremendous changes will occur over time and that these changes will offer opportunities to make the transportation system more compatible with evolving notions of a healthy and sustainable environment.

The report represents the consensus effort of the committee. One committee member, David G. Burwell, offers supplemental points for consideration in Appendix C. Although he endorses the report, he would have preferred a broader examination of transportation's role in ensuring sustainable development.

ACKNOWLEDGMENTS

During the course of its deliberations the committee benefited from presentations by the following experts, whom the committee wishes to acknowledge and thank.

Mark Baldessare, Chairman, Department of Urban Planning, University of California at Irvine, and public opinion analyst, described new developments in transportation, planning, urban design, and land use in southern California.

Ralph J. Cicerone, Dean, School of Physical Sciences, University of California at Irvine, described the status of global climate change research and critical issues.

David L. Correll, Director, Smithsonian Environmental Research Center, discussed new research and data showing changes in precipitation, soil, and water chemistry and the ecology of the Chesapeake Bay region.

Larry D. Harris, Professor, School of Forest Resources and Conservation, University of Florida, described recent experiences in Florida in understanding and managing the effects of road networks on natural processes, ecosystems, and endangered species.

Albert J. Kaehn, Jr., Chairman of the National Research Council Panel on the Atmospheric Effects of Aviation, described issues and concerns about the effects of aircraft emissions and operations on atmospheric composition and efforts under way by NASA and private industry to study these effects.

Alan S. Manne, Professor Emeritus, Operations Research, Stanford University, described decision models for assessing the costs and benefits of alternative strategies for reducing carbon dioxide emissions and alternative time frames for taking action.

H. Ronald Pulliam, Director, National Biological Service, Department of the Interior, described federal programs to inventory plant and animal species in the United States and key issues that will need to be addressed to ensure biodiversity.

Robert F. Sawyer, Professor, Department of Mechanical Engineering, University of California, Berkeley, summarized progress being made in meeting Clean Air Act attainment standards and the prospects for new technologies and standards.

Stephen H. Schneider, Professor, Department of Biological Sciences, Stanford University, briefed the committee on areas of agreement among climate experts regarding the effects of human activities on greenhouse gas buildup and climate change.

William E. Winner, Professor, Department of Botany and Plant Pathology, Oregon State University, summarized the results of biological research into the effects of emissions and ozone pollution on trees and forest ecosystems.

Robert H. Williams, Professor, Center for Energy and Environmental Studies, Princeton University, reviewed the prospects for and benefits of shifting to hydrogen fuels for transportation and summarized the technical and research challenges that would need to be met.

The committee also wishes to thank several liaison representatives whose input and advice were sought through the course of the deliberations. Special thanks are due Jerry Dion, Department of Energy; Rachel Finson, Energy Foundation; Kevin E. Heanue, Federal Highway Administration; and Richard Steinman and Matt Welbes, Federal Transit Administration.

The study was managed by Stephen R. Godwin, Director of Studies and Information Services, TRB. Thomas R. Menzies, Jr., Senior Program Officer, drafted the report under the direction and guidance of the committee and with assistance from Godwin and James J. Zucchetto, Director of the National Research Council Board on Energy and Environmental Systems of the Commission on Engineering and Technical Systems.

The report was reviewed by a group of independent experts according to the policies of the National Research Council Report Review Committee. Suzanne Schneider, Assistant Executive Director of TRB, managed the report review process. The final manuscript was edited and prepared for publication under the supervision of Nancy A. Ackerman, Director of Reports and Editorial Services, TRB. Naomi Kassabian and Norman Solomon edited the report.

Special appreciation is expressed to Frances E. Holland, who assisted in meeting and travel arrangements and communications with the committee and provided word processing support for the preparation of the final manuscript.

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Executive Summary

Through the consumption of natural resources, emission of chemicals into the atmosphere, and other ecological disturbances, humans may be changing some of the essential biological and physical systems on which future generations may depend on both a global and lasting basis. International concern over these effects has spawned far-ranging debate about alternative policies and practices that will foster more sustainable forms of development and reduce the risk of such long-term environmental changes.

Policies, technologies, and practices within the U.S. transportation sector have become part of this debate. An efficient and flexible transportation system is essential to the nation's economy and standard of living. Transportation is also a source of many environmental disturbances and risks, some of which are not well understood or recognized by the public because their most serious consequences may not become evident for years. Because access and mobility are highly valued by Americans, reducing these long-term risks will require well-informed and well-considered public policies.

The influence of U.S. transportation on several critical natural resources and environmental systems is reviewed in this report along with several policy and technology options for lessening this influence. The purpose of the review is to identify some of the challenges that lie ahead in managing transportation's long-term environment effects and the kinds of research and preparations that are needed to inform policy and meet these challenges. Although the report does not recommend specific policies to pursue, it identifies some of the issues and uncertainties that will need to be addressed in evaluating them.

The discussion focuses on motor vehicle transportation, which accounts for most of the energy consumed, pollutants emitted, and physical infrastructure used by the U.S. transportation system. Whether motor vehicles will continue to exert such dominance over the next several decades cannot be anticipated. Nevertheless, should motor vehicle travel grow at even half the rate experienced during the past half-century, the amount of travel by motor vehicles on the nation's roadways will more than double before the middle of the next century. An escalation in motor vehicle travel of this magnitude, or even on a more modest scale, will have important implications for environmental policy. Whereas the focus of this report is on the large motor vehicle transportation system, similar assessments of other fast-growing transportation modes, such as air travel, may be warranted.

LONG-TERM ENVIRONMENTAL RISKS AND UNCERTAINTIES

A number of environmental disturbances from motor vehicle transportation were examined during the course of this study. A decision was made to focus on those posing lasting and adverse environmental consequences that may not become fully manifest for decades. Environmental disturbances that have such delayed consequences are less likely to attract the public's attention or be the subject of public policies and programs to curb them. Left untreated, their adverse consequences may worsen, causing serious environmental problems for future generations. The committee members believe it is critical to single out such environmental risks since they may require special research and public policy responses.

There is incomplete knowledge and active debate within the scientific and social science fields about the extent to which humans are changing the natural environment and whether these changes are irreparable and threaten the well-being of future generations. This study does not attempt to advance this debate by predicting environmental outcomes and their probabilities. The premise of the study is that a significant risk of adverse outcome from environmental disturbances is undesirable and that, as a minimum, caution warrants early steps to be taken to better understand and reduce the risk.

Considered in this report are two long-term environmental risks with such delayed consequences: (*a*) the risk of global climate change caused by the long-term buildup of greenhouse gases in the atmosphere, including carbon dioxide (CO_2) and other greenhouse gases emitted from fuels used in transportation; and (*b*) the risk of losses in biological diversity and ecosystem functions from the changes in air, water, and soil chemistry caused by the chemicals emitted into the atmosphere by motor vehicles and from the gradual changes in habitats and natural processes caused by pervasive road systems and other transportation infrastructure.

Not all of the adverse environmental effects from transportation are delayed or indiscernible to the public. For example, urban air pollution is one of the country's most vexing environmental problems, a highly visible environmental side effect from motor vehicle use that has become a public health concern for millions of Americans living in and around metropolitan areas. Many of its adverse consequences are known to the public, and it has become the subject of research, regulations, and public- and private-sector efforts to better understand and manage it. The committee believes it unlikely that urban air pollution will be allowed to become a worsening public health and environmental problem in the future.

A real challenge in addressing climate change and the other long-term environmental risks examined in this study will be to build the understanding and attention that can generate such effective responses.

Climate Change Risk from CO_2 Emissions and Buildup

There is a preponderance of scientific evidence that concentrations of carbon dioxide (CO_2) and other greenhouse gases are increasing in the atmosphere as a result of human activity. The committee shares the concern expressed by the Intergovernmental Panel on Climate Change that the continued emission and buildup of greenhouse gases in the atmosphere could lead to warming of the earth's surface during the next century. Although the effects of such a warming are uncertain, they could include marked changes in climate and related natural systems influencing sea level and ocean currents, the location and composition of biological communities, and the fertility and productivity of the world's agricultural lands.

Emissions of CO_2, the most abundant of the greenhouse gases besides water vapor, are slowly removed from the atmosphere by natural processes. Because of this lag, growing emissions from human activity cause atmospheric levels of CO_2 to rise over time. The transportation sector worldwide contributes between one-fourth and one-third of such emissions, most of which are produced by the combustion of petroleum and other fossil fuels rich in carbon. U.S. motor vehicles—cars, trucks, and buses—burn more than 140 billion gallons (530 billion liters) of gasoline and diesel fuel each year, emitting an average of more than 1 pound of CO_2 for each mile (more than 300 g/km) they travel.

The U.S. transportation sector as a whole accounts for about 5 percent of the CO_2 emitted by human activities worldwide, although most transportation emissions are from motor vehicles. Though this percentage appears modest, no other energy use sector in the United States or elsewhere in the world accounts for a significantly larger portion of global CO_2 emissions. Changes in U.S. transportation policies, technologies, and practices may be necessary, therefore, to influence long-term emission trends.

Risk to Biodiversity and Ecosystems from Transportation Emissions and Infrastructure

Transportation emissions other than CO_2 have potentially cumulative and long-lasting effects on the function and biological composition of ecosystems. The chemicals emitted from vehicles are dispersed widely and react in the atmosphere to create ozone and other compounds that change air, soil, and water chemistry. Naturally occurring ozone in the higher altitudes of the stratosphere is beneficial, providing a shield against ultraviolet light penetration. Concentrations of ozone in the lower altitudes of the troposphere, however, are generally undesirable. In addition to being a greenhouse gas, tropospheric ozone—formed from photochemical reactions of the oxides of nitrogen (NO_x) and volatile organic compounds emitted by motor vehicles and other sources—may adversely affect mountain and forest ecosystems over large portions of the country. Likewise, emissions of NO_x have been implicated in the production of acid rain and nutrient enrichment, which are suspected causes of biological changes occurring in some important terrestrial and aquatic ecosystems.

Whereas significant progress has been made in understanding the causes and in reducing the high concentrations of ozone and other types of air pollution in urban areas, the longer-term ecological effects of these emissions outside urban areas have not been as extensively monitored or studied. These effects therefore remain poorly understood.

The extensive system of roads and other transportation infrastructure in the United States also has lasting ecological effects. Crisscrossing the nation are nearly 4 million miles (about 6.25 million km) of roadway over which the nation's 200 million vehicles operate. This system is accompanied by hundreds of thousands of miles of railroad track, pipeline, and other kinds of transportation structures and facilities. Not only does this physical infrastructure occupy large amounts of land and modify the specific environments in which it is located, but its ecological effects can extend across broad geographic areas. For instance, the flow of water within a regional watershed may be altered or the movement of species through their natural ranges may be impeded. By interrupting feeding, dispersal, and breeding patterns, even a single roadway that cuts across an otherwise pristine wilderness area can affect the population and types of species found across the landscape.

Emissions from transportation vehicles and the disruption of habitats and natural processes caused by the extensive transportation infrastructure system may be leading to gradual changes in biological diversity and ecosystem functions on a regional or national scale. A more complete understanding of these risks is needed.

CONFRONTING THE RISKS

These emerging environmental risks are sufficiently well understood to warrant more research and public policy attention. Some of the broad policy issues and research topics that will need to be addressed are identified next along with some specific examples of research and other actions that can be undertaken.

Controlling CO_2 Emissions from Transportation

It appears likely that annual CO_2 emissions from U.S. motor vehicle travel will continue to grow—perhaps more than double—in the next half-century as a result of increasing motor vehicle use and petroleum consumption. The growth will undoubtedly be accompanied by even faster growth in transportation activity and emissions elsewhere in the world as developing nations continue to industrialize and convert to motorized transportation.

In the United Nations Framework Convention on Climate Change, signed at the 1992 Earth Summit in Rio de Janeiro, nations around the world committed themselves to a goal, yet to be well-defined, of stabilizing atmospheric concentrations of greenhouse gases at levels that would prevent human interference with global climate systems. Although the efforts to limit emissions under the convention are currently voluntary, the U.S. government, according to statements made in 1996 by the Undersecretary of State for Global Affairs, has proposed the adoption of binding international agreements for emission limitations. If such an approach is adopted, the implications for the domestic transportation sector could be profound. Scenarios presented in this report indicate that even the achievement of a gradual slowdown in the rate of growth in CO_2 emissions from transportation will present significant economic, technical, and political challenges. Achieving stability or reductions in emissions in the near term (the next 10 to 20 years) would be still more demanding.

Two general approaches are available for achieving emission limitations over time. One is to encourage changes in travel behavior to reduce motor vehicle use, and therefore fuel use. The other is to foster changes in transportation technologies to favor those that use less petroleum and emit less CO_2 and other greenhouse gases. These two approaches may be complementary. As an example, the former might include investments in transit and policies that encourage changes in land use and development patterns, both to reduce the demand for motorized travel and to encourage use of alternative, low-emission vehicles such as electric-drive cars. The latter approach might include taxes on carbon-based fuels to reduce travel demand and encourage consumer demand for vehicles that emit less CO_2 and other greenhouse gases.

Both of these general approaches, if seriously pursued, would require far more public understanding of the climate change risk and transportation's role.

Changes in Travel Behavior

Experience in the United States and other nations has demonstrated that higher fuel prices—achieved through energy taxes or as a result of normal market mechanisms—influence both travel behavior and transportation technologies by discouraging motor vehicle use and spurring demand for fuel-saving vehicles and technologies. Gasoline and diesel fuel prices in the United States are low compared with prices in other industrialized nations, primarily because of differences in fuel tax policies. The public, however, has been generally averse to the use of fuel taxes for purposes other than paying for transportation infrastructure. Should market prices for petroleum remain stable or even decline in the future, fuel taxes would need to be raised to achieve fuel prices that would have a substantial effect on travel behavior and consumer demand for fuel-saving technologies. This pricing approach would require broad and deep public support for the tax increases and a fundamental change in the current perception of fuel taxes mainly as revenue for the construction, maintenance, and operation of transportation systems.

Several other options—such as land use policies that increase the density of metropolitan development and expanded transit investments in some areas—may be pursued to curb motor vehicle travel and resulting CO_2 emissions. Compared with a fuel tax, most of these options would have narrower and more indirect effects on motor vehicle use, petroleum consumption, and emissions. None of these options, if pursued by itself, is likely to have a large influence on CO_2 emissions, but taken together and over the course of decades they could have an appreciable effect on emission trends.

Most policy options to influence travel demand are fraught with uncertainties about their effects on emissions of CO_2 and other greenhouse gases, the practicality of their implementation, and their many secondary costs and benefits. More research is needed to develop policies acceptable to the public, to estimate how effective individual policies might be in influencing CO_2 emissions, and to quantify the associated costs and benefits. Also needed are estimates of how various policies in combination would affect emissions of CO_2 and other greenhouse gases.

Changes in Technology

Proven oil reserves are large, and additional oil supplies will continue to be found and extracted for years to come. Yet as recoverable oil supplies dwindle and petroleum fuel prices rise (the timing of these events remains uncertain) other energy sources will undoubtedly become more price competitive. Eventually, spurred by either market forces or government policies, gasoline and diesel fuel could be replaced by other energy sources. In either instance, ensuring the availability of environmentally acceptable energy alternatives for transportation may prove critical. The future availability of petroleum and other energy supplies is not in itself a concern of this study, but the questions of which energy sources will replace petroleum and when are concerns, since the substitutes may or may not produce less greenhouse gases.

Policy options that would induce changes in transportation and energy technology involve many uncertainties and research needs. Policies that promote the development and use of radically different vehicle technologies and low-emission energy sources form one approach. Examples of these technologies are electric-drive vehicles powered by hydrogen-based fuel cells and vehicles with internal combustion engines run on alcohol fuels derived from renewable biomass sources. Encouraging consumers to demand, and manufacturers to supply, far more fuel-efficient petroleum powered vehicles is another approach to reducing emissions through technological change.

Both general approaches may be warranted. In either case, greater progress will be achieved if the approach is accompanied by consumer demand for new technologies, especially since changes in technologies could have vehicle performance and cost disadvantages, at least initially. A tax on the carbon content of energy is one means of shifting consumer demand toward more fuel-efficient and lower-emitting technologies. Other options include government assistance and support for technology research and development, consumer subsidies and taxes that encourage the purchase of fuel-saving or low-emission vehicles, and supplier-oriented inducements for their development.

The time horizon for the development and introduction of new technologies that would dramatically reduce greenhouse gas emissions is difficult to judge. The expectation that new technologies emitting fewer greenhouse gases will emerge quickly and without special encouragement may be overly optimistic and could be risky should the concern over greenhouse gases become more urgent. The development and widespread introduction of radically different transportation vehicles will take decades. Significant early support for technology research and development may prove beneficial in prompting technical progress and enhancing the prospect that responsive technologies will become available sooner.

Reducing Ecological Effects of Motor Vehicles and Road Systems

Environmental disturbances from transportation that contribute to changes in soil and water chemistry and disrupt habitats and natural flows pose long-term ecological risks. Much more needs to be learned about these effects to develop and assess options for addressing them.

Chemical emission and deposition monitoring networks, accompanied by studies of ecosystem responses to these pollutants, are important in gaining a better understanding of the broader environmental repercussions of transportation emissions. Such networks should be oriented toward the kinds and levels of emissions that affect the natural environment in addition to emissions that affect public health. Likewise, more long-term data bases and studies are needed to improve understanding of the effects of road systems and other physical components of transportation infrastructure on habitats and natural processes.

In addition to strengthening scientific understanding of ecological effects, it is important to begin developing appropriate responses. Because many of the ecological effects of transportation are best viewed or anticipated from a broader geographic perspective and over a long time horizon, they are often underappreciated in the early planning and design of transportation systems. Evaluations and mitigative approaches that focus on site-specific ecological effects are often insufficient. An anticipatory approach that has been developed to reduce transportation's ecological effects is to plan, site, and design transportation facilities with the aid of regional maps that locate critical ecological features and natural flows occurring over the landscape. Such innovative approaches need to be evaluated and more widely recognized.

Efforts to develop more effective emission control technologies for motor vehicles continue. Some technical barriers to reducing NO_x emissions, though still high, are less imposing than those that must be overcome to reduce CO_2 emissions. Promising work is under way, for instance, to develop less expensive and more effective catalytic converters. Such technological advances will undoubtedly be of value in reducing the ecological effects of motor vehicle emissions. Many other technological options for reducing NO_x and other vehicle emissions are generally similar to those that would reduce CO_2, as are many of the policy options that would reduce emissions by influencing travel behavior. As discussed in the next section, many of these options warrant more thorough and sustained research.

NEXT STEPS

A prudent course for reducing the uncertainties and risks associated with long-range environmental issues is to further understanding and development of policy and technology options and to improve scientific and technical understanding of their causes. Such a course might enable more effective and timely responses to an environmental crisis and will begin to inform and educate the public about the response options available. The following are examples of research, educational, and information-gathering steps that can be taken.

Research on Determinants of Travel Demand

Research is needed to understand the behavioral, demographic, and social factors that influence transportation demand. Demand for transportation involves many social and behavioral components that are often too poorly understood to predict the effect of alternative policies, such as new taxes, land use controls, and transit investments, on travel demand. For instance, in evaluating such policy options it is helpful to have an understanding of how an individual's choice of travel modes and frequency of travel are influenced by family responsibilities, stage of life, and other personal circumstances and preferences. Such information is also important for evaluating the effect of future demographic changes on travel trends. Greater insight into how future travel patterns may be influenced by changing demographics, including an aging population, will be valuable in devising policies to affect travel behavior.

Long-Range Technology Research and Development

The federal government sponsors a number of research, development, and demonstration activities on alternative transportation technologies and fuels. A varied research and development (R&D) program is important. It is essential, however, that sufficient attention be given to developing a portfolio of high-risk and potentially high-benefit (e.g., low-emission) technological opportunities. Many nonconventional technologies involve substantial technical and cost challenges that will take many years of research to understand and overcome. Such opportunities are unlikely to be pursued by the private sector absent government encouragement and support. A detailed analysis of funding across government agencies is needed to determine whether the focus, scale, direction, and time horizon of current technology R&D efforts adequately emphasize long-term environmental risks.

A varied and aggressive federal R&D program is one means of encouraging technological development. Other approaches might include targeted tax credits for industry or inducements for the private sector to accelerate development of new technologies, such as California's requirement calling for more sales of low- and zero-emission vehicles. A better understanding of these and other options for encouraging long-range technology R&D is needed by policy makers.

Ecological Research

Given the many effects of transportation vehicles and infrastructure on terrestrial and aquatic ecosystems and the lack of integrated research on these effects, an escalation in research on the ecological effects of transportation and the means of controlling them appears warranted. Better ecological data and fieldwork will be fundamental to improving understanding of the multidimensional ecological effects of transportation systems and to begin reducing them.

The most basic data about these effects are needed, such as information on the movement and propagation of motor vehicle emissions across landscapes and regions and the capacity of forests, soils, and aquatic systems to assimilate them. At the same time, little is known about effectiveness of mitigations that are being undertaken by transportation agencies, for instance, how projects to preserve or restore wetlands, facilitate animal movements, and control erosion and stream sedimentation are collectively affecting the environment over the longer term.

Over such a large road and transportation infrastructure system—one that is gradually being added to, renovated, and repaired—many opportunities exist to undertake small-scale but systematic experiments with alternative mitigations. Such pilot efforts provide valuable learning and demonstration opportunities and may warrant federal support, directly in federal programs and indirectly by the use of federal funds passed through to state and local governments.

Public Awareness and Understanding

Changes in transportation policies, technologies, and practices, which can have many ramifications, often require broad and deep public support. Because the risk of climate change and the other ecological effects of transportation are at present largely imperceptible to the public, special efforts are needed to enhance public awareness and understanding of these risks in order to spur dialogue and debate about opportunities for addressing them. These efforts might include informational and educational activities and the development of statistical indicators that link motor vehicle travel with ecological changes (ideally, in concert with other initiatives to support environmental sustainability in areas such as agriculture, manufacturing, energy production, and forestry). Absent such effort, maintaining a long-term focus on research and technology may prove difficult.

LONG-TERM PERSPECTIVE

The risk of climate change and other cumulative and possibly irreversible effects of transportation on the environment constitute an unprecedented challenge. The consequences of these environmental disturbances are not immediately evident or well understood; as a result, there is a tendency to defer concern and action. Yet if adverse consequences become manifest, few good response options may be sufficiently advanced and available. Early and deliberate efforts to develop response capabilities may prove essential in providing the head start needed to respond to these environmental challenges.

Should public interest and perceptions change in ways that enable new policies and practices, a research base will be invaluable. National support for research that will improve public and scientific understanding of environmental problems and provide guidance to policy makers on response strategies is essential. The environmental issues discussed in this report, and the options for addressing them, are complex and will require much forethought and preparation. Not to take precautions is to risk passing costly and irreparable environmental problems on to future generations.

1

Sustainability and Transportation

The threat of long-term changes in the earth's biological and physical systems resulting from greenhouse gas buildup, acid rain, deforestation, and loss of habitats and species has led many national and international organizations to endorse the concept of sustainable development. Although sustainable development has not been uniformly defined, it is generally aimed at ensuring that current generations do not deprive future ones of the essential base of natural resources necessary to meet their needs. Concern over upward trends in world population, land development, natural resource consumption, and associated environmental effects has spurred debate about whether the earth's biosphere and other natural systems—including those essential to providing clean air, water, food, and many other vital services and products—are being significantly and irreparably altered. An important issue in the debate is how best to ensure that such alterations are minimized and managed so as not to become a serious detriment to future generations.

Transportation has a meaningful role in this debate. The extensive transportation system in the United States always has had, and continues to have, important and lasting environmental effects. As early as the nineteenth century, the network of interconnected waterways and canals was linked to shifts in fish populations, and the American bison was brought to the verge of extinction following the westward expansion of railroads. At the turn of the century, when many U.S. cities were facing formidable refuse and sanitation problems created by horse-drawn traffic, the clouds of dust raised by the first motor vehicles were also becoming a source of great public concern and annoyance (Lay 1992, 132, 173–174). By the 1940s, motor vehicle exhaust was found to be a source of urban smog and agricultural crop damage (National Research Council 1991, 21). More recently, wetlands—once routinely filled to build highways, ports, and airports—have become highly valued for their habitats and water quality and flood control functions.

Transportation is a source of environmental disturbances in part because the transportation system is so pervasive. The United States has nearly 4 million miles (about 6.2 million km) of public roadway,[1] over which about 200 million motor vehicles operate. Likewise, there are hundreds of thousands of miles of railroad track, pipelines, waterways, and other transport facilities. The importance of this system is indisputable, enabling a level of personal mobility that is unmatched anywhere in the world and supporting industry and the national economy through multiple options for moving goods and services. Thus, efforts to control the environmental effects of this system must be considered in light of the vital functions that it serves.

In recent years, efforts have been made to identify, understand, and control many of the environmental effects of the transportation system. Some, such as emissions of lead and carbon monoxide from motor vehicles and leakage of ozone-destroying compounds from vehicle air-conditioning systems, have been reduced significantly. In other cases, steps have been taken to lessen or contain environmental influences, for example by controlling sedimentation and contamination of streams near road construction sites and adopting protective measures to reduce the loss of endangered species living near transport corridors. The treatment of environmental disturbances, however, has often been inconsistent and haphazard, and some have gone virtually unnoticed and untreated for years.

Rather than examining all of the environmental effects of transportation, this report focuses on those that are especially prone to being neglected and poorly managed and have the potential to create serious and long-lasting environmental problems. The committee believes, for reasons explained next, that these risks pose particular challenges to the goal of maintaining a sound environment for future generations.

NOTIONS OF SUSTAINABLE DEVELOPMENT

The terms "sustainable development" and "sustainability" have come to encompass a wide variety of environmental, economic, and social concerns. The phrases "sustainable societies" and "sustainable development" had their origin in the mid-1970s, when concern over the environment and an expanding world population began to grow in many industrialized nations (Hitchcock 1991). An often-cited definition of sustainable development is the following, adopted in 1987 by the United Nations World Commission on Environment and Development (WCED) (Brundtland Commission) (WCED 1987, 43): "A sustainable condition for this planet is one in which there is stability for both social and physical systems, achieved through meeting the needs of the present without compromising the ability of future generations to meet their own needs."

The antecedents to contemporary concerns over sustainable development extend back more than 200 years to the theories of Thomas R. Malthus and more recently to concerns raised in the 1960s over "limits to growth" (see Box 1-1). Although the earlier concerns focused mainly on the overuse and depletion of tangible natural resources and materials such as agricultural land, fuel, and minerals, much of the current debate over sustainable development centers on the mistreatment of more ubiquitous but intangible natural resources, such as global climates, the protective ozone shield, and the life support provided by well-functioning ecosystems and a diversity of plants and animals. Often the benefits provided by these resources transcend geographic and generational boundaries; hence their misuse is difficult to regulate by either market mechanisms or government intervention. Yet, if these irreplaceable resources are permanently degraded, the harm to future generations could be significant.

Box 1-1

Malthus, Limits to Growth, and Sustainable Development

The concern over sustainable development is not new, but has roots that extend back at least to the eighteenth-century economist and philosopher Thomas R. Malthus. Theorizing that temporary improvements in human living standards would trigger population surges, Malthus predicted that human population growth would outpace technological growth and resource availability, leading to shortages of agricultural land and food and causing chronic setbacks in human living conditions. Malthus' theories were rekindled during the early 1970s in a report under the title *The Limits to Growth* (Meadows et al. 1974). This prominent report concluded that before the end of the next century, humans would have exhausted the fixed supply of natural resources on which industrial society depends, which would lead to severe food shortages, excessive pollution, and other serious consequences (Meadows et al. 1972; Meadows et al. 1994).

Critics of the Malthusian and *Limits to Growth* theories, including many contemporary economists, have questioned the basic premises upon which they rest. In particular, they contend that assumptions about a finite set of resources and fixed rates of resource consumption do not take into account the continual feedback and incentives that people receive as these resources are used, causing them to adjust their consumption patterns and to develop substitute resources and technologies. These observers tend to be more optimistic about the prospects for a self-sustaining system in which responses to pricing signals and other feedback—achieved through markets or public demand for government intervention—prevent population surges, extreme environmental damage, and resource exhaustion.[1]

As discussed in this report, one of the factors that distinguishes the present debate over sustainable development from earlier debate over growth limits is the concern over human-caused effects on

[1]See, for instance, Kahn et al. (1976) and Simon and Kahn (1984).

intangible and macroenvironmental resources such as the greenhouse gas balance and climate systems. The perceived danger is that it may prove far more difficult to accommodate changes in these resources than to accommodate changes in the supply of specific materials, fuels, and other natural resources that are more amenable to substitutes. Adding to this concern is the growing recognition that humans cannot anticipate and often do not understand all the current and future functions of the many elements of the natural environment; hence, their overuse or mistreatment may have ramifications that are both costly and unexpected.

Thus, an important aspect of sustainable development is ensuring the long-term habitability of the earth's environment, an aim that is not always reflected in conventional thinking about environmental issues, which often focuses on short-term and site-specific environmental and human health effects (Socolow 1994). For instance, an emphasis on the latter has led to standards for clean air and water using threshold levels of pollutants based largely on direct and acute human health effects. Viewed from the broader perspective of maintaining the earth's habitability, the many scattered and repeated environmental disturbances—such as local air and water pollution—can be seen as cumulative, gradually modifying physical and biological systems in ways that can be permanent. These changes, multiplied over time and space, may jeopardize the long-term health and well-being of humans. It is in this regard that Socolow (1994, 8) observes: "In the present period, human beings are perturbing the planet's natural processes significantly on a global scale. We are overwhelming both regional and global environmental systems: lakes, airsheds, fisheries, forests, the ozone level in the stratosphere, global climate. Our planet has become uncomfortably small."

TRANSPORTATION AND SUSTAINABILITY

As notions of sustainable development have evolved and been applied in recent years they have become associated with a wide array of issues and public policy concerns. Although these applications have often been related in their fundamental emphasis on ensuring a habitable planet, some have focused more on ecological and natural resource needs for achieving this goal, whereas others have stressed the social and economic dimensions of this goal. In the transportation field, a number of conferences, papers, and reports have addressed these issues as part of broad conceptions of "sustainable transportation," "sustainable communities," and "sustainable cities" (Replogle 1991; Roseland 1992; Whitelegg 1993; OECD 1995; Sperling and Shaheen 1995; World Bank 1996; President's Council on Sustainable Development 1996a, 1996b). Numerous subject matters have been covered in these activities, such as the role of transportation in ensuring future availability of petroleum and other energy supplies, curbing urban air pollution and traffic congestion, providing access to jobs and services for the low-income and elderly population, and creating more inviting and prosperous central cities.

To illustrate that array of issues encompassed, a recent report by the World Bank (1996, 4–6) defines sustainable transportation as embodying three main components:

- The economic and financial component, which includes issues of adequacy of transportation infrastructure funding, organization, and scale;
- The environmental and ecological component, which includes issues of how transportation investments and mode options influence travel and land use patterns and how these in turn influence energy consumption, emissions, air and water quality, and habitats; and
- The social component, which emphasizes adequate access to transportation services by all segments of society.

Maintaining that a goal of sustainable transportation is to ensure progress in each of these areas by making more strategic and deliberate —rather than incremental and ad hoc—transportation investment and regulatory decisions, the World Bank report contends (1996, 29) that "A policy for sustainable transport is one that identifies and implements the win-win policy instruments and explicitly confronts the tradeoffs so that the balance is chosen rather than accidentally arrived at. It is a policy of informed, conscious choices."

KEY ISSUES

No attempt is made in this study to address all the issues and concerns raised by the term "sustainable transportation." Rather, the committee made a deliberate choice, as noted earlier, to focus the study on transportation's contribution to a specific set of long-term environmental problems: those that are prone to being neglected and have consequences that, accumulated over time, threaten serious and irreparable harm to the environment. Given the many human needs predicated on a sound environment, the possibility of a growing transportation sector contributing to lasting environmental changes is troubling. Thus the decision to focus on this subset of environmental risks is less a reflection of their significance relative to other problems and concerns than an acknowledgment of the unique public policy demands and challenges that they present.

Several criteria were used in identifying these unique environmental risks (Box 1-2). Of particular concern—as emphasized in the criteria—is that some disturbances threaten large and irreversible environmental consequences, but the consequences appear so gradually and imperceptibly that preventive steps are seldom taken. The gradual buildup of long-lived carbon dioxide (CO_2) and other greenhouse gases in the atmosphere, which brings a risk of climate changes several years hence, is an obvious example and one to which transportation contributes through its use of petroleum. A more subtle example is the risk to biological diversity and ecosystems caused by changes in soil and water chemistry from air pollution and the disruptions in habitats and natural flows caused by the transportation network.

Not all environmental effects are either chronically neglected or accumulating and intensifying over time. For instance, the noise created by transportation activity in urban areas—from the constant drone of motorized traffic to the recurrent roar of landing jet aircraft near airports—is among the most noticeable as well as objectionable of these effects. Yet traffic noise in urban areas, as evidenced by the many

Box 1-2

Criteria Used to Identify Environmental Issues Examined

The following kinds of questions were asked by the committee in trying to identify environmental disturbances that warrant special consideration as long-term risks to environmental sustainability.

Irreversibility and Lack of Substitutes
Is the environmental disturbance changing natural resources or systems in ways that may be permanent? Changes that are irreversible—for instance, because resource supplies are finite or very slow to replenish—may pose problems for generations needing the resource. In cases where there are few good substitutes for the lost resource, including substitutes created through technological progress, the loss may be especially costly.

Cumulative and Delayed Consequences
Does the disturbance have effects that accumulate over time and space, with consequences that are delayed or only gradually noticeable? Disturbances that are treated as local or site-specific but that are repeated widely over a region or nation can cause collective or cumulative environmental changes that are routinely overlooked even as they intensify over time. Likewise, changes such as CO_2 buildup, which accrue and could have serious consequences that will not become manifest for many years, are prone to being neglected.

Controls and Feedback on Consequences
Are mechanisms in place—either market or nonmarket—to control the disturbance? Resources providing benefits that transcend geographic and generational boundaries tend to be especially difficult to regulate in this manner. The costs involved in misusing the resource, for instance, may not be appreciated by those responsible because they will be incurred in the future, possibly by distant generations. Effects on global resources, ranging from the atmosphere and oceans to migratory bird and fish populations, are especially difficult to manage because of the absence of well-defined property rights (essential for market controls), governmental jurisdiction (essential for nonmarket controls), or advocates for those who must ultimately bear the cost.

efforts to manage it (e.g., highway noise barriers, requirements for noise-abatement equipment on jet aircraft), is a problem that future generations can, if they so choose, manage and mitigate further as priorities change. Other ramifications of traffic noise, however, may have enduring and irreversible effects—for instance, by disturbing and causing changes in the habitat areas exposed—that are more likely to be overlooked and underappreciated.

Table 1-1 gives examples of environmental disturbances from transportation considered for inclusion in this study. For each disturbance, some of the most immediate and evident environmental risks and consequences are given, as well as the longer-term, cumulative, and more enduring ones. In the committee's view, environmental disturbances that have early and noticeable adverse effects are most likely to be treated, reducing the probability that they will be allowed to worsen. On the other hand, disturbances that have few noticeable environmental effects in the near term are more likely to be neglected and are prone to intensifying in the longer term. These disturbances are the focus of this study and are introduced in the following sections.

Risks from Transportation Emissions of Greenhouse Gases

The absence of timely feedback on transportation's environmental consequences is most conspicuous in the case of the long-lived greenhouse gas emissions. Though scientists have reliable evidence that greenhouse gases are building up in the atmosphere and are likely to continue to do so, the full consequences of this buildup may not become evident or well understood for many years. Absent more tangible evidence of the long-term consequences, the ultimate risk from greenhouse gas emissions has proven especially difficult to evaluate and control.[2]

Most emissions of CO_2—the most abundant of the greenhouse gases that are building in the atmosphere—result from the burning of carbon-rich fossil fuels, including petroleum, which is the predominant fuel used in transportation. Transportation's use of petroleum accounts for about 30 percent of the CO_2 emitted in the United States. Although market prices regulate the near- and longer-term supplies of petroleum (see Box 2-1 in Chapter 2), they do not reflect the many environmental

Table 1-1 Examples of Environmental Disturbances from Transportation and Their Short- and Long-Range Effects

Type of Disturbance	Transportation Source	Most Immediate and Evident Environmental Consequences	Known or Potential Long-Term and Cumulative Consequences
Emission of greenhouse and ozone-depleting gases and substances	Vehicle exhaust (from petroleum combustion) and fuel vapor, consisting of CO_2, other carbon compounds, N_2O, aerosols, and other compounds that affect greenhouse gas balance Fuel extraction, refining, and distribution processes Degradation of leaks in and improper servicing and disposal of vehicle air-conditioning systems containing chlorofluorocarbons and hydrochlorofluorocarbons Production of cement and asphalt for pavements and vehicles and their input materials	Few that are tangible and immediately evident, although changes in greenhouse gases and in stratospheric ozone layer are detectable to scientists	Increase in global temperatures and ultraviolet radiation Changes in precipitation and regional climate patterns Rise in sea level Alteration of terrestrial and aquatic communities Change in incidence of extreme weather events Appearance of new disease vectors

Emissions of air pollutants, including NO_x, hydrocarbons, CO, and particulates	Vehicle exhaust and vapor from fuels Fuel extraction, production, and distribution processes and production of vehicles and infrastructure Road surfaces, facility construction and maintenance activities, and cargo loading and unloading (airborne particulates) Hazardous materials releases, cargo and fuel-related fires, and tire fires at disposal sites	Haze (smog) and degraded atmospheric visibility Acute human disease symptoms during episodes of pollution Damage to crops and urban trees Measurable increase in acidity of precipitation and surface deposits	Possible chronic human health effects from repeated exposures Loss or decline in sensitive forest trees and health of forest ecosystem generally from repeated exposure to ozone and acidification, which can occur over large areas Recurrent nutrient (nitrogen) enrichment in coastal ecosystems, altering biological composition and food chain Changes in biological composition of freshwater aquatic ecosystems experiencing increased acidity, which can occur over large geographic areas

(continued on next page)

Table 1-1 (*continued*)

Type of Disturbance	Transportation Source	Most Immediate and Evident Environmental Consequences	Known or Potential Long-Term and Cumulative Consequences
Material runoff into soils and surface waters	Erosion of debris and sediments exposed during construction of roads and other transport infrastructure and sites where construction materials are extracted Rainwater runoff from paved surfaces and roadsides, including maintenance materials (such as deicing agents and pesticides), degraded pavement, and oil, coolant, and other surface deposits	Sedimentation of nearby receiving streams Contaminants in roadside soils and nearby drainage channels and receiving waters Physical evidence of damage to some roadside vegetation	Contamination of groundwater and receiving waters over larger watershed Decline in sensitive aquatic species within larger watersheds or drainage basins

Chronic and acute material releases and spills into soils and water	Large petroleum and chemical releases by tanker vessels, barges, tank cars, pipelines, and tank trucks, and at storage sites Chronic releases from leaking underground fuel storage tanks (e.g., at filling stations), terminals and equipment maintenance sites (e.g., road salt storage piles), vehicle traffic, and improperly handled waste (e.g., lubricant disposal in stormwater drainage, leaching at tire and vehicle disposal sites)	Contamination of exposed soils and water systems Profound injuries to exposed plants and animals Acute human disease symptoms	Permanent or prolonged loss of some species and disruption of food chain in affected areas Possible chronic human health effects among those exposed

(continued on next page)

Table 1-1 (*continued*)

Type of Disturbance	Transportation Source	Most Immediate and Evident Environmental Consequences	Known or Potential Long-Term and Cumulative Consequences
Permanent alteration of physical landscape by infrastructure	Construction of road networks and traffic moved over them, occupation of habitat land, creation of physical barriers across the landscape, new features (e.g., drainage ditches, detention ponds), and modification of or removal of natural features (e.g., canopy opening, cut-in slopes, stream diversion, river crossings, loss of wetland)	Loss or displacement of some wildlife and habitat at or near the site of new facility Increased incidence of road kills Evident changes in hydrology near site (e.g., flood regimes)	Permanent alteration of vital natural flows and processes across broader landscape (e.g., fires, flood regimes, nutrient and seed flows) Decline or loss of species due to habitat fragmentation and barriers to essential movements (feeding, reproduction); decline in some endangered species from repeated road kills or improved access by predators or humans

Noise	Traffic activity on roads at and near airports and terminals	Unacceptability to humans	Decline in sensitive species near corridor due to noise-disrupted feeding and reproduction behaviors
Introduction of exotic species	Vehicles and cargo, including ship ballast water Infrastructure networks and corridors and connections created by infrastructure (e.g., canal links, highway drainage systems, river crossings) Roadside plantings	Proliferation of pests in area, sometimes with large economic costs (e.g., crop damage, decline in important species of fish or game animals)	Changes in food web and composition of ecosystem as exotic species proliferate further, outcompeting and displacing native plants and animals

costs of its use, including the long-range risks associated with CO_2 emissions.

During this century, annual emissions of CO_2 from human activity have risen by a factor of 10. Emissions have grown rapidly in recent years as many developing nations have increased their rate of fossil fuel consumption (Figure 1-1). Long-range projections suggest that worldwide emissions of CO_2 from energy use could be more than twice their current level before the middle of the next century (Figure 1-2). By remaining in the atmosphere for centuries, these emissions threaten to enhance the natural greenhouse effect that influences the earth's temperature, resulting in warming and climate change. Although the spe-

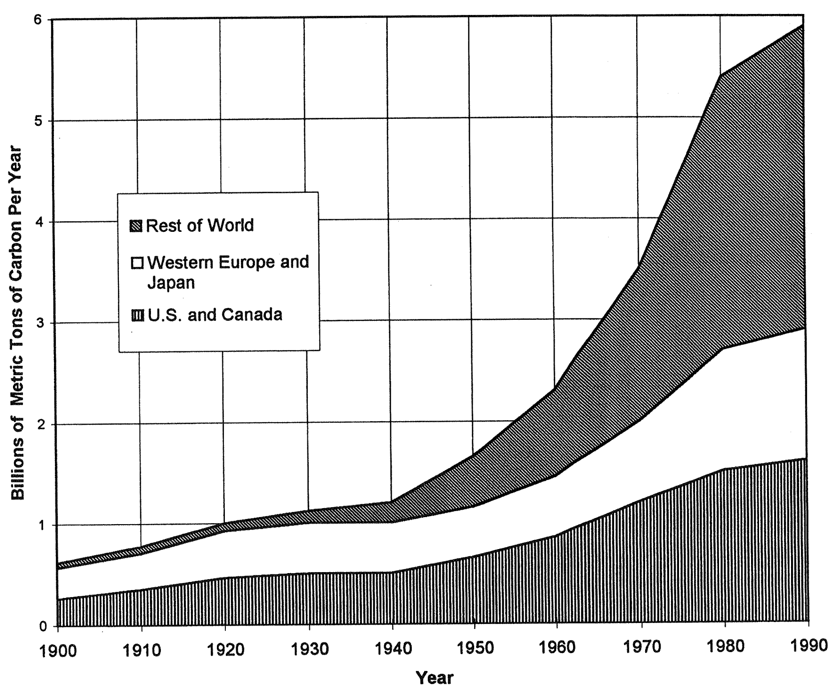

Figure 1-1 Global energy-related emissions of carbon, 1900 to 1990 (IPCC 1996, 13; Keeling 1994; Marland et al. 1994; Grübler and Nakicenovic 1992; Etemad et al. 1990; Fujii 1990; United Nations 1952).

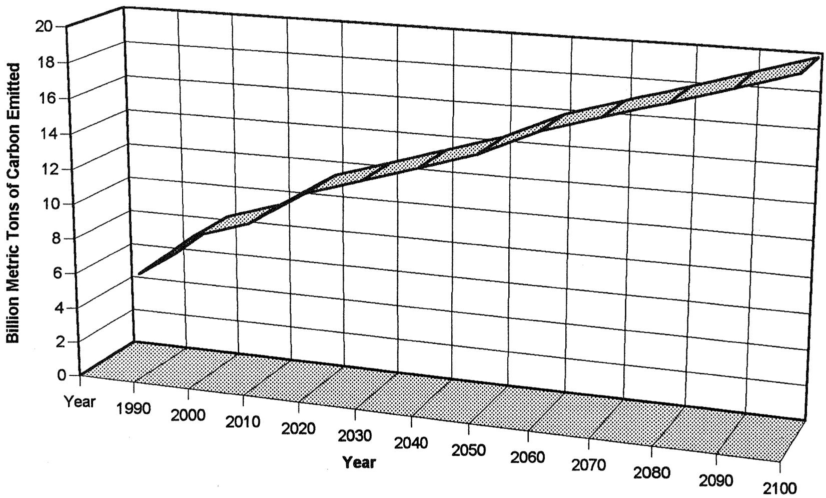

Figure 1-2 Projected global emissions of carbon from energy use, deforestation, and cement production—middle series IPCC scenario IS92a-b (IPCC 1996, 23).

cific mix, timing, and magnitude of climate changes remain uncertain, large and lasting consequences are possible.

Risks to Biological Diversity and Ecosystems from Transportation Emissions and Infrastructure

The gasoline and diesel fuels burned by motor vehicles produce several pollutants that are regulated by the federal Clean Air Act. Motor vehicles (on-road), for instance, account for about one-third of the nitrogen oxides (NO_x) and hydrocarbons and other volatile organic compounds emitted in the United States (EPA 1996). These chemicals combine in the atmosphere to form ground-level (tropospheric) ozone and other compounds that degrade air quality and settle to the surface, where they can alter the chemistry and composition of soils and water. Biological communities and ecosystems hundreds of miles away can be affected. Some of the effects are evident, such as a decline in the population of sensitive trees and measurable changes in the composition and acidity of rainfall. However, many of the collective and long-term ecological effects of these disturbances (from both transportation and nontransportation sources) remain poorly understood. Absent such an understanding, mitigation is difficult, increasing the risk that these effects will intensify over time and cause lasting ecological changes.

As is evident from Table 1-1, road systems and other transportation infrastructure are also sources of numerous environmental disturbances. They range from the acute episodes of air and water pollution caused by hazardous cargo spills to more chronic effects such as the fragmentation of habitats resulting from expanding road networks. Mitigation efforts have often focused on the more obvious and acute effects, for instance, by reducing the adverse consequences on nearby wetlands or streams caused by a project to widen or extend an individual road. Viewing individual roads as components of large and permanent road networks allows consideration of their contribution to other, more far-reaching ecological effects. Such networks, for instance, can impede natural flows that take place across a wide landscape, affecting the movement of wildlife, water, and nutrients over large areas. These longer-term ecological changes can be so subtle or gradual that they are overlooked.

It is primarily with these collective and longer-range consequences in mind—consequences that have tended to receive little attention in research and mitigation—that the many individual environmental disturbances from transportation in Table 1-1 are considered in this study.

STUDY PURPOSE AND ANALYTICAL APPROACH

The purpose of this study is to expand recognition of the environmental issues identified in this chapter and to frame them in a way that fosters more informed examination and debate. The report is intended as a primer, rather than as a comprehensive or technical assessment of the many subjects covered. It does not offer answers or solutions; it aims to inspire inquiry into the issues and options considered.

In reviewing environmental disturbances and transportation's role, the study relies heavily on the assessments and data of scientific and governmental bodies such as the International Panel on Climate

Change, the World Meteorological Organization, the U.S. Environmental Protection Agency, and the U.S. Departments of Energy and Transportation. The report summarizes and synthesizes this information, including areas of certainty and uncertainty. No attempt is made to assess the quality of the science or scientific data.

Likewise, in considering policy options, the report summarizes what is known about their potential influence, but only in a very limited sense. After a review of the literature and with the aid of some simple scenarios, several broad policy courses are examined with respect to their potential effect on CO_2 emissions from transportation. This is far short of examining the full array of environmental, technical, political, social, and economic implications of individual policies; thus, no attempt is made to recommend policy actions. Nevertheless, the committee believes that such assessments, however limited, are essential to forming a clearer picture of the many policy challenges that lie ahead.

Some additional points about the study that are made in the Preface warrant repeating. First, time constraints made it difficult to give equal attention to all modes of transportation. The committee therefore elected to focus on motor vehicle transportation because it accounts for the largest share of transportation energy consumption, emissions, and activity. Second, the committee limited its considerations of future transportation developments to about a 50-year time horizon. This limitation appeared prudent given the historical pace of innovation and change in transportation technology and demand. Finally, environmental issues are treated individually, without much attention to their possible direct or indirect effects on other environmental issues—for instance, how urban air pollution and traffic noise may contribute to the migration of people from central cities, which in turn may influence greenhouse gas emissions by generating additional demand for roads, motor vehicle travel, and petroleum usage. As these environmental problems and their effects are better understood individually, integrated and dynamic evaluations may become more feasible.

ORGANIZATION OF REPORT

In Chapter 2, as background to examining the environmental risks just mentioned, historical trends in U.S. motor vehicle travel and petroleum use are reviewed. Plausible future trends are projected to provide a general sense of the related environmental challenges from growth in motor vehicle travel that may lie ahead. The focus of Chapters 3 and 4 is on these environmental challenges. Considered in Chapter 3 is the role of transportation in greenhouse gas buildup and the risk of climate change. In Chapter 4 the risks from transportation to biological diversity and ecosystems are considered. Research and policy options for lessening the risks are examined in each instance. In Chapter 5 the key findings and points from this discussion are summarized and suggestions for research to better understand and begin reducing these long-term environmental risks are offered.

NOTES

1. This figure includes all public roads and bridges under the jurisdiction of federal (all agencies), state (including toll authorities), and local (county and municipal) authorities, including Interstate freeways, toll highways, other major and minor arteries, residential streets, roads in parklands and reservations, and federal forestlands. Not included are the many private roads (e.g., on logging land, ranches, industrial sites), driveways, parking facilities, and other off-road (public and private) facilities over which motor vehicles operate.
2. The risk to earth's stratospheric ozone shield from emissions of certain man-made chemicals has some of the same characteristics as the greenhouse gas risk. Depletion of ozone in the high altitudes of the stratosphere, though observable to scientists, is not apparent to the public, and the most serious consequences of this disturbance may not become evident for many years. A major difference, however, is that the human activities that threaten the ozone shield, such as the use of halocarbons for motor vehicle air-conditioning systems, are not nearly as pervasive, and therefore difficult to control, as those that produce CO_2 and several other greenhouse gases. This difference has enabled international controls on ozone-depleting chemicals that appear to be working.

REFERENCES

ABBREVIATIONS

EPA	Environmental Protection Agency
IPCC	Intergovernmental Panel on Climate Change
OECD	Organization for Economic Cooperation and Development

TRB Transportation Research Board
WCED World Commission on Environment and Development

EPA. 1996. *National Air Quality and Emission Trends Report 1995.* Report EPA 454/R-96-005. Office of Air Quality Planning and Standards, Research Triangle Park, N.C.

Etemad, B., J. Luciani, P. Bairoch, and J.C. Toutain. 1990. *World Energy Production 1880–1985.* Librarie Droz, Geneva, Switzerland, 272 pp.

Fujii, Y. 1990. An Assessment of the Responsibility for the Increase in the CO_2 Concentration and Intergenerational Carbon Accounts. Report WP-90-55. IIASA, Laxenburg, Austria, 31 pp.

Grübler, A., and N. Nakicenovic. 1992. *International Burden Sharing in Greenhouse Gas Reduction.* Environmental Working Paper 55. World Bank Environment Department, Washington, D.C.

Hitchcock, D. 1991. *Sustainable Transportation.* Center for Global Studies, Houston Advanced Research Center, Houston, Tex., 4 pp.

IPCC. 1996. *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report. Cambridge University Press, Cambridge, England, 572 pp.

Kahn, H., et al. 1976. *The Next 200 Years: A Scenario for America and the World.* Morrow, New York.

Keeling, C.D. 1994. Global Historical CO_2 Emissions. In *Trends '93: A Compendium of Data on Global Change.* Report ORNL/CDIAC, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., pp. 501–504.

Lay, M.G. 1992. *The Ways of the World: A History of the World's Roads and of the Vehicles That Used Them.* Rutgers University Press, New Brunswick, N.J., 401 pp.

Marland, G., R.J. Andres, and T.A. Baden. 1994. Global, Regional, National, CO_2 Emissions 1950–1991. In *Trends '93: A Compendium of Data on Global Change.* Report ORNL/CDIAC, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., pp. 505–581.

Meadows, D., et al. 1974. *The Limits to Growth.* Universe Books, New York.

Meadows, D., et al. 1972. *Dynamics of Growth in a Finite World.* Wright-Allen Press, Cambridge, Mass.

National Research Council. 1991. *Rethinking the Urban Ozone Problem in Urban and Regional Air Pollution.* Commission on Geoscience, Environment, and Resources. National Academy Press, Washington, D.C., 500 pp.

OECD. 1995. *Urban Travel and Sustainable Development.* European Conference of Ministers of Transport, Paris, France, 238 pp.

President's Council on Sustainable Development. 1996a. *Energy and Transportation Task Force Report.* Sept.

President's Council on Sustainable Development. 1996b. *Sustainable America: A New Consensus for Prosperity, Opportunity, and a Healthy Environment for the Future.*

Replogle, M. 1991. Sustainability: A Vital Concept for Transportation Planning and Development. *Journal for Advanced Transportation,* Vol. 25, No. 1, pp. 3–17.

Roseland, M. 1992. *Toward Sustainable Communities: A Resource Book for Municipal and Local Governments.* National Round Table on the Environment and the Economy, Ottawa, Ontario, Canada, 340 pp.

Simon, J., and H. Kahn. 1984. *The Resourceful Earth: A Response to Global 2000.* Blackwell, New York.

Socolow, R. 1994. Six Perspectives from Industrial Ecology. In *Industrial Ecology and Global Change* (R. Socolow, C. Andrews, F. Berkhout, and V. Thomas, eds.), Cambridge University Press, Cambridge, England.

Sperling, D., and S.A. Shaheen (eds.). 1995. *Transportation and Energy: Strategies for a Sustainable Transportation System.* American Council for an Energy-Efficient Economy, Washington, D.C., and Berkeley, Calif.; Institute for Transportation Studies, University of California, Davis, 305 pp.

United Nations. 1952. *World Energy Supplies in Selected Years: 1929–1950*, New York.

WCED. 1987. *Our Common Future.* Oxford University Press, Oxford, England.

Whitelegg, J. 1993. *Transport for a Sustainable Future: The Case of Europe.* Belhaven Press, London, 202 pp.

World Bank. 1996. *Sustainable Transport: Priorities for Policy Reform.* The World Bank, Washington, D.C.

2

Trends and Outlook in Motor Vehicle Transportation

Transportation has played a major, even legendary, role in shaping the United States, influencing the location of economic activity, the form and size of cities, and the style and pace of life in the nation. Its central role in shaping development, however, is not unique to this country. The mobility and access provided by transportation have been instrumental to economic and social development worldwide and throughout history. Transportation systems foster economic growth by facilitating trade, permitting access to resources, and enabling greater economies of scale and specialization. They also expand cultural and social connections, increase employment and educational opportunities, and offer more options for where to live.

What is perhaps most exceptional about the U.S. transportation system is the unmatched scale and the extent to which one mode of travel, the motor vehicle, has become so integrated into the daily lives and activities of Americans, influencing where and how people reside, work, shop, and socialize. Americans drive their cars about one hour each day; both as drivers and as passengers, they travel by car more than 14,000 miles (22,400 km) each year (BTS 1996, 7–9; FHWA 1995, 31). Trucks are nearly as pervasive, having become the major means of delivering finished goods and moving raw materials in many segments of the economy.[1]

Together, expenditures on cars, buses, and trucks account for nearly 10 percent of the gross domestic product (GDP), by far the largest source of investment and expenditures in the broader transportation sector. These vehicles consume three-fourths of the gasoline and diesel fuel supplied to the transportation sector, accounting for more than half of the national petroleum demand (Davis 1995, 2–7; BTS 1996, 35–40). Each year, public roads in the United States cost nearly $100 billion to build, repair, operate, and maintain. This system of public roads enables access by people and goods to most other modes of transport, reaching into even the most remote and sparsely populated areas of the country.

Because of the ubiquity and vital role of the motor vehicle within the transportation sector, the emphasis of this chapter is on providing insight into forces contributing to trends in motor vehicle travel and how these trends might unfold in the years ahead. The trends that emerge will have an important bearing on transportation's environmental effects and on the actions that may be warranted to manage them.

The chapter begins with a detailed review of how several demographic, economic, and social developments and public policies and programs since World War II have exerted powerful influences on trends in motor vehicle travel and petroleum use in the United States. These influences range from the emergence of the baby boom generation and the influx of women into the workforce to the proliferation of freeways. Understanding these influences, and how they are changing and being replaced by others over time, is important to anticipating trends in motor vehicle travel and fuel use and related environmental challenges that may lie ahead.

Following this background discussion, long-range projections of trends in motor vehicle travel and petroleum use are developed on the basis of forecasts by the Census Bureau and U.S. Departments of Transportation (DOT) and Energy (DOE). These plausible, albeit rudimentary, projections are described in more detail in Appendix A and referred to again later in the report when various policy options for controlling transportation's long-term environmental effects are reviewed.

Reviewed briefly in the third section are developments taking place in motor vehicle transportation worldwide. An understanding of past trends in U.S. motor vehicle travel can help illuminate the potential paths of other countries that are beginning to experience demographic and economic changes spurring demand for motor vehicles. In many respects, the rapid motorization occurring in many other regions of the world resembles trends in the United States earlier in the century.

KEY INFLUENCES ON PAST AND RECENT U.S. TRENDS

In the more than 50 years since the end of World War II, the United States has experienced extraordinary growth in motor vehicle travel. During this period, the U.S. population has increased by about 75 percent, growing an average of about 1.2 percent per year (Figure 2-1). At the same time, annual travel by the fleet has grown an average of nearly 4 percent per year, doubling about every 20 years and increasing a total of fivefold. Meanwhile, the amount of petroleum used each year by the vehicle fleet has more than tripled.

A number of factors have influenced this extraordinary growth in vehicle use and petroleum consumption. Although it is not possible to review all of these influences here, several warrant attention. Most notably, the economic prosperity that followed World War II and the subsequent influx of baby boomers and of women into the workforce and the driver population had dramatic and lasting effects on the sharp rate of growth in motor vehicle use. The postwar shift in population to the suburbs and the advent of a national freeway system were also important factors spurring growth. Tempering the upward trend in motor vehicle travel, and having an even greater effect in slowing the rate of growth in petroleum consumption, were the oil supply shocks beginning in the mid-1970s.

Many of the trends and influences discussed in this section began long before 1950, some dating from before the turn of the century. For instance, streetcar patronage and private investment in transit began to

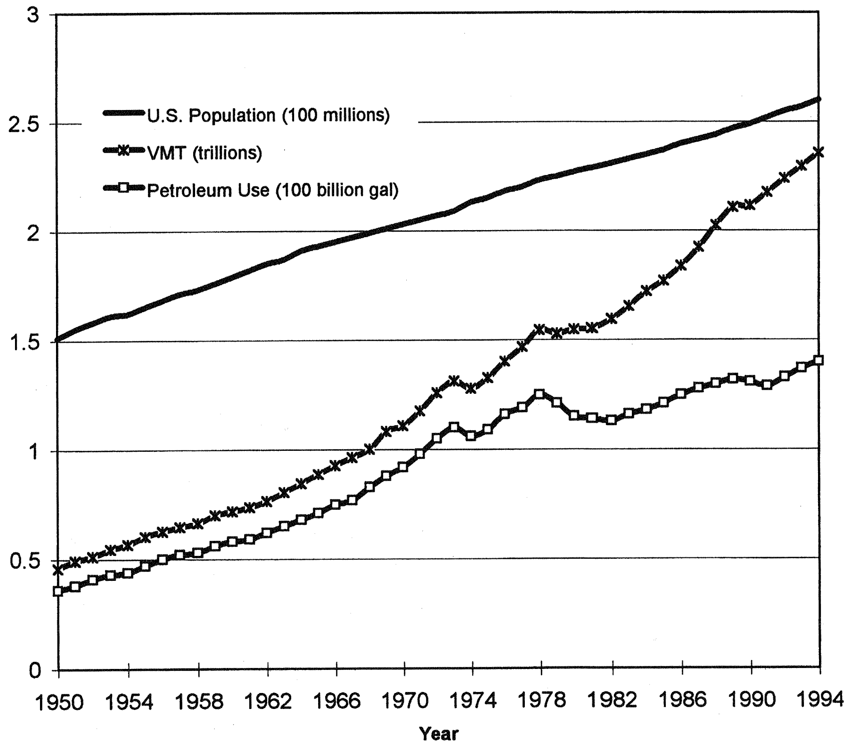

Figure 2-1 Trends in U.S. motor vehicle travel, petroleum motor fuel use, and population, 1950 to 1994 (FHWA 1985, Table VM-201a; FHWA 1986–1994, Table VM-1; Bureau of the Census 1995, Table 2). Note: 1 mile = 1.6 kilometers; 1 gallon = 3.8 liters.

decline in many urban areas during the 1920s, when motorized buses emerged along with inexpensive, mass-produced automobiles such as the Ford Model T (Jones 1985; Pushkarev et al. 1982). In 1910, there was 1 registered car for every 44 households in the United States; by 1930, there were nearly as many registered cars as households (Lay 1992, Table 6.1). Likewise, the tolled turnpikes and federal parkways built during the 1920s and 1930s made up the nation's first class of high-speed motorways; two decades earlier—on the eve of World War I—only 5 percent of the nation's roadways was even paved. Arguably, the changes and trends that have occurred since these revolutionary earlier developments have been relatively modest.

Postwar Prosperity

The economic prosperity and affluence that followed the end of the Great Depression and World War II led to a consumer revolution that not only spurred more motor vehicle travel, but also was itself fostered by the mobility that motor vehicles provided many Americans. Rising incomes and affluence enabled more people to buy and operate motor vehicles and caused them to attach a higher value to time, making the speed and convenience of motorized travel increasingly valuable.

The United States experienced vibrant economic growth following World War II. From 1950 to 1980, the GDP grew at an annual pace of more than 3 percent (Figure 2-2). During the same 30 years, motor vehicle registrations grew nearly 4 percent per year, causing the number of vehicles in the fleet to increase threefold (Figure 2-2). Whereas in 1950 there were not quite 7 motor vehicles for every 10 licensed drivers, by 1980 this ratio had surpassed 1 to 1 (Figure 2-3). On both a per-driver and a per-capita basis, vehicle travel nearly tripled during the period (Figure 2-4).

Growing prosperity not only spawned more vehicle use for passenger travel, it also fostered growth in the trucking industry. As rising incomes enabled more people to afford consumer goods, more demand for trucking followed. Increasing freight demand, coupled with the advent of a national network of freeways and more liberalized truck size and weight allowances, led to rapid growth in truck travel starting in the 1950s. By virtually all measures, trucking activity grew phenomenally, especially among long-haul freight trucks. Between 1965 and 1980, the number of heavy-duty tractor-trailers in the national fleet nearly doubled, and their total travel (per year) grew nearly twice as fast as passenger car travel, which itself was experiencing dynamic growth (FHWA 1985, Table VM-201a).

There is evidence that some of these trends have stabilized over the past several years and that growth in the motor vehicle fleet may be less correlated with growth in the GDP. Since 1980, the annual rate of growth in the motor vehicle fleet has slowed considerably. Whereas

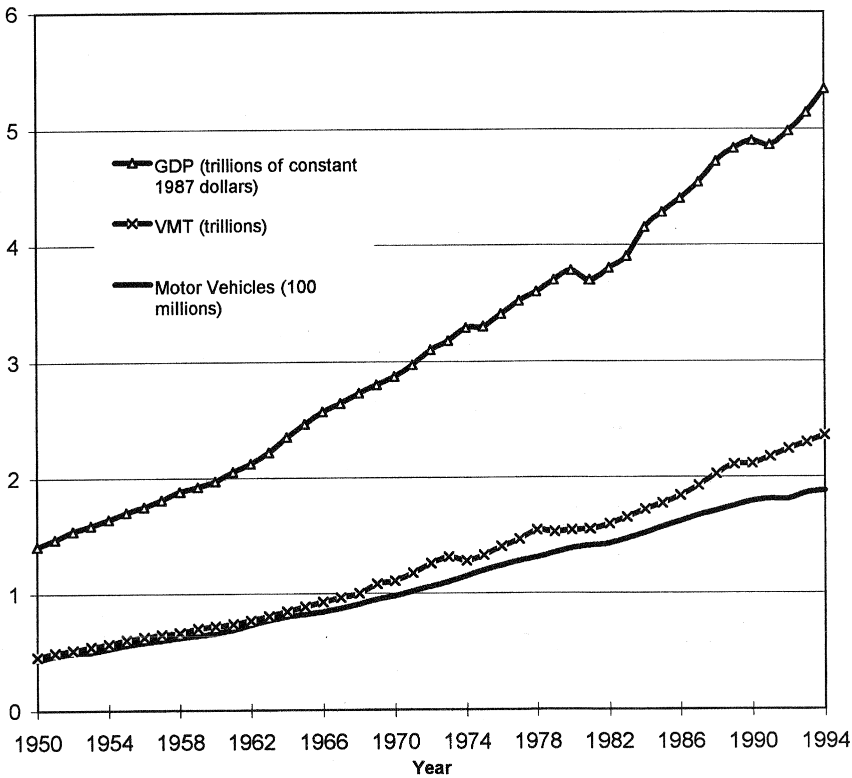

Figure 2-2 Trends in U.S. GDP, VMT, and motor vehicle fleet size, 1950 to 1994 (FHWA 1985, Table VM-201a; FHWA 1986–1994, Table VM-1; Bureau of the Census 1995, Table 699). Note: 1 mile = 1.6 kilometers.

from 1950 to 1980 the fleet grew at about the same rate as the GDP, it has grown only two-thirds as fast since then (Figure 2-2). The slowdown in fleet expansion, however, has not translated into a comparable slowdown in travel by motor vehicles. During the past decade, annual motor vehicle travel has increased nearly 30 percent. Americans are apparently driving their vehicles farther and more often than they did in the past.

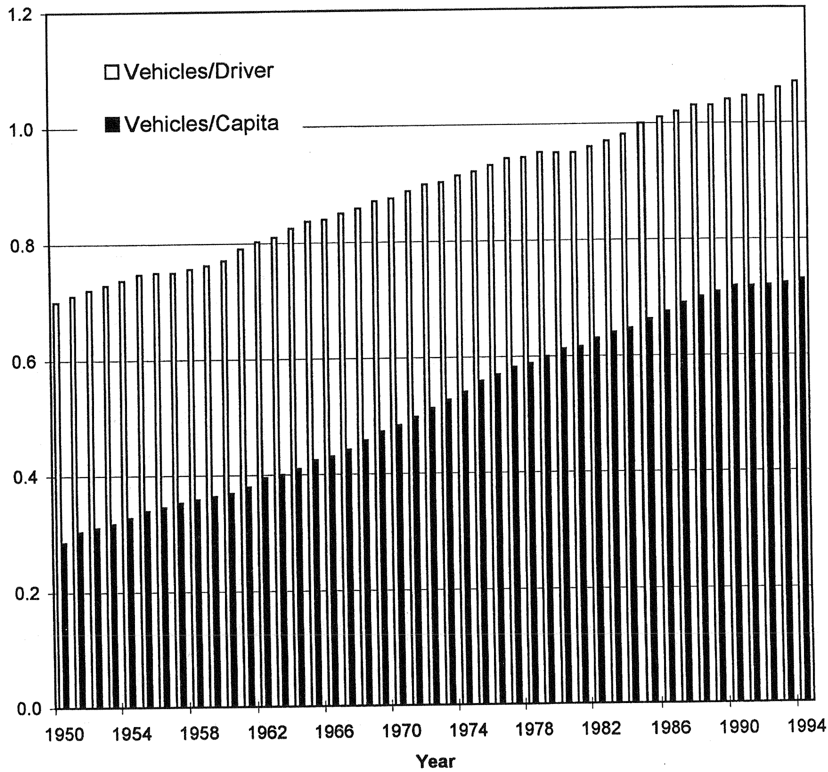

Figure 2-3 Motor vehicles per capita and per driver in the United States, 1950 to 1994 (FHWA 1950–1995, Tables VM-1 and DL-1). Note: Data include large trucks and other commercial vehicles.

Increase in Population, Workforce, and Women Drivers

Upon closer examination of the demographic and social changes in the United States during the past five decades, it is difficult not to appreciate the profound effect of the large baby boom cohort on vehicle ownership rates, the driver population, and a number of other factors influencing motor vehicle travel. Between 1950 and 1965, the U.S. population grew at an annual rate of 1.6 percent (Bureau of the Census 1960–1995, Tables 2 and 16). Virtually all of this growth was the result of sharply higher birth rates, as the number of children grew by 20 million and accounted for nearly half the gain in population.

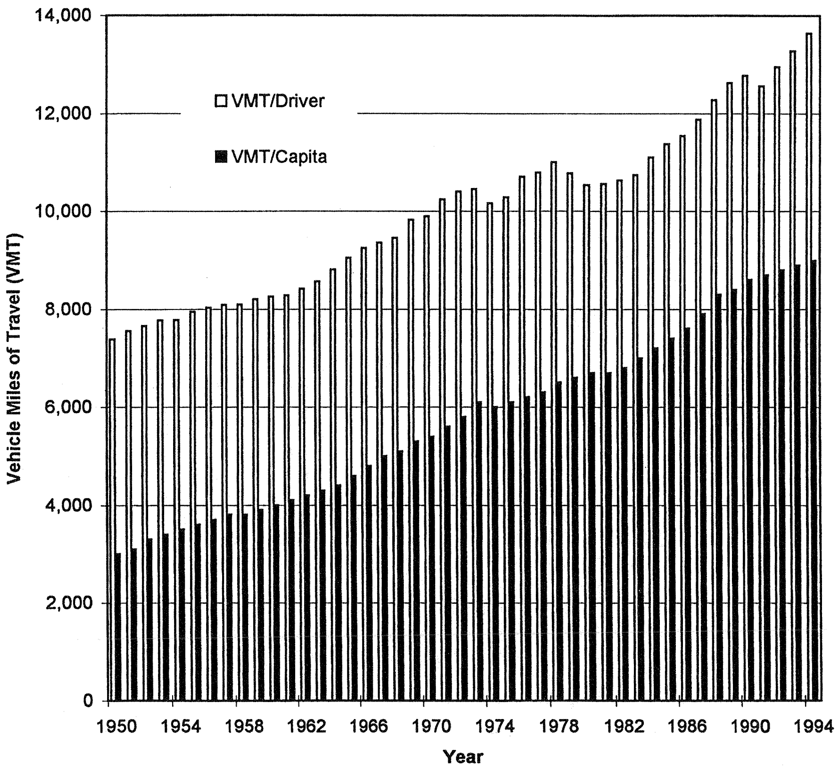

Figure 2-4 Motor vehicle travel per capita and per driver in the United States, 1950 to 1994 (FHWA 1985, Table VM-201a and DL-201a; FHWA 1986–1994, Tables VM-1 and DL-1). Note: Data include travel by trucks and other commercial vehicles. 1 mile = 1.6 kilometers.

As this large cohort started reaching adulthood and driving age during the 1960s and 1970s, it had an abrupt and broad influence on many factors shaping travel trends and patterns. During the mid-1960s, the leading edge of the baby boom cohort began entering the workforce, swelling the number of new drivers. During the next 20 years (1965 to 1985), the adult population grew at an annual rate of 1.8 percent, nearly twice as fast as the general population (Bureau of the Census, 1960–1995, Tables 2 and 16). As a consequence, the adult population grew from 64 percent of the total U.S. population in 1965 to nearly 75 percent when the last of the baby boom generation was reaching adulthood in 1980 (Bureau of the Census, 1960–1995, Table 16).

More adults led to more drivers. The number of licensed drivers nearly doubled from 1960 to 1980, growing by nearly 60 million (FHWA 1985, Table GL-220; FHWA 1986–1994, Table DL-1A). The growing number of adults also led to a sharp rise in the number of workers and households, both of which are associated with more driving. Between 1965 and 1985, the U.S. labor force grew at an annual pace of 2.1 percent, nearly twice the rate of growth from 1950 to 1965 (Bureau of the Census 1995, Table 628). Meanwhile, the number of households grew almost three times as fast as the general population (Bureau of the Census 1995, Table 65).

An equally important and related trend that emerged in the 1960s—and escalated during the 1970s—was the movement of women into the labor force. In 1965 only 39 percent of women over 16 years of age were employed outside the home; by 1985, this figure had risen to more than 55 percent (Bureau of the Census 1995, Table 636). Participation in the labor force resulted in more driving by women. Thirty years ago, only 55 percent of adult women were licensed to drive; by 1985, nearly 80 percent were, including more than 90 percent of women under age 50 (FHWA 1985, Table DL-220). The number of female drivers grew by 35 million between 1965 and 1985, compared with an increase of only 23 million male drivers (FHWA 1985, Table DL-220). Occurring together, this surge of maturing baby boomers and women workers led to tremendous growth in licensed drivers during the 1960s and 1970s.

Although the wave of new drivers was a chief source of growth in motor vehicle ownership and travel 20 to 30 years ago, its influence has since been surpassed by that of other factors. More recently, a major force behind the growth in motor vehicle travel has been the continued escalation in the amount of travel per driver. Contributing to this development has been the movement of baby boomers into middle age, traditionally the most travel-intensive period of life. Findings from DOT's 1990 Nationwide Personal Transportation Survey show that motorists aged 30 to 49 drive 25 to 30 percent more than motorists aged 50 to 64 and about 10 percent more than motorists under age 30 (Figure 2-5). During the 1980s, the aging of the large baby boom cohort led to a marked rise in the number of drivers at these peak driving ages. In

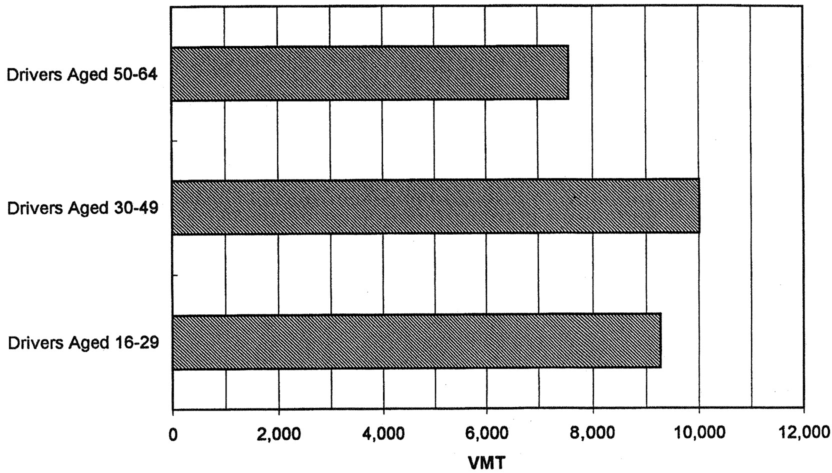

Figure 2-5 Average vehicle miles traveled by driver age group in 1990 (DOT 1994, Table 5.1). Note: Data are for personal travel only. Travel by large trucks and other commercial vehicles is excluded. 1 mile = 1.6 kilometers.

1983—when about half of baby boomers were still in their twenties—drivers aged 30 to 49 accounted for 38 percent of all drivers and 42 percent of all motor vehicle travel (DOT 1993, 3–18; DOT 1994, 5–5). Only 7 years later, when most baby boomers had reached age 30, the share of drivers aged 30 to 49 had grown to 42 percent and their share of total motor vehicle travel had risen to nearly 50 percent.

The Census Bureau forecasts continued growth in those aged 30 to 49 during the first decade of the next century, but with declining numbers thereafter (Bureau of the Census 1995, Tables 17 and 24). As discussed later, the expected drop-off in this travel-intensive population and the attendant growth in the elderly population, who tend to drive relatively less, are likely to affect motor vehicle travel trends and patterns.

Rapid Suburbanization and Dispersed Urban Development

In the years since World War II, metropolitan areas in the United States have expanded swiftly in both population and land area. Urban areas—defined by the Census Bureau as having population densities exceeding 1,000 people per square mile (625 people per km^2)—now contain nearly 80 percent of the nation's population, compared with only 55 percent in 1950 (Pisarski 1996, 18). Most of this urban growth has occurred in the suburbs of older northeastern and midwestern cities and in the sprawling, lower-density cities now common in the South and the West. The share of the nation's metropolitan population living in higher-density central cities fell dramatically between 1950 and 1980, from 60 to 42 percent (Pisarski 1996, 18). This drop occurred because from 1950 through the 1980s the population of the nation's central cities grew at an annual pace of 1 percent, whereas the number of people living in the surrounding suburbs grew by more than 3 percent per year (Pisarski 1996, 18). As a result of the expanding suburbs and trend toward low-density urban development, the share of U.S. land area (in the contiguous states) encompassed within metropolitan areas has nearly tripled since 1950, growing from 7 to nearly 20 percent (Bureau of the Census 1995, Table 40).

Although motor vehicles are sometimes cited as the cause of population dispersion, there are many earlier examples of lower-density suburbs forming after the introduction of time-saving transportation technologies. For instance, suburbs of New York City emerged in the early 1800s after the introduction of ferry service between Brooklyn and Manhattan; the subsequent introduction of trams and trolley lines led to further population dispersion along these lines (Rybczynski 1995; Pushkarev et al. 1982, 5). A similar pattern occurred in many other cities; for example, the Los Angeles community of Beverly Hills started in the early 1900s from a subdivision created near transit tracks along Santa Monica Boulevard (Lay 1992, 307). It seems that rather than creating the demand for low-density suburban living, automobiles have provided a revolutionary means of satisfying this demand by increasing the amount of land accessible to development. Home ownership programs, telecommunications advances, increasing affluence, changes in family structure, and numerous other factors have also undoubtedly contributed to this change in settlement patterns.

Irrespective of impetus and cause, the trend toward suburbanization has clearly contributed to still more motor vehicle travel in the United States. Residents of suburban communities drive more often and over longer distances than do residents of center cities. According to DOT's 1990 Nationwide Personal Transportation Survey, suburban households—which represent about 40 percent of all households in the United States—accounted for a disproportionate 47 percent of all motor vehicle travel (Figure 2-6). In comparison, households in center cities, which constitute 37 percent of all U.S. households, accounted for only 29 percent of all motor vehicle travel (Figure 2-6).[2]

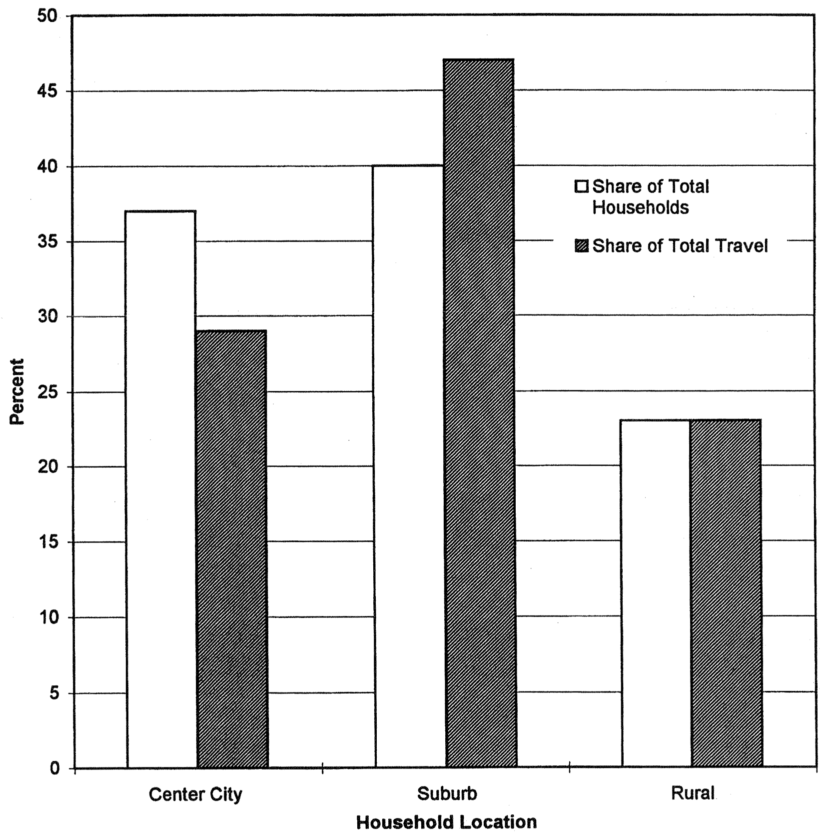

Figure 2-6 Distribution of U.S. households and motor vehicle travel by city, suburban, and rural location in 1990 (DOT 1994, Table 5.6). Note: Data are for personal travel only. Travel by large trucks and other commercial vehicles is excluded.

The difference in motor vehicle travel between households in center city and suburban settings is partly because suburban households have, on average, higher incomes and more cars than households in center cities, where a larger proportion of the population uses mass transit and has irregular access to motor vehicles. Another important reason for the city-suburb difference is that distances between homes, employment, shopping, and recreation areas tend to be greater in the more sparsely settled suburbs than in city centers. Hence, not only do suburban households average 10 percent more vehicle trips per day than households of center cities (4.6 versus 4.2), but also their average trip is about 25 percent longer (DOT 1994, 5–17).

Although still much more rapid than growth in center-city and rural populations, suburban population growth slowed from its peak annual rate of 2.9 percent in the 1950s and 1960s to an annual pace of 1.6 percent during the 1980s (Pisarski 1996, 18). In particular, suburban growth in northeastern and midwestern metropolitan areas has slowed substantially over the past three decades because many of these older urban areas have experienced weak (or negative) population growth and a large share of the middle-income city residents long ago migrated to the surrounding suburbs. Most population growth since the 1970s has been in the cities and suburbs of the South and the West (Bureau of the Census 1995, Tables 30, 42, and 44).

Further shifts in U.S. population to the lower-density and less-transit-oriented areas of the South and the West may add to the growth in motor vehicle travel, though by how much is unclear. In terms of effect on aggregate travel, the relatively recent shifts in population to low-density western and southern cities do not represent as dramatic a change in settlement patterns as the transformation that occurred following World War II, when millions of Americans moved from high-density center cities to their lower-density suburbs. Indeed, most of the population growth in the United States since the middle of the century has been in metropolitan areas with moderate densities of 1,000 to 4,000 people per square mile (625 to 2,500 people per km^2), irrespective of geographic region.[3] DOT's 1990 Nationwide Personal Transportation Survey indicated that people living in areas at the lower end of this density range had travel patterns that were quite similar to those of people living in areas with higher population densities (TRB 1995, 194–197; Dunphy and Fisher 1996).

The already high share of the population living in suburbs and low-density cities implies that further decentralization will not have the same stimulative effect on travel trends as it did in years past. Likewise, because most people now live and work in lower-density cities and suburbs—a changed pattern that is now several decades old—efforts to discourage further movement away from the higher-density cities will have only limited effects on travel trends nationally.

Freeway Building Boom

Undoubtedly an important factor in the trend toward lower-density metropolitan development in the United States and in the escalation of motor vehicle travel generally was the advent of a modern national freeway network in less than three decades. In 1956, when the Interstate highway program began in earnest, the nation had only about 10,000 miles (16,000 kilometers) of divided multilane highway, of which less than 15 percent consisted of full-access-control, freeway-type mileage[4] (FHWA 1985, Tables SM-211 and HM-265). Less than 20 years later, more than 70,000 miles (110,000 kilometers) of divided highway crisscrossed the country, more than half consisting of full-access-control freeways (FHWA 1994, Table HM-65).

The emergence of such an expansive network of high-speed and high-capacity freeways has had far-reaching consequences for travel patterns, affecting travel both within and between population centers. The newly built freeways most certainly contributed to fast growth in long-haul trucking as the Interstate system greatly increased travel convenience and speeds between many areas of the country that were previously linked by two-lane roads. Average travel speeds on main rural routes, the trunk corridors for most long-haul trucking, increased from 47 miles per hour (75 km/hr) in 1950 to 60 miles per hour (96 km/hr) in 1970 (by which time many main rural roads had been upgraded to freeways) (FHWA 1985, Table VS-201).

The construction of freeways within and around metropolitan areas has also transformed intrametropolitan travel patterns. The time savings provided by the new concentric and radial freeways enabled commercial and residential development in areas located farther from city centers and away from traditional transit and rail lines. Although the trend toward suburbanization and lower-density development was already under way before construction of the Interstate system, the new freeways undoubtedly hastened this transformation. Whereas in 1950 only 40 percent of motor vehicle travel occurred in urban areas, by 1970 the proportion was more than 60 percent, and more than one-third of this travel was on Interstate highways and other major arteries (FHWA 1985, Tables VM-201 and VM-201a).

During the past two decades, the freeway construction boom ended in the United States. The amount of freeway-quality highway has grown by approximately 3,000 miles (4,800 kilometers) or 5 percent since 1985 (FHWA 1985, Tables SM-211 and HM-265; FHWA 1994, Table HM-65). This compares with an increase of more than 12,000 miles (19,200 kilometers) between 1975 and 1985 (FHWA 1975, Table HM-65). Although in 1965—the peak period of Interstate highway construction—more than 70 percent of all state highway expenditures was on capital outlays, such outlays accounted for only 45 percent of those expenditures in 1994 (FHWA 1965; FHWA 1994). Most capital spending today is on renovation, rehabilitation, and widening (lane additions) of existing routes rather than on new route construction. Although this trend does not indicate that the freeway system is becoming less important, it does suggest that freeway building, and road building in general, may have a less influential role in spurring future travel activity than in the recent past.

Perhaps the next major development in the highway program—one that could affect future highway travel as fundamentally as did the Interstate highway program in the 1960s—is the development and deployment of automated highway and vehicle technologies, often referred to as intelligent transportation systems. As envisioned by some, these systems, consisting of traveler information, traffic management, and automated vehicle control systems, may greatly enhance the operational efficiency of the road network, enabling higher traffic volumes with less congestion. FHWA has a large research effort under way to explore and develop these emerging technologies and concepts. At this early stage, however, it is difficult to do more than speculate on how these systems will affect motor vehicle travel patterns and trends.

Aftermath of Oil Supply Shocks

As might be expected, growth travel by the motor vehicle fleet has traditionally exerted the strongest influence on petroleum fuel usage. This relationship, however, weakened during the 1970s and 1980s, largely as a result of gains in motor vehicle fuel economy. Had fuel economy not risen so sharply, motorists might be using considerably more petroleum today given the fast pace of growth in motor vehicle travel (absent other changes). Since the mid-1970s, vehicle travel has risen by 75 percent; petroleum consumption, on the other hand, has grown a third as fast (see Figure 2-1).

The gains made in fuel economy starting in the mid-1970s were driven in large part by the higher petroleum prices that followed the disruptions in foreign oil supplies during the period. At the beginning of the 1970s, the U.S. motor vehicle fleet differed very little in fuel-use characteristics from the fleet that had been on the road 10 to 20 years earlier. From the 1950s through the mid-1970s, successive generations of new motor vehicles barely changed in weight, engine size, and other characteristics that influence fuel economy.[5] As a consequence, average fuel economy of the fleet remained relatively flat (Figure 2-7). In response to sharply higher fuel prices, however, consumers began to demand smaller and more fuel-efficient vehicles, and automobile manufacturers began to offer them.[6] The higher fuel prices also prompted government measures, such as the Corporate Average Fuel Economy (CAFE) program (discussed further in Chapter 3), to induce manufacturers to develop and sell less-fuel-intensive vehicles. In only 5 years, from 1975 to 1980, the average weight of new passenger cars declined by nearly 800 pounds (360 kg), or about 22 percent (Davis 1995, 3–24). During this period, the average fuel economy of the fleet started a rapid ascent (Figure 2-7).

Figure 2-8 shows the trend in retail gasoline prices (including tax) in the United States from 1970 to 1993. As the trend line indicates, oil supply disruptions and resultant price increases lasted for relatively brief periods during the mid-1970s and early 1980s, but their consequences for the fuel economy of the fleet were pronounced and longer lasting.[7] The more fuel-efficient vehicles purchased in the 1970s and early 1980s remained in the fleet for many years after fuel prices started to decline

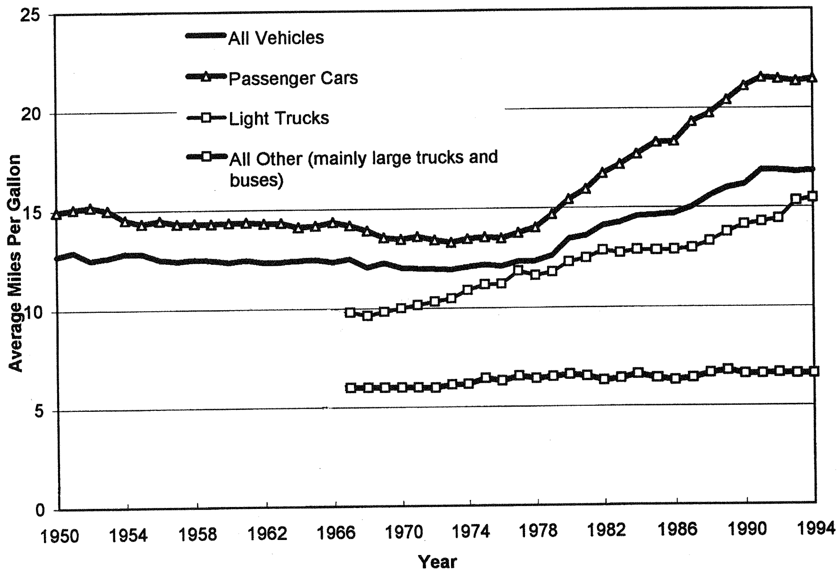

Figure 2-7 Average fuel economy of the fleet, 1950 to 1994 (FHWA 1985, Table VM-201a; FHWA 1986–1994, Table VM-1). Note: Data on trucks before 1966 are incomplete. Average fleet fuel economy is derived by dividing travel by fuel use. 1 mile = 1.6 kilometers; 1 gallon = 3.8 liters.

in the mid-1980s. Meanwhile, federal fuel-economy standards started having a broader effect on the fleet. From 1980 to 1990, average fuel economy of the passenger car fleet grew by one-third, averaging gains of about 3 percent per year (see Figure 2-7).[8] The gains stemmed in part from the continued retirement of older fuel-intensive vehicles, but also from the introduction of new vehicles built with lighter materials, more aerodynamic designs, and smaller but more powerful engines (relative to earlier small-engine designs) (National Research Council 1992). The introduction of performance-enhancing technologies such as fuel-injection systems also increased fuel economy as an important side benefit (National Research Council 1992).

Today, the results of the oil price shocks of the 1970s and 1980s appear to be fading. Although some efforts continue to promote alternative fuels and petroleum conservation (such as the CAFE program),

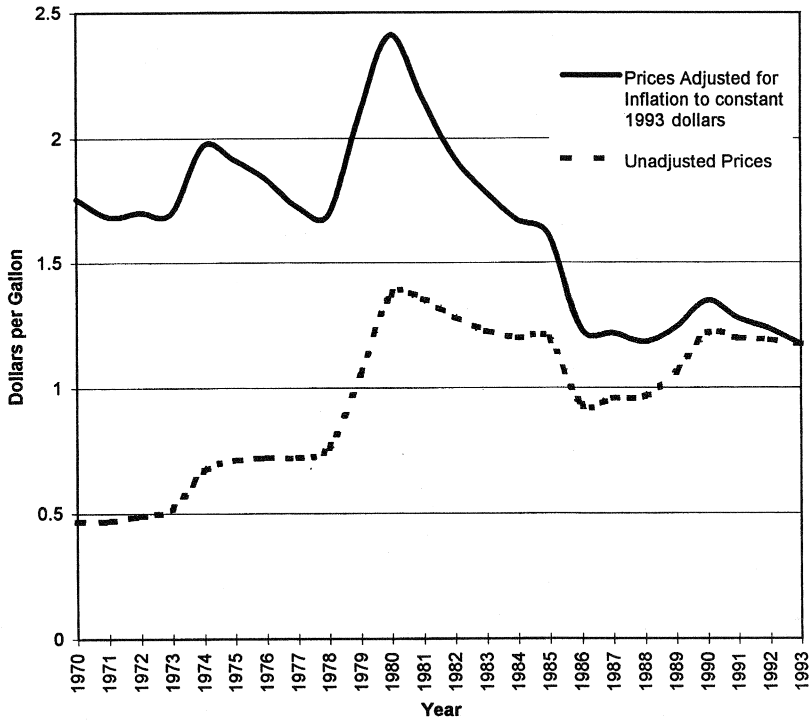

Figure 2-8 Retail prices for regular-grade gasoline in the United States (including taxes), 1970 to 1993 (AAMA 1994, 84; Bureau of the Census, 1975–1984). Note: Prices adjusted to 1993 dollars using consumer price index. 1 gallon = 3.8 liters.

the impetus for such programs is more often to improve air quality. Public interest in fuel conservation has waned over the past 15 to 20 years. Since the late 1980s, the average fuel economy of the fleet has changed very little (Figure 2-7). Whereas more fuel-saving technologies have been introduced in the fleet, the average size (mass) of new vehicles has gradually risen as motorists have purchased more fuel-intensive sport-utility vehicles, pickup trucks, and minivans (Davis 1995, 3–4, 3–24). Late-model versions of these larger vehicles, often classified as light trucks, use less fuel per distance traveled than do most passenger cars built in the 1960s and 1970s (Figure 2-7). Nevertheless, as the light-truck share of motor vehicle travel and petroleum use has increased in recent years (Figures 2-9 and 2-10), the upward trend in fleet fuel economy has begun to stabilize. Growth in large-truck travel has also dampened gains in overall fleet fuel economy (Figures 2-7 and 2-9). Nevertheless, since 1975 the average fuel economy of the fleet (total travel divided by total petroleum fuel use) has increased an average of 1.7 percent per year [from 12 to 16.9 miles per gallon (5 km/l to 7 km/l) between 1975 and 1995].

Whether the recent slowdown in fuel economy gains will persist or future events will spur further interest in fuel efficiency is difficult to predict. Long-term trends in fleet fuel economy—whether stable, higher, or lower—will depend on various factors, such as the retail price of gasoline and diesel fuel, changes in federal fuel-economy standards, shifts in consumer preferences among vehicle sizes and types, and the advent of more effective and less expensive fuel-saving technologies. It is difficult to foretell how these interrelated variables will change and combine over time to affect trends in fleet fuel economy.

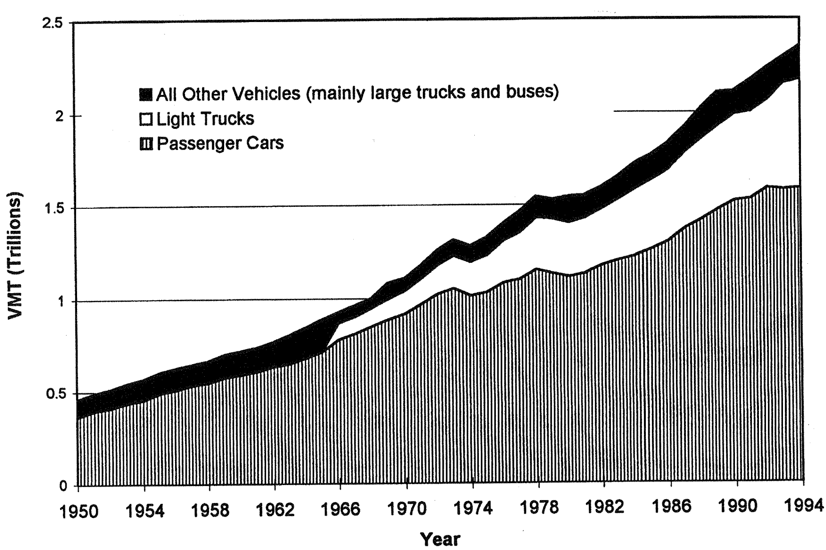

Figure 2-9 Travel by U.S. motor vehicle fleet, 1950 to 1994 (FHWA 1985, Table VM-201a; FHWA 1986–1994, Table VM-1). Note: Before 1966, travel by light trucks is included in "all other vehicles" category. 1 mile = 1.6 kilometers.

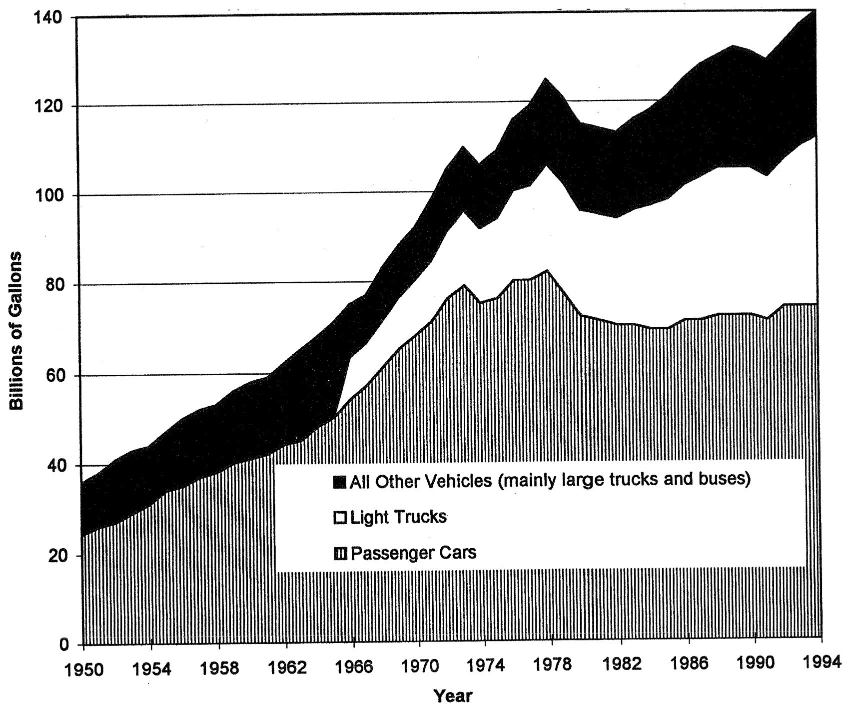

Figure 2-10 Petroleum fuel use by U.S. motor vehicles, 1950 to 1994 (FHWA 1985, Table VM-201a; FHWA, 1986–1994, Table VM-1). Note: Before 1966, data on light trucks are included in "all other vehicles" category. 1 gallon = 3.8 liters.

LONG-TERM U.S. OUTLOOK

In projecting long-term trends in motor vehicle travel and fuel use, it is tempting to look at past developments and infer that similar changes will occur in the future. Yet several of the key demographic and social factors contributing to the dynamic growth in motor vehicle travel in past decades appear to be subsiding, whereas the market factors (i.e., large petroleum price increases) that stirred public interest in motor vehicle fuel economy during the 1970s and 1980s have all but disappeared from public consciousness.

The influx of women drivers, perhaps the most significant force shaping post-World War II trends in motor vehicle travel, has ended. During the past decade, women have come close to having the same driver licensing rates as men. Today, the ratio of female to male drivers is nearly 1 to 1; about 95 percent of women between the ages of 20 and 50 are now licensed (as compared with 93 percent of men) (FHWA 1994; Bureau of the Census 1995). Whereas women, on average, still drive less than men, the effect on total travel from more driving by women is not likely to approach that of the 1960s and 1970s, when new female drivers outnumbered new male drivers by 4 to 1.

Likewise, the influx of baby boomers into the workforce and the driver population ended long ago. During the past decade, growth in the U.S. adult population has slowed to 1 percent per year, about half the rate of the 1960s and 1970s. As a consequence, many of the demographic and social trends spurring motor vehicle travel during the 1960s and 1970s have begun to taper off. For example, the labor force and number of households have grown at an annual rate of 1.4 percent since 1985, which is significantly lower than the rate of growth during the previous two decades (Bureau of the Census 1995). Partly as a result of these factors, growth in the driver population has slowed to about 1 percent per year, well below the levels of 20 to 30 years ago (FHWA 1985, 1994).

Changes in the driver population—dependent mainly on changes in the adult population—can be forecast with a reasonable degree of certainty, at least for the next two decades. In its middle-series population forecasts, the Census Bureau predicts stable growth in the adult population during the next 25 years. For the period 1995 to 2020, the rate of growth is expected to remain steady at about 1.1 percent per year and then drop to under 1 percent for the second quarter of the century. During this time frame, the adult portion of the general population is expected to remain steady at about 75 percent. By comparison, the adult population grew by about 2 percent per year from 1960 to 1980.

Recall, moreover, that middle-aged adults drive the most (see Figure 2-5), and that the share of the population in middle age is expected to fall during the next 20 years. By 2005 approximately 30 percent of the general population will be aged 35 to 54. By 2025, people in this age category are projected to account for only 23 percent of the population, and their numbers will have declined in absolute terms by about 5 percent from 20 years earlier (Bureau of the Census 1995, Table 24). By 2020, when all baby boomers will have reached age 55, the share of the population aged 55 to 74 will reach nearly 25 percent (compared with 15 percent today). Motorists over the age of 55 have traditionally driven less than younger motorists, averaging about 25 to 30 percent less travel than 30- to 54-year-olds (Figure 2-5). It is likely that this gap will narrow in the years ahead, as retiring baby boomers—who are more likely to reside in suburbs and operate vehicles than current retirees—boost the amount of driving by the elderly. Nevertheless, it is still reasonable to expect older baby boomers to drive less in 20 years than they do today, thereby having a diminishing effect on aggregate motor vehicle travel over time.

These emerging demographic trends suggest a slower increase in motor vehicle travel over the next several decades. Other demographic, technical, and economic forces—some of which are unforeseeable today—could counter these trends. For instance, faster economic growth could lead to more freight movements and truck traffic, as well as more personal travel. Continued advances in information and telecommunications technology, which reduce geographic barriers, may dramatically alter travel patterns by changing how and where people work, live, shop, and socialize (see Chapter 3). The development and deployment of intelligent transportation systems—as discussed in Chapter 3—could also have profound effects on motor vehicle use patterns and travel behavior in general.

The Census Bureau, in its middle-series projections, forecasts growth in U.S. population on the order of 0.75 percent per year during the next 25 to 50 years, up by about 100 million people by 2040. This is considerably lower than the 1.2 percent average annual increase in population from 1950 to 1995, which caused the population to grow by 110 million. Of course, future levels of immigration and birthrates are unknown. Largely because of the difficulty of predicting these influential variables far into the future, the Census Bureau's population forecasts are less confident beyond a 20-year time frame. In addition to its middle-series projections (0.75 percent annual growth), it has developed less probable low- and high-series projections. The former projects population barely growing (0.2 percent annual growth), up less than 10 percent between now and 2050; the latter (assuming 1.4 percent annual growth) projects a doubling of population during the same period. Either of these alternative scenarios would lead to significantly different trends in motor vehicle travel during the next 50 years.

Another uncertainty is how growth in U.S. motor vehicle travel will be affected by changes in the supply and price of petroleum. As a finite resource, supplies of petroleum are declining with consumption; but the rate of decline remains unclear (see Box 2-1). In this century so far, continued advances in petroleum discovery and extraction technologies have led to growing reserves of recoverable oil (American Petroleum Institute 1995, 13–33). When oil supplies will indeed begin to tighten, causing fuel prices to rise in response, will depend in large part on technological developments and trends in petroleum demand worldwide.

Acknowledging these uncertainties, DOT and DOE have developed forecasts of U.S. motor vehicle travel and petroleum use trends 10 to 20 years ahead. Their most recent forecasts are discussed in the following paragraphs. Unfortunately, few projections have gone beyond a one- or two-decade time frame. Hence, simple extrapolations of these trends are made here. Although these extrapolations are highly uncertain, they are sufficiently plausible to provide a general sense of how trends could unfold over the course of several decades. The basis for these projections is reviewed briefly here and described in more detail in Appendix A.

DOT projects growth in vehicle travel averaging 2.37 percent annually for 1996 to 2013 (DOT 1995, 162–168). This projection assumes continued growth in per-capita travel by the still middle-aged baby boom cohort. In comparison, DOE projects a 1.5 percent average annual increase in motor vehicle travel from 1995 to 2015 (DOE 1996a, 24; DOE 1996b, 11). DOE's projections anticipate less driving by an aging U.S. population. They also assume petroleum prices rising 0.9 percent per year and increased use of alternative fuels.[9] DOE projects growth in motor vehicle petroleum use on the order of 0.6 percent per year from 1995 to 2015 (DOE 1996a, 24).

After reviewing these forecasts, the committee believes DOE's expectation of 1.5 percent annual growth in vehicle travel is sufficiently reflective of emerging demographic trends for use in developing a plausible baseline for longer-range (40- to 50-year) trends in motor vehicle travel.[10] Where the committee chooses to take a different approach than

Box 2-1

Concern over Petroleum Scarcity and Its Relevance for Sustainable Development

Being finite in supply, petroleum provides an example of a natural resource that, through the actions of humans, is subject to increased scarcity and possibly depletion. Though new sources and reserves of petroleum are frequently discovered and new technologies for its extraction are developed, the actual supplies are limited, and therefore current use reduces the amount of petroleum available for future consumption.

What differentiates petroleum and other marketable natural resources (such as minerals) from nonmarketable resources (that is, those that are not subject to clear property rights) is that the value of its future use is directly accounted for in current decisions. This is because the current market price of petroleum embodies the lost value—or opportunity cost—of sales forgone in the future (Nicholson 1983, 526). Hence, as petroleum reserves dwindle and supply is constrained, the price of gasoline and other petroleum products will gradually rise to reflect the increased scarcity. This of course assumes that there is continued demand for petroleum. As petroleum prices rise, demand is likely to weaken as other energy sources become more price competitive and of greater interest to both energy users and suppliers.

As a practical matter, it is unlikely that natural stocks of petroleum will one day be exhausted, simply because alternative energy sources are likely to become price competitive long before petroleum supplies dwindle to the point of depletion. The scarcity of petroleum in itself is therefore not a sustainability concern addressed here, since substitute energy sources will almost certainly emerge. Rather, as discussed later in this report, of greater relevance to concern over environmental sustainability is whether the energy sources that eventually do replace petroleum have more positive environmental qualities (such as limited effect on greenhouse gas buildup). Public policies to ensure such an outcome may be warranted.

DOE is in not projecting changes in other variables such as the price of petroleum fuel, vehicle fuel efficiency, and alternative fuel usage. Whereas these variables will no doubt change over the next several decades, the magnitude and direction of change are unclear. For the purposes of developing a simple baseline trend—one that can be used to consider the influence of subsequent changes in petroleum prices, vehicle fuel efficiency, alternative technologies, and other factors—these variables are held constant. This simple baseline trajectory, which assumes U.S. motor vehicle travel and petroleum use will grow an average of 1.5 percent per year during the first half of the next century, is shown in Figure 2-11. This baseline is referred to again in Chapter 3 and described in more detail in Appendix A.

In presenting a baseline scenario for growth in motor vehicle travel, the committee recognizes that any projection spanning several decades is highly speculative and subject to criticism. A 1.5 percent annual increase in motor vehicle travel over 40 years, for instance, implies a 35 percent increase in vehicle travel per capita assuming U.S. population grows at a rate of only 0.75 percent per year, as forecast by the Census Bureau. Is such a large increase in per-capita travel reasonable? Since 1950, per-capita VMT has increased threefold, suggesting that this baseline rate of growth may be too low. On the other hand, as discussed earlier, the rapid growth in motor vehicle travel since World War II was influenced by several demographic, social, and economic factors, the magnitude and confluence of which may have been unique. This baseline scenario is offered not as a probable outcome, but as one sufficiently plausible for use as a benchmark against which other scenarios and assumptions can be compared.

MOTOR VEHICLE TRENDS WORLDWIDE

As discussed in this section, much of the world is experiencing growth in motor vehicle transportation that resembles past developments in the United States. As this trend continues, the U.S. share of the world's motor vehicles and petroleum demand gradually declines. At the same time, however, the U.S. remains a world leader in automotive technol-

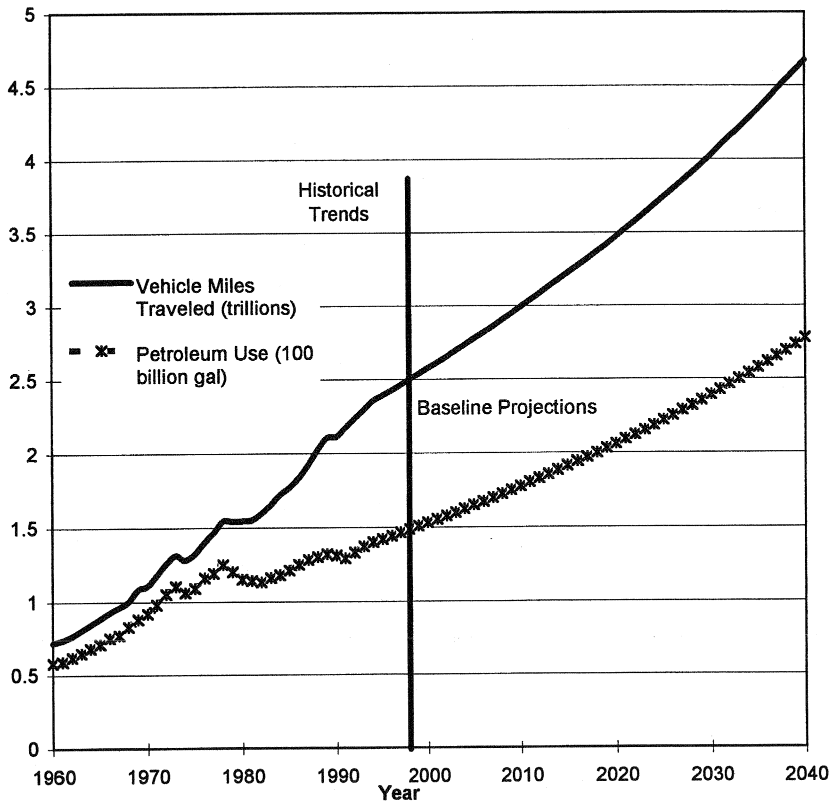

Figure 2-11 Illustrative baseline trend for motor vehicle travel and petroleum use assuming 1.5 percent average annual growth rates. Note: 1 mile = 1.6 kilometers. 1 gallon = 3.8 liters.

ogy, having an expanding influence on the worldwide escalation in motor vehicle use.

Trends in Other Industrialized Nations

Passenger cars and trucks have become the dominant means of personal and freight transportation in all industrialized nations during the past 30 years. Whereas the United States continues to rank first in motor vehicle use for personal travel and freight transportation, many other countries have experienced high rates of growth in motor vehicle use in recent years (Figure 2-12).[11] Though motor vehicle ownership and use remain lower in other industrial nations—explained in part by differences in transportation policies pursued in individual nations over the course of many decades (as discussed in Chapter 3)—the direction of the trends is similar to that in the United States over the past several decades.

Since the 1960s, Japan and the large nations of western Europe experienced average annual increases in vehicle registrations ranging from 5 percent (United Kingdom) to more than 10 percent (Japan) (AAMA

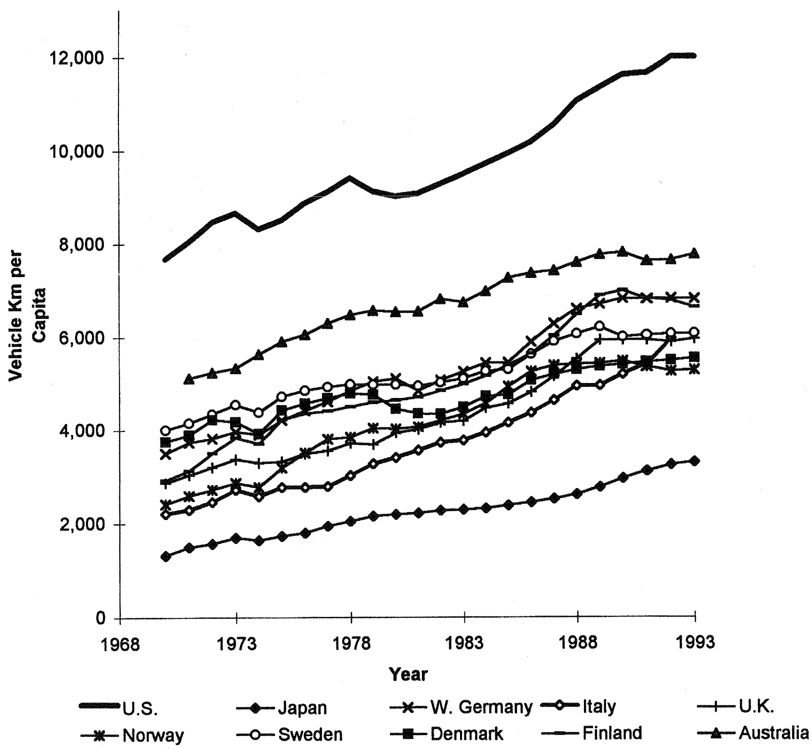

Figure 2-12 Passenger car travel per capita in the United States and selected nations since 1970 (data derived from Schipper 1995). Note: Travel data exclude travel by commercial vehicles. 1 kilometer = 0.6 miles.

1996). This growth was initially spurred by the post-World War II recovery, especially during the 1960s, when western Europe and Japan experienced 100 to 1,000 percent growth in passenger car registrations (Schipper 1995). The United States, by comparison, entered the 1960s with already high levels of vehicle ownership. The motor vehicle fleets of Japan and western Europe have continued to grow at a faster pace than that of the United States. During the 1970s and 1980s, the U.S. fleet grew by 50 percent, whereas the number of motor vehicles more than doubled in western Europe and Japan.

Economic growth and rising incomes in these countries have been important factors in the diffusion of motor vehicles, as shown in Figure 2-13. It is interesting to note that by the late 1980s, the rate of vehicle ownership in western Europe was comparable to that of the United States during the late 1960s (Schipper 1995). At that time, as noted earlier, growth in the U.S. motor vehicle fleet began to subside as the ratio of drivers to vehicles moved closer to 1 to 1.

As motor vehicles have proliferated in other industrial nations, the U.S. share of world petroleum consumption has declined steadily. Whereas U.S. motorists continue to consume the most fuel per capita, the rate of growth in fuel use has been more rapid elsewhere. This is explained in large part by the increase in motor vehicle travel in Europe and Japan. Another important reason, however, has been rising motor vehicle fuel economy in the United States fleet, and relative stability in Europe and Japan. Although the U.S. fleet has the lowest average fuel economy, the gap with other nations has declined since the 1970s.

Figure 2-14 shows the on-road fuel economy of the passenger car fleets in the United States and several other countries. Whereas average fuel economy has risen significantly in the United States over the past two decades, it has changed very little elsewhere. Though passenger cars in Europe have become somewhat more fuel-efficient over time, they have also become larger and more powerful. This fuel-economy gap has narrowed despite the rapid growth in diesel-powered vehicles in Europe. Diesel fuel, which is taxed by many European countries at a lower rate than gasoline, offers more miles per gallon than does gasoline (see Chapter 3). Whereas diesel-powered vehicles account for an insignificant portion of cars sold in the United States, almost half of the new cars sold in France in 1995 were diesel powered, as were 15 to 25

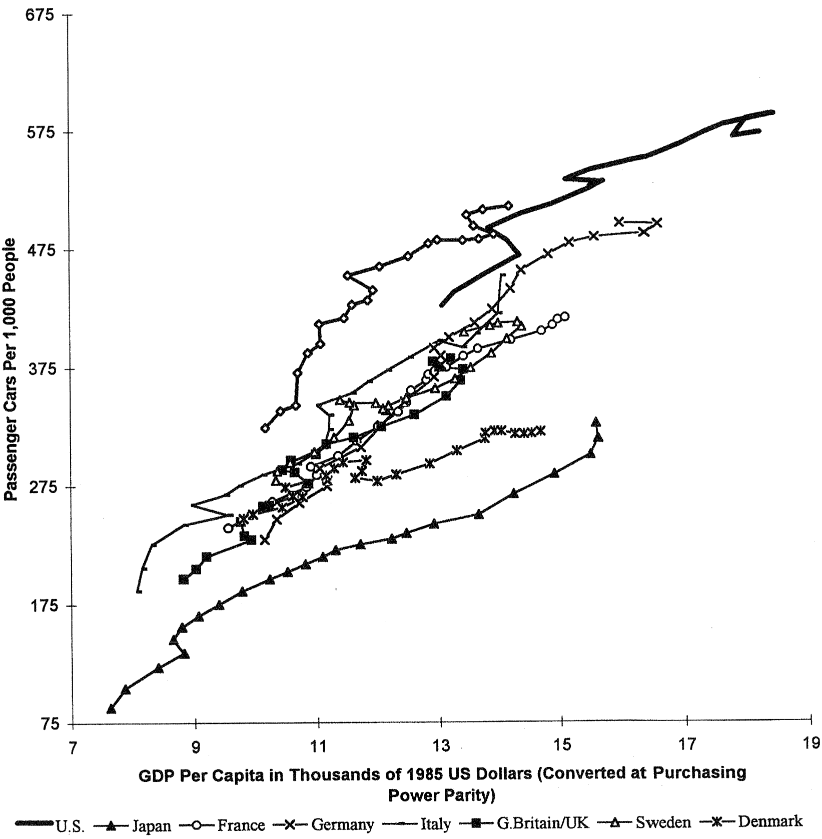

Figure 2-13 Passenger car ownership rates relative to GDP per capita in selected nations, 1972 to 1995 (data derived from Schipper 1995). Note: Each data point represents a year. Light trucks for personal travel are included for the United States.

percent of new cars sold in Great Britain, Italy, and Holland (Schipper 1995; FHWA 1994, Table MF-33E).

Altogether, Americans still consume 35 to 40 percent more motor fuel per capita than Europeans and Japanese. According to international comparisons by Schipper (1995), three factors help explain this lingering gap: (*a*) Americans continue to have much higher rates of motor vehicle ownership, (*b*) they use their vehicles more often (especially more trips per day), and (*c*) the U.S. fleet still consists of many more

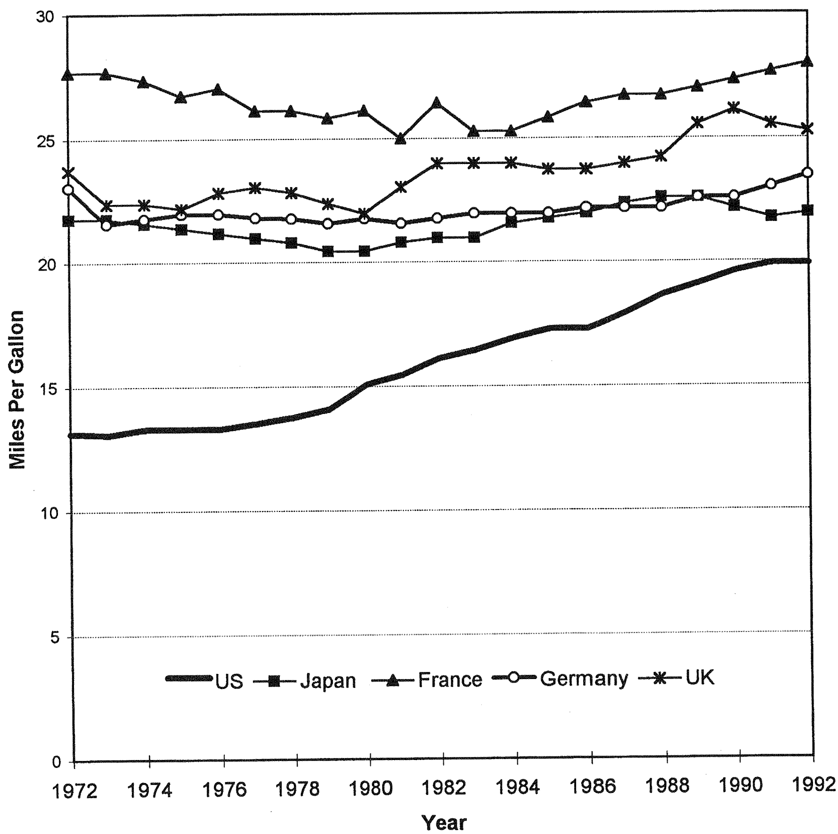

Figure 2-14 Trends in passenger car and light truck fuel economy in the United States and selected countries, 1972 to 1992 (data derived from Schipper 1995, 336–345). Note: Light truck data are relevant mainly for the United States and are combined with passenger car data. 1 mile = 1.6 kilometers.

larger vehicles that have fuel-intensive features such as automatic transmission and air-conditioning. The third factor is less important now than 20 years ago; however, it remains significant and again appears to be increasing in importance. Whereas the U.S. average fuel economy for new vehicles (passenger cars and light trucks) was approaching that of Japan and several European countries (e.g., Sweden, Germany) during the late 1980s, this average has been flat in recent years as Americans have been using more fuel-intensive light trucks, minivans, and sport-utility vehicles for personal travel (Schipper 1995).

World Trends

Worldwide, the number of motor vehicles is growing far faster than population. Since 1960, the number of vehicles registered has risen more than fivefold, tripling the average number of vehicles in operation per capita (Figure 2-15). Most of this growth has occurred as a result of increased vehicle ownership outside the United States. Between 1960 and 1994, the U.S. share of worldwide vehicle registrations declined

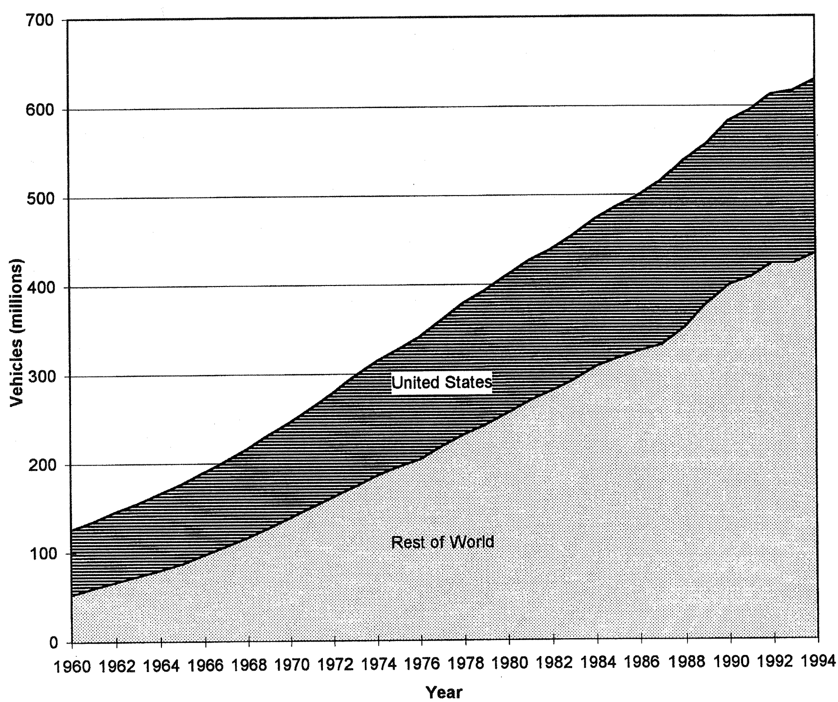

Figure 2-15 Motor vehicle registrations (all types) in the United States and worldwide, 1960 to 1994 (AAMA 1996, 15).

from about 60 to 30 percent (Figure 2-15). Further declines in the U.S. share of the world fleet are expected (Orfeuil 1993).

In recognition of the increased motor vehicle ownership worldwide, DOE, in its *International Energy Outlook 1996*, projects that world petroleum consumption will increase at a rate of 2 percent per year during the next two decades, or by about 45 percent by 2015 (DOE 1996c, 21). Only about one-third of this increase is expected to be derived from present industrialized nations, where petroleum demand is expected to grow by about 0.9 percent per year (on the basis of assumptions about rising vehicle fuel efficiency and higher petroleum prices, as discussed earlier). The rapidly developing nations of Asia and Latin America are projected to account for most of the remainder of this increase.

The U.S. transportation sector currently accounts for about 20 percent of world petroleum use (including petroleum used in nontransportation activities) (DOE 1996c). Because of more rapid growth in petroleum demand elsewhere, this share is expected to decline in the years ahead, even as absolute levels of petroleum use in the United States continue to rise (DOE 1996c). Similar trends are expected in other industrialized nations.

Finally, the U.S. role does not appear to be diminishing in the development and production of transportation vehicles and technologies. U.S.-based vehicle manufacturers and suppliers operate internationally and are industry leaders in the development and application of new vehicle designs, standards, and technologies. About one-fourth of new motor vehicles sold worldwide are manufactured by U.S. companies (AAMA 1996). As motor vehicle markets expand into developing nations, international demand for U.S. automotive products has been rising. Thus, as motor vehicles proliferate worldwide, the influence of the United States transportation sector looms even larger.

SUMMARY AND ASSESSMENT

During the past half-century, the motor vehicle has become integrated into the daily lives of Americans and the national economy. Growth in motor vehicle travel has far surpassed increases in U.S. population. Many factors are responsible, especially increasing affluence, the influx of baby boomers and women as drivers, the growth of the suburbs, and the advent of a national freeway system.

Sharp growth in motor vehicle travel has been accompanied by increased demand for gasoline and diesel fuel. In recent years, increases in fleet fuel economy have lessened the influence of growing motor vehicle use on petroleum demand. Gains in fleet fuel economy, however, have subsided in recent years, suggesting that further growth in motor vehicle travel will yield comparable increases in petroleum use.

By how much motor vehicle travel will grow during the next several decades is unclear, though continued growth is expected. Further understanding of the demographic, economic, and technological factors likely to influence trends in motor vehicle travel is needed to improve forecasts of long-term travel trends and some of the challenges that growth may present. Demographic trends suggest that future growth in motor vehicle travel may be more stable and slower than it was over the preceding four decades, when the nation's motor vehicle travel doubled every 20 years. Yet even a 1.5 percent average annual rate of growth—about half the growth rate since 1950—would cause a doubling in motor vehicle travel by the middle of the next century.

More certain is that the United States will continue to have a large role in international trends in motor vehicle use and technology. Demand for motor vehicles is burgeoning in many of the newly industrializing regions of the world. As a leader in automotive technology, the United States will supply much of this demand. As discussed in more detail in Chapters 3 and 4, such a broadening of U.S. influence—and that of other industrialized nations—may prove important to addressing emerging environmental concerns linked to motor vehicle use and its globalization.

NOTES

1. The terms "motor vehicle" and "vehicle" are used in this chapter and the remainder of the report in reference to all types of vehicles on the road. Included are passenger cars (sometimes referred to as automobiles), light trucks such as vans and pickups, medium- and heavy-duty trucks, and buses. Where the general term "truck" is used, it is in reference to medium- and heavy-duty trucks that are used mainly for freight and services, not in reference to light trucks, used mainly as passenger vehicles. "Fleet" refers to all motor vehicles on the road.

2. Households in rural areas make up 23 percent of households and accounted for 24 percent of motor vehicle travel.
3. The population densities of metropolitan areas in the South and the West now average 2,200 persons per square mile (1,375 people per km^2); in comparison, population densities of northeastern and midwestern metropolitan areas are only slightly higher, averaging 2,400 persons per square mile (1,500 people per km^2) (FHWA 1994; Bureau of the Census 1995, Table 46).
4. Roads that have full-access control have a limited number of exit and entrance ramps as typified best by Interstate highways. Controlled access enables higher speeds with greater safety.
5. The exception was trucks, which became longer and heavier.
6. The impact of fuel prices on the demand for motor fuel and on the demand and supply of fuel-efficient vehicles is discussed in Chapter 3.
7. Another smaller price spike occurred in the early 1990s as a result of the Iraqi invasion of Kuwait and the Persian Gulf War.
8. Unless specified otherwise, average fuel economy refers to total vehicle travel (encompassing all types of vehicles) divided by total gasoline and diesel use as reported by the Federal Highway Administration in its annual and historical *Highway Statistics* reports.
9. The projected 10 percent penetration of alternative fuels is anticipated to be the result of natural supply and demand (spurred by lower production costs and higher fuel prices) and government inducements already in place or planned, such as the state of California's mandate for elevated sales of "zero-emission" vehicles over the next decade (discussed in Chapter 3).
10. This growth rate, for instance, is twice the rate of growth in U.S. population forecast by the Census Bureau for the first half of the next century.
11. International data from Lawrence Berkeley Laboratory cited in *Transportation Energy Data Book* (Davis 1995, Tables 1.8 and 1.9) and Appendix C.

REFERENCES

ABBREVIATIONS

AAMA	American Automobile Manufacturers Association
BTS	Bureau of Transportation Statistics (DOT)
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration (DOT)
TRB	Transportation Research Board

AAMA. 1994. *Facts and Figures 1994*. Washington, D.C.
AAMA. 1996. *World Motor Vehicle Data*. Washington, D.C.
American Petroleum Institute. 1995. *Reinventing Energy: Making the Right Choices*. Washington, D.C.

BTS. 1996. *Transportation Statistics Annual Report 1996: Transportation and the Environment.* U.S. Department of Transportation.

Bureau of the Census. 1960–1995. *Statistical Abstract of the United States.* U.S. Department of Commerce.

Davis, S.C. 1995. *Transportation Energy Data Book: Edition 15.* Report ORNL-6856. Oak Ridge National Laboratory, Oak Ridge, Tenn.; U.S. Department of Energy.

DOE. 1996a. *Annual Energy Outlook 1996: With Projections to 2015.* Report DOE/EIA-0383(96). Energy Information Administration.

DOE. 1996b. *Alternative Transportation Fuels 1994*, Volume 2: *Greenhouse Gas Emissions.* Report DOE/EIA-0585(94)/2. Energy Information Administration.

DOE. 1996c. *International Energy Outlook 1996: With Projections to 2015.* Report DOE/EIA-0484(96). Energy Information Administration.

DOT. 1993. *Nationwide Personal Transportation Survey: Data Book Volume I.* Report FHWA-PL-94-010A.

DOT. 1994. *Nationwide Personal Transportation Survey: Data Book Volume II.* Report FHWA-PL-94-010B.

DOT. 1995. *1995 Status of the Nation's Surface Transportation System: Condition and Performance.* Report to Congress.

Dunphy, R., and K. Fisher. 1996. Transportation, Congestion, and Density: New Insights. In *Transportation Research Record 1552,* TRB, National Research Council, Washington, D.C., pp. 89–96.

FHWA. 1950–1995. *Highway Statistics* (annual). U.S. Department of Transportation.

FHWA. 1975. *Highway Statistics: Summary to 1975.* U.S. Department of Transportation.

FHWA. 1985. *Highway Statistics: Summary to 1985.* U.S. Department of Transportation.

FHWA. 1994. *Our Nation's Highways: Selected Facts and Figures.* U.S. Department of Transportation.

Jones, D.W. 1985. *Urban Transit Policy: An Economic and Political History.* Prentice-Hall, Inc., Englewood Cliffs, N.J., 182 pp.

Lay, M.G. 1992. *The Ways of the World: A History of the World's Roads and of the Vehicles That Used Them.* Rutgers University Press, New Brunswick, N.J., 401 pp.

National Research Council. 1992. *Automotive Fuel Economy: How Far Should We Go?* Commission on Engineering and Technical Systems. National Academy Press, Washington, D.C.

Nicholson, W. 1983. *Intermediate Microeconomics and Its Application,* 3rd ed. Dryden Press, Chicago, Ill.

Orfeuil, J.P. 1993. *Elements pour une Prospective Transport, Energie, Environnement.* Institut National de Recherche sur les Transports et leur Securite, Arceuil, France.

Pisarski, A.E. 1996. *Commuting in America II: The Second National Report on Commuting Patterns and Trends.* Eno Transportation Foundation, Inc., Lansdowne, Va.

Pushkarev, B.S., J.M. Zupan, and R.S. Cumella. 1982. *Urban Rail in America.* Indiana University Press, Bloomington, 289 pp.

Rybczynski, W. 1995. How to Build a Suburb. *Wilson Quarterly,* Summer, pp. 114–126.

Schipper, L. 1995. Determinants of Automobile Use and Energy Consumption in OECD Countries. *Annual Review of Energy and Environment*, Vol. 20, pp. 325–386.

TRB. 1995. *Special Report 245: Expanding Metropolitan Highways: Implications for Air Quality and Energy Use.* National Research Council, Washington, D.C.

3

Carbon Dioxide Buildup and Motor Vehicle Transportation

Reviewed in this chapter are key issues and concerns surrounding the buildup of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere, motor vehicle transportation's role as a source of these gases, and various options and opportunities for reducing this role.

What should be done to control emissions of CO_2 and related greenhouse gases, who should do it, and at what cost are issues now being debated in the United States and the international community. Complicating this debate is uncertainty about the pace and consequences of greenhouse gas buildup and the extent to which emissions will need to be curtailed and over what time frame. The debate includes how and when U.S. transportation should be the subject of serious efforts to control these emissions. If stronger support for curbs on emissions does emerge, it may become necessary to lessen or offset the large amount of CO_2 produced by the U.S. motor vehicle fleet.

The chapter consists of two main sections. The first is an overview of the greenhouse gas concern and transportation's role as a source of CO_2, which is the most significant of the greenhouse gases increasing in the atmosphere. It begins with what scientists have learned about the growth of this gas in the atmosphere, its potential effects on climate, and other possible consequences. Much of this discussion is drawn directly from reports of the United Nations' Intergovernmental Panel on Climate Change (IPCC),[1] the U.S. Department of Energy (DOE), and other scientific and governmental bodies. Next the contribution of U.S. motor vehicles to CO_2 buildup is reviewed.

In the second half of the chapter various policy options and opportunities for reducing this contribution are considered. The options examined range from those that seek to reduce growth in motor vehicle travel and enhance vehicle fuel economy to those aimed at fostering fundamental changes in transportation technology. Many involve complex and controversial issues that cannot be thoroughly examined here, and thus no attempt is made to judge the efficacy, technical feasibility, or political acceptability of individual policy options. Rather, the main purpose of the review is to provide a general sense of the potential for alternative policies to influence CO_2 emissions over different time horizons. To cast this discussion within a broader perspective, the section concludes with a brief review of international efforts to address CO_2 buildup.

The chapter ends with a summary and assessment of areas of uncertainty with regard to several of the policy options considered, particularly the economic, technical, and implementation uncertainties that warrant further evaluation.

CO_2 BUILDUP AND TRANSPORTATION'S ROLE

Greenhouse Effect

The atmosphere behaves as a blanket in retaining and redistributing heat to maintain the earth's mean surface temperature at about 15°C (Helm and Schneider 1990, 214). Certain gases in the atmosphere have an important role in this regard, trapping outgoing heat and reradiating it back to the earth's surface. Without the natural action of the gases, described further in Box 3-1, the earth's mean surface temperature would be about 30°C colder than it is today, too cold to support most existing life forms (Schneider 1993, 13; Houghton 1994, 21). The

Box 3-1

Greenhouse Gases, Radiative Forcing, and Influences on Climate (adapted from IPCC 1996a, 14)

The earth absorbs radiation from the sun. This energy is then redistributed by the atmosphere and oceans before being radiated back into space as infrared energy. On average (for the earth as a whole), incoming solar energy is balanced by outgoing infrared radiation.

Factors that alter the radiation received from the sun or radiated back into space can affect the earth's climate. Such a change in the energy balance is called "radiative forcing." Greenhouse gases cause radiative forcing because they reduce the efficiency with which the earth releases energy into space. The greenhouse effect has operated in the earth's atmosphere for billions of years as a result of naturally occurring carbon dioxide, ozone, methane, nitrous oxide, and other greenhouse gases, especially water vapor. Each gas contributes differently to this effect, depending on the size of its concentration, its radiative properties, and the concentrations of other greenhouse gases already present in the atmosphere. Humans have increased concentrations of all of these gases during the past century, particularly during the past few decades.

Other emissions that alter the earth's radiative balance include aerosols, which are small particles suspended in the atmosphere. Volcanoes are sources of aerosols, particularly those found in the stratosphere. Aerosols in the lower altitudes of the troposphere are emitted mainly by fossil fuel combustion and the burning of biomass (by humans and naturally occurring wildfire). Aerosols can absorb and reflect solar radiation. In addition, changes in aerosol concentrations can alter cloud cover and reflectivity. In most cases tropospheric aerosols produce negative radiative forcing, cooling the earth's surface. They have a much shorter lifetime (days to weeks) than that of most greenhouse gases (decades to centuries), so their concentrations respond much more quickly to changes in emissions.

Any changes in the radiative balance of the earth, including those due to human-induced emissions of greenhouse gases and aerosols,

continued

Box 3-1 *continued*

will tend to alter atmospheric and oceanic temperatures and associated circulation and weather patterns. These changes will be accompanied by alterations in the hydrological cycle, for example, altered cloud distributions or changes in rainfall and evaporation regimes.

At the same time, human-induced changes in climate will be superimposed on a background of natural climatic variations that occur over different space and time scales. Natural climate variability can occur as a result of changes in the radiative forcing of the climate system, for example, as a result of aerosols emitted from volcanic eruptions. Climate variations can also occur without a change in radiative forcing as a result of complex interactions between components of the climate system, such as the atmosphere and the ocean. To distinguish anthropogenic climate changes from natural variations, it is necessary to identify the anthropogenic "signal" against the "background noise" of natural climate variability.

greenhouse gases in the atmosphere are therefore crucial to maintaining the earth's climate patterns and sustaining the natural conditions and systems that depend on them.

Most greenhouse gases in the atmosphere occur naturally. In addition to CO_2, they include methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Water vapor is the most abundant greenhouse gas. Anthropogenic emissions of certain greenhouse gases, however, threaten to expand this natural layer, enhancing greenhouse warming and altering climates and other related systems (IPCC 1996a).

Rising Concentrations of CO_2 and Other Greenhouse Gases

Several greenhouse gases are increasing in the atmosphere as a result of human activities (IPCC 1996a, 3). Atmospheric levels of CO_2 are now nearly 30 percent higher than they were in preindustrial times, methane levels have more than doubled, and N_2O concentrations are about 15 percent higher (Table 3-1). In addition, some new greenhouse gases have been added to the atmosphere; most notably, the manmade chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs).[2]

With the exception of water vapor, CO_2 is the most plentiful and among the most long-lasting of the greenhouse gases accumulating in the atmosphere. About 0.035 percent of the earth's atmosphere by volume consists of CO_2, a concentration governed by natural processes that cycle CO_2 and carbon in and out of the atmosphere, oceans, land, and biosphere. This natural cycle causes CO_2 concentrations to remain largely stable, because CO_2 emitted naturally into the atmosphere is offset by CO_2 absorbed by plants (e.g., through photosynthesis), soils, and oceans. Disrupting this balanced cycle, however, are anthropogenic emissions of CO_2. Because many of the natural processes that remove carbon from the atmosphere (for instance, the absorption of CO_2 into the deep oceans) work on very long time scales, a portion of the CO_2 emitted by human activities is not countered, causing atmospheric con-

Table 3-1 Several Greenhouse Gases Affected by Human Activities (IPCC 1996a, 15)

	CO_2 (Carbon Dioxide)	CH_4 (Methane)	N_2O (Nitrous Oxide)
Preindustrial concentrations	280 ppmv	700 ppbv	275 ppbv
Concentration in 1994	358 ppmv	1720 ppbv	312 ppbv
Rate of concentration change per year[a]	1.5 ppmv (0.4%)	10 ppbv (0.6%)	0.8 ppbv (0.25%)
Atmospheric lifetime (years)[b]	50–200	12	120

Note: ppmv = parts per million by volume; ppbv = parts per billion by volume. Information was not available for CFC-12 and HFC 134a, chemicals used in automotive air conditioners.

[a]The growth rates of CO_2, CH_4 and N_2O are averaged over the decade beginning in 1984.

[b]No single lifetime for CO_2 can be defined because of the different rates of uptake by different sink processes.

centrations to gradually rise over time (Table 3-1).[3] As a result, CO_2 concentrations are growing about 0.4 percent per year, equivalent to about half the CO_2 emitted each year as a result of human activity.

On the basis of data from air bubbles found in ice cores, it has been determined that atmospheric concentrations of CO_2 are currently about 28 percent higher than they were in preindustrial times (Table 3-1). According to the IPCC, if current rates of emissions prevail during the next century, CO_2 concentrations will rise even further, nearly doubling their preindustrial, or natural, level by the end of the 21st century (IPCC 1996a, 3).

Possible Consequences

Most atmospheric scientists and climate experts agree that rising concentrations of CO_2 and other greenhouse gases in the atmosphere will cause average surface temperatures on the earth to rise. The timing and magnitude of this warming and the subsequent effects on climates and other natural systems are more controversial. The IPCC and other scientific groups have estimated that a steady-state increase in CO_2 concentrations, equivalent to a near-doubling of concentrations since preindustrial times, would lead to an increase in the earth's mean surface temperature of between 1° and 3.5°C within a century (IPCC 1996a, 5–6). Most computer-based climate models predict that warming of this magnitude would be accompanied or followed by marked changes in precipitation patterns, new climate patterns within regions, and disruptions in other natural systems and processes (IPCC 1996a, 6).

In its latest publication on climate change science, IPCC concludes that meteorological records and other data over large geographic areas and many decades provide evidence that some system changes are already under way (IPCC 1996a, 4). The panel reports that global mean surface temperatures have increased by between 0.3° and 0.6°C since the late 19th century and that sea levels have risen 10 to 25 cm during this period (IPCC 1996a, 4). Noting that much uncertainty remains about the influence of humans on these observed trends and their longer-term implications, the panel nevertheless concludes that the risk of far-reaching consequences from continued greenhouse gas buildup is real and that the possibility of unexpected, perhaps catastrophic, outcomes cannot be ruled out (IPCC 1996a, 3–7).

Among the theorized or potential effects of climate change are warming of the oceans and melting of ice caps and glaciers, which would cause sea levels to rise, flooding low-lying areas and coastal communities. Alterations in regional temperature and precipitation patterns and changes in the incidence and severity of extreme weather events (such as droughts and monsoons) are other possibilities. These and other consequences could cause shifts in the location and composition of species in aquatic and terrestrial systems, introduce new disease vectors, and change regional patterns of soil fertility and water availability. Some of these vulnerabilities are identified in Box 3-2. Each is a subject of controversy and inquiry.

Motor Vehicle Transportation, Petroleum Use, and CO_2 Emissions

The greenhouse gas CO_2 is emitted by a large and growing number of human activities. The most important and varied source of CO_2 is the combustion of fossil fuels (mainly coal, petroleum, and natural gas) used in transportation, heating, manufacturing, electricity generation, and numerous other applications that are growing throughout the world. Buried deposits of oil, coal, and other fossil fuels are 75 to 95 percent carbon and act as long-term carbon storage bins, or reservoirs. Normally, it would take millions of years for this supply of carbon to be freed from these underground reservoirs to affect atmospheric concentrations of CO_2. The extraction and combustion of fossil fuels, however, alter and greatly accelerate this process. The loss of forestland, particularly in tropical regions where large quantities of CO_2-absorbing vegetation have been removed, has exacerbated this problem.

The data in Table 3-2 indicate the importance of the U.S. motor vehicle fleet as a source of CO_2. One gallon of motor fuel used in the existing motor vehicle fleet (all vehicle types, which average 16.9 miles per gallon) produces an average of 19.5 pounds of CO_2, equivalent to about 1.15 pounds (or more than 520 grams) of CO_2 per mile.[4] In 1995 the U.S. motor vehicle fleet used 143 billion gallons of motor fuel; at a CO_2 emission rate of 19.5 pounds per gallon, this implies emissions of

Box 3-2

Examples of Potential Vulnerabilities to Climate Change (adapted from IPCC 1996b, 4–12)

In its latest assessment of the science of greenhouse gas buildup and its repercussions, the IPCC identifies the following possibilities from a potential rise in the earth's mean surface temperature of 1° to 3.5°C over the next century as predicted by models.

Forests, Rangelands, and Deserts
Changes in global climate patterns would affect the growth and regenerative capacity of forests in many regions, since climate change would occur more rapidly than forest species could grow, reproduce, and reestablish themselves. Altered rainfall in rangelands could shift species composition. Deserts could become more extreme, often hotter and drier.

Cryosphere and Mountain Areas
Between one-half and one-third of the existing mountain glacier mass could disappear in 100 years. Changes in the amount and depth of permafrost could lead to large-scale damage to infrastructure and release of trapped methane gas. Little change in the extent of the Greenland and Antarctic ice sheets would be expected within a 50- to 100-year period. The projected decrease in the extent of mountain glaciers would alter altitudinal distribution of vegetation and other biota.

Lakes, Streams, and Wetlands
Inland aquatic systems would be influenced by climate change through altered water temperatures, flows, and levels. In lakes and streams, warming could have the greatest effect at high latitudes, where biologic activity would increase. At the lower-latitude boundaries of cool- and cold-water range species, the most extinctions may occur.

Oceans and Coasts

Climate change would lead to changes in sea level, increasing it on average. It could also lead to changes in ocean circulation and reductions in sea ice cover. Nutrient availability, biologic productivity, and the functions of marine ecosystems would be affected. A rise in sea level or changes in storms and storm surges could result in erosion of shores and associated habitats, increased salinity of estuaries and freshwater aquifers, altered tidal ranges, changes in sediment and nutrient transport, and coastal flooding regimes.

Hydrology

Climate change would lead to an intensification of the global hydrological cycle and could have major effects on regional water resources. A change in water volume and the distribution of water would affect both ground and surface water supply for in-stream ecosystems, navigation, domestic use, and other purposes.

Agriculture

Changes in crop yields and productivity caused by climate change would vary considerably across regions and among localities, thus changing the patterns of production. Productivity would increase in some areas and decrease in others, such as the tropics and subtropics. Lumber supplies would be affected because of stresses placed on forests.

Fisheries

Globally, marine fishery production would be the same, but species mixes and centers of production would shift, affecting local areas dependent on fishing. High-latitude freshwater production would likely increase.

Disease Vectors

Indirect effects of climate change would include increases in the potential transmission of vector-born infectious diseases, such as malaria, dengue, and yellow fever. A larger share of the world population would live in climates conducive to vector organisms.

Table 3-2 U.S. Carbon Dioxide Emissions from Fossil Energy Consumption by End-Use Sector, 1987–1994 (DOE 1995, 12, 92)

Energy End-Use Sectors	1987	1988	1989	1990	1991	1992	1993	1994
Transportation	1,507	1,568	1,584	1,584	1,556	1,580	1,601	1,635
Gasoline	959	981	978	967	963	976	996	1,013
Diesel and distillates	247	270	280	280	269	279	286	297
Jet fuel	202	212	217	223	215	213	215	223
All other fuels	99	105	109	114	109	112	104	102
Residential	920	971	979	928	942	939	996	997
Commercial	722	761	770	759	757	755	778	796
Industrial	1,550	1,628	1,632	1,657	1,601	1,663	1,665	1,690
Total emissions	4,699	4,928	4,965	4,928	4,856	4,937	5,040	5,118

Note: Data are in million metric tons of CO_2 ($CO_2/3.667$ = carbon quantity). Electricity generation is an important source of CO_2 emissions; however, its contribution is embedded in the values for the energy end-users given in the table.

about 2,800 billion pounds of CO_2, or about 1,260 million metric tons. These calculations, which are developed in Appendix A, correspond with similar estimates developed by DOE for 1994, as shown in Table 3–2. DOE estimates that the entire fleet of transportation vehicles in the United States emitted about 1,600 million metric tons of CO_2 in 1994 and that about 75 percent of this total (or 1,300 million metric tons) was derived from motor vehicle fuel.[5]

To put these numbers in perspective, an estimated 5,118 million metric tons of CO_2 was produced by all energy-use sectors in the United States in 1994 (Table 3-2). The transportation sector in its entirety accounted for about one-third of this total (1,600/5,118), and motor vehicles accounted for about 25 percent (1,300/5,118). Overall, transportation is a close second to industry as the energy-use sector producing the most CO_2 emissions (DOE 1995, 16).

Other Transportation Sources of Greenhouse Gas

In addition to producing CO_2 from the combustion of gasoline and diesel fuel, transportation produces greenhouse gases in other ways, for instance, during the manufacture of transportation vehicles, construction of transportation facilities, and the production of motor fuel. Depending on how broadly one defines the transportation system and its constituent elements, these sources can be quite extensive, encompassing the entire motor fuel production and distribution system (including construction and operation of refineries and tanker vessels), all of the activities involved in transportation infrastructure construction and maintenance, and the large fraction of the U.S. economy that supplies automobiles and automotive parts and materials.

Whereas attempts have been made to calculate these "upstream" emissions, such efforts are fraught with uncertainty. For instance, such calculations require many determinations about which products and activities, among thousands, warrant consideration as inputs to the transportation sector and how much CO_2 and other greenhouse gases are emitted by each. Because of these difficulties, concerns related to upstream emission sources are raised only when new vehicle propulsion technologies and energy sources are discussed, some of which would have emission streams and sources that would differ substantially from those of prevailing automotive technologies and petroleum fuels.

Transportation is currently a source of greenhouse gases besides CO_2, though to a lesser extent. The long-lasting (in the atmosphere) and powerful greenhouse gas N_2O, for instance, is emitted from catalytic converters (DOE 1995, 45–50). N_2O is also a by-product of nitrogen fertilizer use in the production of grains for ethanol used in oxygenates added to reformulated gasoline and in "gasohol" (a blend of gasoline and ethanol).[6] CFCs (mainly CFC-12) and the shorter-lived HFCs (mainly HCF-134a) that are replacing them are released from motor vehicle air-conditioning systems (DOE 1995, 52). Methane is generated as a result of the incomplete combustion of petroleum and during petroleum extraction and production (DOE 1995, 33–34).

Motor vehicles are not the only important transportation source of these other greenhouse gases and substances that affect the earth's radiative balance. For instance, aircraft flying in the troposphere emit aerosols (microscopic airborne particles) and water vapor that can create cirrus clouds, which reflect incoming solar radiation and have a cooling effect (WMO 1995, Chapter 11). The aerosols in vehicle exhaust, especially from diesel-powered vehicles, also may scatter some sunlight back into space.[7] Ozone is created in the troposphere from chemical reactions involving hydrocarbons and oxides of nitrogen (NO_x) produced by fuel vapor and combustion.[8] However, emissions of NO_x and other substances from aircraft flying at high altitudes may destroy ozone in the stratosphere, where this substance is a natural greenhouse gas and an important protection against ultraviolet light penetration (WMO 1995, Chapter 11; IPCC 1996a, 96). Some concerns about the stratospheric ozone shield are discussed in Box 3-3.

Transportation and CO_2 Emissions Globally

The United States, the largest energy user and emitter of CO_2 in the world, accounts for about 23 percent of the CO_2 produced from fossil fuel combustion (DOE 1995, 9; DOE 1996b, 109). Therefore, U.S. transportation—given its roughly 25 percent share of domestic CO_2 emissions—accounts for 5 to 6 percent of global CO_2 emissions from energy use (25 percent $\times$ 0.23). Although nearly all (more than 95 per-

Box 3-3

Ozone Shield Depletion and Efforts To Control Destructive Emissions

Although artificially high concentrations of ozone near the earth's surface are undesirable, ozone is beneficial when concentrated naturally in the higher altitudes of the stratosphere. Ozone is formed naturally in the stratosphere when energy from sunlight splits oxygen molecules (O_2), causing some atoms to combine with molecular oxygen atoms to form O_3 (ozone). Because of its molecular structure, stratospheric ozone absorbs and prevents penetration to the earth's surface of short-wave ultraviolet light, high exposure to which is associated with skin cancer in humans and harmful effects for many plants, aquatic species, and other organisms (WMO 1995). More penetration of ultraviolet light may also lead to increased surface warming (by allowing penetration of more energy from the sun) and cause changes in atmospheric chemistry and temperature structures that have implications for greenhouse warming and the formation of tropospheric ozone and other pollution in the atmosphere (SPARC 1993, 9).

CFC Controls

Several chemicals are known to destroy ozone, in particular the man-made CFCs developed as refrigerants and for certain industrial processes and aerosol propulsion. Because CFCs are chemically stable, they can rise to the higher altitudes of the stratosphere, where they are eventually broken down by ultraviolet radiation. Once liberated, the chlorine atoms are free to react with and destroy thousands of stratospheric ozone molecules. Principal transportation sources of CFCs are vehicle air-conditioning systems, many of which contain the refrigerant CFC-12. CFC-12 is among the most common of the ozone-depleting substances, accounting for about one-fourth of CFC production in the United States during the 1970s and 1980s and about 50 percent of CFC concentrations currently in the atmosphere (WMO 1992, 8). About one-third of the

continued

Box 3-3 *continued*

CFC-12 currently being used in the United States is contained in more than 90 million automobile air conditioners (DOT 1994, 166).

Substitute refrigerants for air-conditioning systems (shorter-lived HFCs) have been developed, however, and their introduction into the fleet of new vehicles has been accelerated by international treaties and domestic legislation phasing out production and use of CFCs. In addition, disposal and replacement procedures for refrigerants from automobile air-conditioning systems are now subject to federal requirements. Favorable results from domestic and international controls on CFC production and use are becoming evident. Growth in CFC concentrations in the atmosphere has stopped (WMO 1995, 2.3).

Related Issues

Emissions of nitrogen compounds from high-flying subsonic and supersonic aircraft are another suspected source of ozone-depleting chemicals in the stratosphere, although the extent is not clear (WMO 1995, 11.3). The effects on atmospheric chemistry of aircraft exhaust (including water vapor and nitrogen compounds) at these altitudes are not well known because experience to date with high-altitude commercial flights has been limited.

These nitrogen emissions are produced by jet fuel combustion. Although only a small fraction of jet fuel is burned by supersonic aircraft in the stratosphere, continued growth in air travel and the possible future development of a large fleet of supersonic civil aircraft for stratospheric flight may cause this share to rise (WMO 1995, 11.3). Also of concern is the growing number of subsonic commercial flights (several hundred per day in the United States) entering the atmospheric region encompassing the upper troposphere and lower stratosphere (tropopause, averaging 40,000 ft above sea level).

Currently, there are no national or international standards governing aircraft emissions at cruising altitudes, partly because of insufficient scientific information upon which to base them. However, the atmospheric effects of aircraft are being taken seriously in the aeronautical and scientific communities. Extensive research and evaluation of the atmospheric effects of aviation are currently under way by the National Aeronautics and Space Administration (as part of its High-Speed Research Program), with participation by the aerospace industry, to assess the emission characteristics and effects of the current aircraft fleet, as well as the potential effects of a future fleet of high-speed (supersonic) air transports (WMO 1995; NASA 1995).

cent) of the CO_2 in the United States is emitted from energy use (i.e., fossil fuel combustion), this rate differs elsewhere in the world. About one-fourth of the anthropogenic additions of CO_2 to the atmosphere is believed to be the result of deforestation, especially in tropical regions (IPCC 1996a, 17).[9] Considering the effect of deforestation, energy use from U.S. transportation accounts for 4 to 5 percent of worldwide additions of CO_2 to the atmosphere from human sources.

As discussed in Chapter 2, U.S. petroleum use and by implication its CO_2 emissions have continued to grow, but at a pace slower than that in many other nations. Hence, the U.S. share of world CO_2 emissions has been declining and is expected to decline further over the next two decades, from 23 to 18 percent (DOE 1996b, 109). According to DOE, the transportation sectors of Japan, France, and Italy experienced more than a doubling of CO_2 emissions from 1970 to 1990 (DOE 1994, 38). Nevertheless, the U.S. transportation sector continues to be a high producer of CO_2 relative to other industrialized nations, producing twice as much as the combined transportation sectors of Germany, Japan, France, and Great Britain (countries that together have a larger population than that of the United States) (DOE 1994, 38; DOT 1995a, 78).

During the next two decades, transportation's share of U.S. energy consumption is expected to rise gradually in relation to that of other domestic users, such as industry, agriculture, and residential heating. DOE projects that transportation's share of energy use will rise from 23 to 27 percent over the next 20 years, with slightly larger gains in the share of CO_2 emissions because of the carbon intensity of petroleum relative to natural gas (DOE 1996a, 13–14). Similar upward trends in transportation's share of emissions are expected to occur on a worldwide basis as a result of increased motor vehicle use in newly industrializing nations (see Chapter 2). In light of these trends, opportunities for reducing CO_2 emissions from the transportation sector are likely to become the focus of increased attention and action in the years ahead.

OPTIONS AND OPPORTUNITIES FOR CONTROLLING CO_2 EMISSIONS

Interest in finding ways to curtail transportation's production of CO_2 is increasing because of transportation's role as a major user of fossil fuel and producer of CO_2 and the fast pace of transportation growth. Even in the United States, where transportation activity is increasing more slowly than in many other places in the world, the absolute change in CO_2 emissions could be substantial over the course of decades. For example, applying the current rate of CO_2 emissions by motor vehicles to the baseline projection for growth in travel (discussed in Chapter 2), CO_2 emissions from U.S. motor vehicles will be about one-third higher than current levels in 20 years and nearly twice current levels by the middle of the next century (Figure 3-1 and Table A-1 of Appendix A).

After considering some of the options available for influencing these trends, a recent IPCC report (1996b) concluded that reductions in greenhouse gas emissions (mainly CO_2) of up to 40 percent could be achieved from the transportation sector by 2025 by "changing vehicle engineering to use more efficient drive trains and materials; reducing the size of vehicles; switching to alternative fuels; reducing the level of passenger and freight activity; and altering land use patterns, transport systems, mobility patterns, and lifestyles, and shifting to less energy-intensive transportation modes" (IPCC 1996b, 39).

Whether emissions will need to be curtailed by this much in the future, and whether they can be, are unclear. If large reductions are warranted, they will most certainly require changes in travel behavior and perhaps in the types of vehicles and fuels used. As a follow-on to the IPCC effort, as well as similar previous evaluations by others (OTA 1991; OTA 1994; Sperling and Shaheen 1995; DOE 1996a; Greene 1996), various options and opportunities for reducing CO_2 emissions

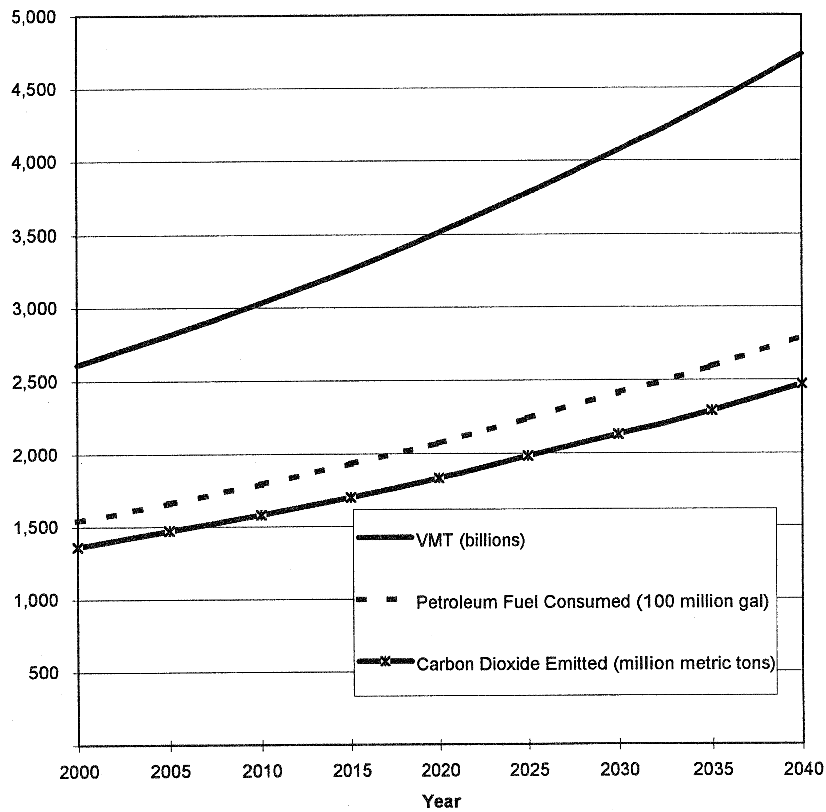

Figure 3-1 Baseline scenario trends in U.S. motor vehicle travel, petroleum use, and carbon dioxide emissions, 2000 to 2040. (See Appendix A for assumptions and calculations.)

from transportation are considered here. They are grouped according to whether their main influence is on travel demand, the kinds of transportation technologies used, or the price of energy, which influences both travel activity and technology. Although these groupings are conceptually convenient, many of the options are interrelated, as the discussion indicates.

An objective of this review is to provide a better sense of how each set of policy options could affect emission trends over time and to highlight some of the important technological, economic, and institutional issues that would need to be addressed in pursuing them. To illustrate quantitatively the potential effects of policy options on emission trends, several simplified and hypothetical scenarios are developed for each set of policy options. Appendix A contains a more complete description of the assumptions and methods used in developing these scenarios.

The first set of options reviewed includes those that would have their main influence on motor vehicle travel. As discussed in Chapter 2, Americans are driving more each year. Slowing this growth in travel to reduce emissions might be possible but would not be easy or straightforward, since motor vehicle use is inextricably linked to the development of infrastructure, economic activity, settlement patterns, and the daily habits and life-styles of Americans. The policy options reviewed here for achieving such an outcome range from inducements for ride-sharing to investments in transit, efforts to foster new community designs that encourage less highway travel, and use of nonmotorized transportation.

The second set of policy options encompasses those that would affect CO_2 emissions mainly by raising the fuel economy of motor vehicles so that they would emit less CO_2 per mile of travel. As a practical matter, near-term reductions in emissions of CO_2, if not accomplished through changes in travel behavior, will need to be achieved by reducing the amount of petroleum used per mile traveled through changes in either vehicle technologies or the highway environment. The focus of this discussion is on options for spurring the use of fuel-saving technologies that do not involve radical departures from existing gasoline- and diesel-powered vehicles; other options for fostering dramatic changes in technology are discussed in a subsequent section.

A third general option is to raise the price of gasoline and other carbon-rich fossil fuels to reduce consumption. This option cuts across the first two sets of options because higher gasoline and diesel fuel prices have two important effects: (*a*) they cause a reduction in motor vehicle travel and (*b*) they increase the demand by motorists for and the provision by manufacturers of more fuel-efficient vehicles. Because of this broad influence, fuel taxes are often viewed as an efficient means of reducing transportation CO_2 emissions. Energy taxes that are graduated for carbon content (from fossil sources),[10] known as carbon taxes,[11] have also been proposed (in some cases adopted) as a means of shifting consumer interest toward vehicles that are powered by energy sources other than petroleum and other carbon-based fuels. Since the oil supply shocks of the 1970s, much has been learned about how changes in fuel prices affect motor vehicle use and fuel economy (see Chapter 2). Some of this experience is reviewed.

A fourth set of options includes several that would have the longer-range aim of encouraging the development and use of radically different transportation propulsion technologies and energy sources. Over time, transportation's dependence on petroleum will undoubtedly diminish as petroleum reserves dwindle, although the time horizon for such an outcome is unknown. A plausible scenario is that declining oil reserves coupled with growing transportation demand will cause motor fuel prices to rise gradually and will spur greater interest in the development and use of substitute energy sources. This transition could prove beneficial in slowing or reversing the upward trend in CO_2 emissions. On the other hand, the outcome could be less favorable if the energy sources that replace petroleum fuels are high producers of CO_2 or other greenhouse gases—for instance, if inexpensive, carbon-rich coal is converted to motor fuel. In this respect, policies that further the development of low-emission technologies and fuels may prove valuable in expanding the energy alternatives.

Finally, brief consideration is given to potential opportunities for countering, or offsetting, U.S. transportation emissions of CO_2 by reducing emissions of CO_2 and other greenhouse gases from other nations and sectors. Inasmuch as CO_2 and other greenhouse gases are emitted worldwide, actions to control emissions are best developed cooperatively across nations and economic sectors.

Reduction in Motor Vehicle Travel Demand

As discussed in Chapter 2, sharp growth in automotive travel has historically been the single most important factor governing trends in motor vehicle petroleum use. During the late 1970s and early 1980s, this relationship weakened somewhat as automotive travel grew much more rapidly than petroleum demand as a result of continued gains in motor vehicle fuel economy. Recently declining fuel prices have reduced consumer interest in fuel economy, causing the link between levels of travel and fuel consumption to become reestablished over time.

Slowing growth in motor vehicle travel has become a public policy goal of many state and local governments in the United States and abroad,[12] largely because of concerns about urban air quality and traffic congestion. Jurisdictions across the country have thus devised—though seldom fully deployed—various measures to deter automotive travel (Anderson and Howitt 1995). Among the measures that have received attention are the following, which are discussed in this section:

1. Road use fees and parking taxes,
2. Vehicle ownership and acquisition taxes,
3. Inducements for ridesharing and telecommuting,
4. Metropolitan land use controls and plans, and
5. Investments in transit and other nonmotorized modes of transportation.

What is known generally about these measures and their effects on motor vehicle travel—and hence their likely effect on motor vehicle petroleum use and CO_2 emissions—is reviewed next. Some projections are then made to illustrate how these strategies might influence trends in motor vehicle use, petroleum consumption, and CO_2 emissions during the next several decades.

Road Use Fees and Parking Taxes

Governmental fees and taxes for road use and parking are not uncommon in the United States. About 4 percent of state and local highway revenues (excluding federal aid) is collected from tolls (FHWA 1995, Table FH-10). Many large municipalities impose a sales tax on customers of commercial parking facilities, and many charge for the use of public parking lots and curbside spaces (e.g., through parking meters). The purpose of these levies is mixed. Whereas most are used to raise revenue and cover the cost of special facilities (e.g., bridge construction), some also serve as demand-rationing devices (e.g., time-limited parking meters). Few, if any, however, are designed for the specific purpose of deterring motor vehicle use and resultant petroleum consumption and emissions.

Though tolls continue to be levied on many major bridges, tunnels, and turnpikes throughout the United States, reliance on tolls for funding highway projects reached its peak in the early 1950s. Toll use has since declined in the wake of the Interstate highway program and the dedication of federal fuel taxes to the Highway Trust Fund for dispersal to state and local highway programs (Seely 1987, 204–208). Although they are more common in Europe and Asia, tolls are used in a similar manner to raise revenue rather than to regulate travel demand or motor vehicle use. In a few countries, however, tolls and other road pricing schemes have been instituted as a means of regulating traffic and travel demand in heavy-volume areas. Examples include France, which has instituted time-variable tolls on one of its intercity expressways to reduce traffic congestion during peak weekend travel periods. Several Scandinavian cities have also introduced road pricing on entire street systems by cordoning off central business districts with a ring of toll stations. The toll rings reduce downtown travel during peak traffic periods (Gómez-Ibáñez and Small 1994). For more than 20 years Singapore, to manage traffic congestion, has required motorists to purchase supplementary permits to drive during peak hours into the city's central district.

Many studies and some practical experience indicate that congestion tolls or peak-period road pricing programs can reduce motor vehicle travel and resultant fuel consumption and emissions. The magnitude of the effect varies depending on how the program is structured. In general, reductions in motor vehicle travel—that is, total miles traveled within the affected region—could be expected to be smaller relative to the reduction in congestion because some traffic will be diverted to other time periods and to less-traveled routes. Simulations of congestion pricing proposals in San Francisco and Los Angeles, for instance, indicate that road fees on the order of \$2 to \$3 per day would reduce peak-period travel by 10 to 15 percent, whereas total fuel use and CO_2 emissions would decline by only 6 to 9 percent as some travel shifts to off-peak (nonpriced) hours (TRB 1994).

To achieve a larger reduction in emissions by preventing major shifts in travel from toll roads to unpriced routes, road pricing programs would need to have broad coverage, affecting road networks over large geographic regions for much of the day. Advances in automated toll collection systems have increased the technical feasibility of such areawide networks. Automated toll-collection technologies, such as electronically scanned tags, have been deployed successfully by a number of transportation agencies in the United States (Pietrzyk 1994, 464). Meanwhile, Singapore uses low-technology solutions such as paper windshield displays.

Many daunting institutional and jurisdictional issues would need to be overcome to enable areawide road pricing (Downs 1992; Gómez-Ibáñez and Small 1994, 62). Most large metropolitan areas consist of dozens of state, county, and municipal governments, each having partial or exclusive authority over the bridges, highways, and streets within its jurisdictional boundaries. In the United States, for example, there are more than 40,000 government units—many with autonomy in local street systems and taxes. Thus a major challenge will be in creating regional institutions to coordinate road pricing programs and overcome the political and jurisdictional issues (Olson 1994, 219; TRB 1994, 5–6).

Finally, a potentially greater obstacle to road pricing is the development of public trust and acceptability of road pricing technologies and intentions. As pointed out by Gómez-Ibáñez and Small (1994), road pricing represents a radical change in practice. Public concern over unanticipated and unpleasant side effects of new pricing programs, such as the privacy issues arising from the potential use of vehicle tracking and toll billing systems for law enforcement, are often cited as significant impediments to public acceptance of comprehensive systems (Downs 1992, 58; Gómez-Ibáñez and Small 1994).

Acknowledging the near-term obstacles to road pricing, some metropolitan areas have explored the use of parking taxes as a simpler means of discouraging motor vehicle travel and encouraging transit use and ridesharing. Parking taxes and fees, like tolls, are commonplace in the United States but seldom used to reduce vehicle use. Some large cities impose a sales tax on parking garage users; for example, New York City levies an 18 percent surtax on users of commercial parking facilities. On most trips, however, motorists do not pay directly for parking. Shoup (1994) estimates that at least 90 percent of commuters who drive to work are not charged directly for parking. Street parking is free in most locations, and private owners of parking facilities, such as retailers, seldom charge for parking except in the highest-demand locations.

One area in which some researchers believe changes in parking policies could have an appreciable effect on travel behavior concerns the tax treatment of employer-provided parking in high-demand areas. Most workers are exempt from paying federal and state income taxes on parking privileges provided by employers.[13] This exemption, it is argued, encourages employers to offer, and employees to demand (in lieu of taxable wages), parking privileges in locations where private parking is expensive. A study surveying commuters to downtown Los Angeles found that changing these incentives by substituting equivalent cash payments (in after-tax value) for parking benefits would cause average vehicle miles traveled per employee to decline by 15 to 20 percent (Shoup 1994, 178). To produce such an effect on a larger scale, some researchers have proposed that federal and state tax codes be changed to treat parking benefits as taxable compensation (TRB 1994). Kessler and Schroeer (1995) estimate that if such policies were adopted, national vehicle miles traveled would decline measurably.

Vehicle Ownership and Acquisition Taxes

Nearly all states impose sales taxes and yearly registration fees on motor vehicles. Some jurisdictions also levy personal property taxes that apply to motor vehicles. In virtually all instances these taxes and fees are imposed to raise state and local revenue rather than to affect vehicle ownership and use.

Vehicle registration and sales taxes tend to be much lower in the United States than in European and Asian countries, which often impose high vehicle taxes and fees to generate revenue (Schipper and Eriksson 1995, 218). In cases where fees are uniformly high for all vehicles, the main effect is to discourage vehicle ownership. During the 1980s, Hong Kong doubled its tax rates on vehicle ownership and acquisition as a means of reducing vehicle use and congestion. This tax increase was followed by a 20 percent decline in vehicle ownership rates (Button 1993, 111; May 1994, 415).

Among the advantages of vehicle fees is that they can be straightforward to implement and administer. If sufficiently high, they can lead to a smaller vehicle fleet by restraining ownership, leading to less travel overall. The major drawback of most vehicle fees is that they do not diminish the intensity of vehicle use since the size of the fee is usually independent of the number of miles driven. In drawing cross-country comparisons, Schipper and Eriksson (1995) conclude that sales taxes and registration fees, unless exceptionally high, have had less effect on motor vehicle travel than levies on fuel, principally because vehicle fees in most countries are one-time sales taxes or annual fees that do not increase with miles driven. In other words, high vehicle fees that produce smaller fleets are also likely to induce more driving of the vehicles that are in the fleet. To minimize these distortions, some European countries are considering placing more emphasis on fuel taxes—and less on vehicle taxes—as means of controlling travel and motor fuel demand (Schipper and Eriksson 1995).

Numerous schemes have been proposed to replace or supplement simple vehicle registration fees. Examples include annual vehicle miles traveled (VMT) fees, whereby registration renewal fees are adjusted upward on the basis of miles driven, and pay-at-the-pump (per-gallon) methods of charging for motor vehicle insurance, in which some insurance costs are paid through gasoline and diesel fuel surcharges (Schipper and Eriksson 1995, 224). In many respects, the influence of these alternative fee systems on travel would more closely resemble that of fuel taxes since they target marginal driving. The influence of fuel taxes is discussed later in this chapter.

Inducements for Ridesharing and Telecommuting

In the U.S. Department of Transportation (DOT) 1990 Nationwide Personal Transportation Survey, it was found that approximately two-thirds of morning peak-hour commuters drive alone in private vehicles. Fewer than 15 percent travel in organized carpools, vanpools, or commuter buses (DOT 1994, 53; Pisarski 1996, 64). These findings are indicative of a gradual downward trend in carpooling and vehicle occupancy rates in the United States during the past two decades (DOE 1996c, 5–21; Pisarski 1996).

Faced with these trends and concerns about traffic congestion and urban air pollution, many state and local governments are seeking to encourage more ridesharing by dedicating traffic lanes to high-occupancy vehicles (HOVs), providing commuter parking lots near HOV facilities, offering ridesharing information services, and reducing tolls paid by drivers of vehicles with multiple passengers. More than 400 miles of HOV lanes are now in operation in the United States, up from less than 100 miles in 1980 (Davis 1995, 3–57).

The main purpose of most ridesharing programs is to increase traffic flow and reduce congestion during peak driving periods. Reductions in petroleum use and emissions are often promoted as important side benefits, although they are seldom the primary goal of these programs.

Still unclear, however, are the net effects of ridesharing programs on total travel. It is argued that the construction of HOV lanes has the effect of increasing road capacity, which may increase overall system travel (Dahlgren 1995, 26). One reason for this effect is that HOV lanes may draw ridership from transit and commuter rail. Another is that they may stimulate travel by improving traffic flow generally, inducing travel by motorists who otherwise would not have driven because of the time penalty of congestion. A paradox of ridesharing programs, especially those involving the construction of new lanes, is that the more successful they are in encouraging carpooling and improving traffic flow generally (i.e., systemwide), the more difficult it becomes to lure solo travelers into ridesharing arrangements.

The ultimate success of ridesharing programs in reducing motor vehicle travel will depend on local traffic conditions and the specific types of programs implemented. In general, however, it appears that ridesharing programs offer only indirect and incremental benefits in curbing aggregate travel demand and resultant fuel use and CO_2 emissions. The main influence of these programs has been on a subset of urban motorists traveling to and from work during peak driving hours. Such motorists account for less than one-fourth of total miles traveled (DOE 1996c, 5–22; Pisarski 1996). Advances in ridesharing technologies, such as the smart paratransit services discussed in Box 3-4, may one day enhance the appeal of ridesharing for a wider variety of travel purposes (Michalak et al. 1994; Walbridge 1995). Such a broadening of appeal, perhaps facilitated by further advances in computer and com-

Box 3-4

Smart Paratransit

Paratransit involves the use of small transit vehicles to provide more flexible scheduling and more varied rider pickup and drop-off points. Since passage of the Americans with Disabilities Act in 1991, many public transit authorities have introduced paratransit services for disabled and elderly riders. Some transportation planners and researchers envision the expansion of paratransit to provide services to the more general population of travelers, operating in a manner similar to that of airport jitneys, though for more varied purposes and employing more sophisticated reservation, scheduling, and dispatching systems (Sperling 1995, 24). Paratransit services would therefore offer an alternative to automobile travel.

The attraction of paratransit in principle is that services can be tailored to the schedule needs and other circumstances of individual travelers, increasing transit utilization. However, a disadvantage of existing paratransit programs is that many have proved expensive to operate reliably. Dispatching, routing, and scheduling of paratransit services are costly and complex (Stone et al. 1994). To overcome these problems, automated or "smart" transit and paratransit systems are being explored as part of the federal government's research and development program for intelligent transportation systems (ITS).

Developments in computer and communications technologies may permit paratransit vehicles to be dispatched and scheduled on a more efficient and timely basis, enabling operators to provide more dependable service at lower cost. Riders may have a more direct role in making and adjusting reservations by using computer-based reservation systems much as air travelers do today (Stone et al. 1994). Envisioning travelers using cellular telephone and computer-modem connections to make real-time reservations, Sperling (1995, 24) anticipates the expanded commercial availability of smart paratransit or smart ridesharing systems as an alternative to conventional transit vehicles and single-occupant automobiles.

> The first probable application of smart paratransit technologies will be to improve the operation and services of systems dedicated to the elderly and disabled. Whether these applications will make paratransit service more practical for other travelers remains unclear. This kind of application, however, may warrant further emphasis in ITS research and development programs.

munications technologies, may make ridesharing a more promising approach to reducing motor vehicle emissions.

Where computer and communications technologies may already be having an effect on motor vehicle travel is in enabling some commuters to work productively at or closer to their homes, thereby reducing the total number of trips they make by motor vehicle to work. It has been estimated that 3 to 7 million workers, sometimes referred to as telecommuters, are taking advantage of advances in computer and communications systems to conduct some or all of their office work at home or in nearby satellite offices (Ritter and Thompson 1994, 240). DOT estimates that telecommuting results in 200 million fewer work trips annually (0.25 percent of work trips) and predicts that by 2010 as much as 10 percent of the work force will be regularly or periodically working from home or at special work sites using telecommunication technologies (DOT 1993).

The effect of telecommuting on travel patterns remains uncertain and difficult to predict. Although telecommuting may reduce peak-period travel, some studies have found that vehicles that would have otherwise remained idle at the work site are used for other travel purposes during the day such as shopping and trips to and from child day-care (Ritter and Thompson 1994). To the extent that workers are free to live farther away from city centers, telecommuting may also encourage more dispersed land use patterns and longer and more frequent non-work-related trips (DOE 1996c, 5–23). By freeing up highway capacity during peak periods, telecommuters may enable other commuters to take their place, offsetting some of the reductions in travel. A study by the Department of Energy estimates that nearly half the travel avoided by telecommuters would be replaced by other travel (DOE 1994).

The net effect of telecommuting on total travel, at least during the next decade, is likely to be modest. Accepting that only a portion of all jobs are candidates for telecommuting (mainly sales-, information-, and knowledge-based jobs), DOT estimates that if as much as 10 to 15 percent of workers engaged in telecommuting periodically or regularly by 2010, total motor vehicle miles traveled could decline by about 2 percent (DOT 1993; Ritter and Thompson 1994, 242).

Some public agencies have sponsored telecommuter demonstration projects using their own work forces (OTA 1994, 242). California requires large employers in the Los Angeles area to establish programs for reducing commuter travel, which may include telecommuting options. In addition, the state's Telecommuting Advisory Council serves as a clearinghouse for telecommuting information.

Recent experience suggests that further advances in telecommunications will continue to have effects that extend beyond the work environment and commuting patterns. Teleshopping, teleconferencing, and telebanking services are already being offered widely. Gates of Microsoft Corporation and others go so far as to predict that rapid advances in information technologies will alleviate the need for manufacturing and transporting many goods and services and ultimately transform communities by remotely linking individuals and institutions (Gates 1995).

The implications of such a telecommunications revolution for transportation could be tremendous, yet they remain vague. Whereas new information and communications systems could result in less travel by reducing the need for personal mobility and freight movement, travel demand could be stimulated by the more dispersed development patterns enabled by telecommunications (OTA 1995, 1–21). There are other implications; for example, telecommunications and computer advances that facilitate just-in-time inventorying could lead to more travel by freight trucks carrying smaller shipments and at the same time improve the efficiency of trucking (i.e., fewer empty backhauls, more efficient routing) so that aggregate travel would be reduced. As a practical matter, it is not yet possible to determine whether telecommunications advances will lead to more or less motor vehicle travel, much less to speculate on the magnitude of this influence.

Metropolitan Land Use Controls and Plans

Many of the options discussed earlier would have an influence on land use and settlement patterns. They might also be accompanied, however, by changes in land use policies that seek to reduce motor vehicle travel by increasing the density of settlement and reversing the trend toward decentralization. As discussed in Chapter 2, whereas metropolitan populations have been growing in the United States, residential and commercial developments within these areas have become increasingly dispersed. The decentralized land use patterns that have developed in most U.S. metropolitan areas during this century have undoubtedly been facilitated by motor vehicles. In most suburban developments, it is possible to have long distances between residential, commercial, and employment locations because of the ready availability of motor vehicles. Conversely, motor vehicles might not be so popular absent the apparent strong appeal of the decentralized and lower-density land use patterns that have emerged in most urban areas.

Public policies have most certainly contributed to dispersed land use patterns. Local zoning ordinances, for instance, have encouraged the separation of residential and commercial land uses, discouraging mixed-use developments that enable more walking and nonmotorized travel. Centralized land use planning and zoning restrictions, however, have proved to be weak instruments for altering public choices about land use. One reason is that land use planning is rarely coordinated at the metropolitan level, which usually involves dozens of local jurisdictions with authority over neighborhood zoning and community design. Even if institutional and jurisdictional issues could be overcome, the public at large would need to be persuaded of the benefits of land use arrangements that differ significantly from those that prevail.

Since the 1970s, some states have begun requiring local governments to develop plans for managing growth. These efforts have met with varying degrees of success but have stimulated interest in new community designs that place less emphasis on motor vehicle use and encourage people to walk more (Diamond and Noonan 1996). These designs include mixed-use and clustered developments in which jobs, retail establishments, and housing are in close proximity and accessible to transit. They also include more comprehensive efforts to integrate investments in transit and nonmotorized transportation facilities with land use policies (see Box 3-5). The idea is that such designs will engender greater interest among the public in denser development patterns, making state and regional growth management plans more acceptable and effective.

One of the most widely discussed state growth management policies is that of Oregon, which for over 20 years has required urban areas to restrict growth within the boundaries established for residential and commercial development (Nelson and Moore 1993). Other states, such as Florida, New Jersey, and Washington, have land use plans with features similar to those of the Oregon plan, whereas several others have adopted growth management plans in specific areas of the state, such as environmentally sensitive coastal regions.

Experience with growth management plans in Oregon, especially in its largest city, Portland, suggests that these efforts can achieve some success (Nelson and Moore 1993). In the Portland area, most new development has been directed to occur within a defined growth boundary. The density of development within the boundary, however, has been lower than expected, as more development has occurred outside the specified growth area. An unexpectedly largely number of requests for zoning variances and exceptions to the boundaries have been approved by local authorities. Whereas proposals have been made to strengthen the Portland plan—for instance, by imposing higher fees for outlying development (Nelson and Moore 1993)—the evidence to date does not suggest that large effects on travel demand will ensue.

In general, there is a lively debate ongoing among urban and transportation planners about the effects of increasing development density to reduce motor vehicle travel. Some studies show meaningful effects, whereas others do not (Cervero and Graham 1995; Crane 1996). Often the results from these studies are for specific locations, rather than for entire metropolitan regions or states where the influence would be diluted. In general, because of what Downs (1992) refers to as the "marginality problem," [14] the application of land use measures and new community designs to increase metropolitan densities is likely to require considerable time to achieve appreciable increases in land use density and subsequent reductions in motor vehicle travel.

Box 3-5

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Examples of Alternative Community and Land Use Development Patterns

In seeking to make land use more compatible with goals to reduce automotive travel, a number of alternative community designs have been devised by architects, developers, and urban planners. One emphasis has been on mixed-use development that seeks to better integrate residences, workplaces, schools, stores, and other destinations. Deemed as a way to increase the appeal of mixed use, architectural and design principles combine large numbers of dwelling units per acre, narrower streets, grid-style road patterns (instead of cul de sacs), and sidewalks and bikepaths. Such development is often referred to as "neotraditional" because it strives to re-create the mix of land uses, small lots, and access more typical of small towns and suburbs in the pre-World War II era. Integrated within or located nearby these residential developments might be clustered commercial and employment sites with direct access to transit, rail, or busways, as is common in Europe (Downs 1992).

Simulations of travel behavior suggest that mixed-use and clustered development patterns could reduce automobile trips and shorten trip distances, but since relatively few such developments have been built for this purpose, there is not much empirical evidence on how large and lasting these effects might be. Proponents of neotraditional development contend that these designs reduce automobile travel and congestion because grid patterns distribute traffic more efficiently and, by reducing the distances between trip destinations, increase walking and bicycling (Berman 1996). Some researchers and developers, however, are skeptical of whether there is consumer interest in higher-density development and whether such development actually reduces travel. Concern has also been expressed about the effects of narrower streets and the dispersal of traffic throughout a neighborhood on road safety and the access of emergency (fire and rescue) vehicles (Berman 1996).

continued

Box 3-5 *continued*

Downs (1992) argues that competition for investment in development and jobs among the local governments surrounding central cities makes it unlikely that clustering on a large scale would be feasible. He also contends that without metropolitan areawide land use regulation, efforts to encourage mixed-use and job-clustered development are likely to have minimal success in most places. Mixed-use zoning is often resisted by neighborhoods and local governments, reflecting the preferences of many residents for separate land uses.

Roughly half of the U.S. population now resides in areas that fit the general description of suburban, which is typically at a density below that which will support conventional transit systems (Rosenbloom 1996). Many years of denser growth patterns would be required to alter this general pattern. For example, an exceptionally fast-growing metropolitan area might double its total population within 10 years. If under these circumstances all new residents settled in areas accommodating twice as many residents per square mile as in the established development, a 50 percent increase in population would lead to only a 20 percent increase in overall metropolitan density (Downs 1992, 80). A slower-growing metropolitan area with such a design would take several decades to experience such an increase in residential density.

In principle it would be possible to increase the density of existing neighborhoods or small towns within the metropolitan area through the replacement of old structures with higher-occupancy buildings or through denser redevelopment. Such change would take many years, however, because many structures can provide useful service for 50 to 100 years, and replacement would be resisted in areas where residents favor historic preservation. Indeed, as Downs (1992) argues, neighborhoods are usually reluctant to accept any sort of change in their design and density characteristics.

Thus the most promising area for higher density is in new development, which is currently occurring at low densities. Given the marginality problem, gradually increased densities in the typical metropolitan area would likely take many decades to influence aggregate metropolitan travel substantially.

Investments in Transit and Other Nonmotorized Modes of Transportation

The importance of road building and other transportation investments to the continued pattern of decentralized urban development in the United States is a subject of much debate (Giuliano 1995; Cervero and Landis 1995). Regardless of the direct causality of development patterns, however, there is an evident relationship between transportation infrastructure investments and the pattern of adjacent land use (Kelly 1994). In the case of highway investments, surrounding land development has tended to be more spread out, whereas land development near public transit stations tends to be clustered, consisting of higher-density residential and commercial areas.

A fundamental and largely unresolved question is the extent to which transportation investments influence the density of development, given the many other factors influencing land use patterns. There is controversy over the extent to which road building has encouraged low density, and there is similar uncertainty and controversy over the extent to which other transportation investments such as transit will spur higher-density development. Clearly the influence of such investments will depend on complementary policies and the public's willingness to use transit. Yet given the development trends that have already occurred in most metropolitan areas, it is likely that sustained investments in transit, walking, and cycling facilities would be required to alter density patterns. The provision of transit in established, lower-density developments is unlikely to achieve success. As a general rule of thumb, at population densities below roughly 4,200 to 5,600 persons per square mile, or about 7 dwelling units per acre, transit use is minimal (Pushkarev and Zupan 1977; Downs 1992; TRB 1996).

Experience with transit investments during the last 30 years in the United States indicates that transit can influence the density of development at transit stops along the corridor when accompanied by zoning that permits high-density, mixed-use investments (TRB 1996). The evidence for a broader effect of transit investments on overall urban form and population density is more equivocal (TRB 1996). Certainly the vision of many urban planners of the 1960s has not been realized; major transit investments since the 1970s have been unable to reverse the trend of population relocation from central cities to the suburbs. In some instances, transit investments may well have had a stabilizing effect on urban centers and may even have increased the density of certain cores, as in San Francisco (Cervero 1995). The existence of extensive systems that predate the major investments of the last 30 years or so has probably been helpful in maintaining the strength of urban cores in cities such as Boston and New York. Many established mass transit systems that receive public subsidy are struggling as this financial support has waned. Indeed, most large transit systems in the United States have been experiencing reductions in ridership that have exacerbated these financial problems.

The success of transit investments depends upon many supportive conditions, among them a strong regional vision and willingness of local governments within the region to exercise appropriate zoning (TRB 1996). The failure of many transit systems to affect urban form may be explained in part by the size of the public investment in transit systems relative to investments in other transportation facilities such as highways. Other explanations include the lack of success in coupling regional transit investments with local land use planning and state road-building programs and changes in public preferences for modes of travel. Whereas many regional transit agencies have been created, local governments within a region tend to guard zealously their prerogative to regulate land use.

Where land use measures and transit investments are being coordinated in the United States, projected results have been positive but modest. For example, Portland has an aggressive plan for supporting transit investment that is complementary to its land use policies. It will take many years, however, before the ultimate effect of this plan on land use and resultant motor vehicle travel is fully realized, since current density remains low and more than 90 percent of trips are made by motor vehicle. Recent projections of the effects of a proposed transit system expansion in suburban western Portland, which would be complemented by land use measures to induce higher residential and commercial densities near transit service areas, indicate that total motor vehicle travel per household would decline by 6 to 7 percent (Cambridge Systematics 1996, 24). This result is comparable with those from simulations conducted for the Puget Sound metropolitan area in Washington State, which predicted that the advent of denser and transit-oriented developments would reduce vehicle miles traveled in the study area by 10 to 15 percent (Waterson 1993; DOE 1996c, 5–25).

Most studies suggest that the provision of transit, even when integrated into a transit-oriented land use plan, can reduce motor vehicle travel, but only over relatively long time frames and by modest amounts unless accompanied by many other measures to control travel demand. The Portland study, for instance, projects that a combination of subsidized and demand-responsive transit services, complementary land use plans (e.g., residential and commercial development clustered around transit stops), parking fees ($3 per day), ridesharing inducements, and peak-period road pricing ($0.15 per mile) would double the effect on travel, achieving a reduction of more than 10 percent in the study area (Cambridge Systematics 1996, 24).

Illustration of Effects of Travel Demand Measures on CO_2 Emissions

Steps to deter motor vehicle travel are being taken or seriously considered in many metropolitan areas of the United States. Although the impetus behind most of these efforts is to reduce traffic congestion and improve urban air quality, an often-claimed side benefit is that they will reduce motor vehicle petroleum use and resultant CO_2 emissions. Considered individually, most travel demand measures offer prospects for incremental decreases in motor vehicle travel; their collective effect, however, could be more meaningful.

One means of approximating the potential effect of these measures in curbing automotive travel is to examine travel forecasts for major metropolitan areas that have long-range plans to implement travel control measures during the next several years. These measures include increased transit investment, ridesharing inducements, and parking restrictions. A number of metropolitan areas are required by the federal Clean Air Act to begin implementing these measures during the next several years. Many states and metropolitan planning organizations have therefore factored the influence of these travel control measures into their long-range forecasts of regional travel demand. In its most recent report to Congress on the status of the nation's surface transportation system, DOT reviewed the regional travel forecasts developed by state and metropolitan planning organizations across the country (DOT 1995b, 162–168). In assessing and synthesizing these forecasts (and weighting them on the basis of population), DOT found that they predict annual growth in motor vehicle travel on a national basis to be about 10 percent lower than what might otherwise be expected (absent the controls on travel demand in large metropolitan areas) (DOT 1995b, 164).

Whether jurisdictions will succeed in instituting their travel control plans and take even more determined action in the future remains unclear. Currently, no jurisdiction has serious plans to impose road pricing, large parking surcharges, or vehicle taxes as a means of deterring motor vehicle use (Anderson and Howitt 1995). Likewise, few state and local governments have plans to adopt more aggressive and concerted land use controls to affect travel demand over longer time frames.

The limited U.S. experience with land use controls and planning as a direct means of curbing motor vehicle travel makes it difficult to judge the potential effect of such measures on petroleum use and CO_2 emissions. Nevertheless, there are some fundamental attributes of existing land use patterns in the United States that enable rough approximations of how such steps, if taken, might reduce motor vehicle travel and CO_2 emissions. In particular, Downs' marginality problem, discussed earlier, is an important consideration, suggesting that changes in land use policies will have a very gradual influence on overall (e.g., regional or national) land use patterns and aggregate motor vehicle travel.

Figure 3-2 shows how efforts to reduce motor vehicle travel through demand management methods and land use planning might alter long-term trends in motor vehicle miles traveled, petroleum use, and resultant CO_2 emissions. This hypothetical scenario, which is described in Appendix A, essentially assumes that the annual rate of growth in motor vehicle travel declines gradually during the next 40 years (from 1.5 percent to about 1 percent per year) as a result of travel demand measures and new land use patterns that are less travel intensive.

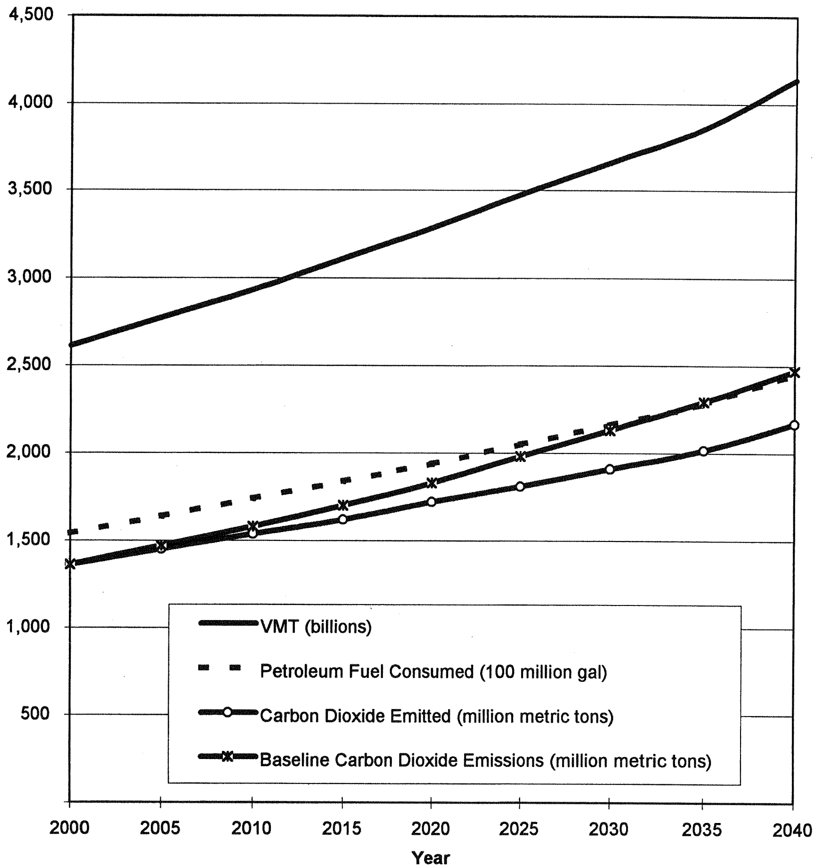

Figure 3-2 Scenario assuming policies to reduce travel demand: resultant trends in vehicle travel, petroleum use, and carbon dioxide emissions, 2000 to 2040. (See Appendix A for calculations and assumptions.)

Though highly simplified, the scenario illustrates how efforts to control travel demand to reduce motor vehicle travel will likely require many decades to have a sizable effect, in large part because of the length of time required to change land use and development patterns. Presumably, however, if such a pattern were to persist over several more decades (beyond the time horizon depicted in the scenario), the share of the population in higher-density communities would continue to grow, which would have larger and more enduring effects on travel behavior. The scenario shows a reduction in motor vehicle travel relative to the baseline trend (shown in Figure 3-1) on the order of 5 percent by 2020 and 10 to 15 percent by 2040. It is presumed that such reductions in travel would cause equivalent reductions in petroleum use and CO_2 emissions.

More difficult to assess, even in a cursory manner, are the costs, benefits, and political and institutional issues associated with adopting more restrictive land use programs as a means of curbing motor vehicle travel. What is clearer is that changes in land use would need to be accompanied by fundamental changes in incentives and preferences. Because land use patterns are a function of so many social, economic, and institutional influences, attempting to change these patterns as a means of achieving changes in travel behavior and CO_2 emissions would be especially challenging. Hence, a better understanding of the influences on land use patterns will be essential to developing effective strategies for limiting growth in motor vehicle travel and CO_2 emissions.

Increase in Conventional-Vehicle Fuel Economy

Petroleum is the predominant transportation fuel because it provides high energy density—principally in gasoline and diesel fuel—at a low price. High energy density (energy per unit of mass or volume) is essential for mobile vehicles with limited fuel storage space. Petroleum meets this need, because just 4 or 5 ounces of gasoline or diesel fuel, costing motorists only about 5 cents, generates enough power to move a 4,000-pound vehicle 1 mile in 1 minute. No other gas or liquid fuel comes close to providing this combination of high energy density and low price. From a strictly technical standpoint, there is little doubt that further gains in motor vehicle fuel economy can be achieved. For instance, at a minimum, fuel economy can be raised by making vehicles smaller and lighter. A real challenge, however, is in finding ways to minimize the cost and performance trade-offs that are often required to achieve such gains and in engendering consumer interest in fuel economy.

As discussed in Chapter 2, the oil supply shocks of the mid-1970s and early 1980s precipitated a sharp rise in the fuel economy of the U.S. motor vehicle fleet. In 1975, the motor vehicle fleet averaged less than

12 miles per gallon; by 1985 it averaged nearly 15 miles per gallon, representing an average growth rate of more than 2 percent per year. Though fleet fuel economy has recently stabilized, these earlier achievements have demonstrated how increased vehicle fuel economy can greatly affect total petroleum used. Recent concern over CO_2 emissions has therefore generated renewed interest in furthering the development and use of fuel-saving technologies and measures.

With the exception of higher fuel prices (discussed in the next section), the following options for increasing vehicle fuel economy, and therefore reducing petroleum use and CO_2 emissions, are reviewed in this section:

1. Highway capacity and traffic flow improvements,
2. Intelligent transportation systems (ITS),
3. Mandates for the supply of fuel-saving vehicles,
4. Incentives to boost consumer demand for fuel efficiency,
5. Measures to reduce fuel-intensive large-truck traffic, and
6. Efforts to further the development of fuel-saving technologies.

The presumption throughout this discussion is that these options would reduce the amount of gasoline and diesel fuel used by the fleet per mile but would not involve the use of substantially different technologies and energy sources, which are discussed later in the chapter. The section concludes with some illustrative projections of how continued and significant improvements in fleet fuel economy could change trends in motor vehicle petroleum use and CO_2 emissions over the course of several decades.

Highway Capacity and Traffic Flow Improvements

Motor vehicle fuel use is a function not only of vehicle size and design but also of how vehicles are driven, especially how fast they travel and how frequently travel speeds fluctuate as a result of stopping and starting. In general, fuel use per mile is lowest for vehicles traveling at cruising speeds between 35 and 45 miles per hour (An et al. 1993). At higher travel speeds—such as in freeway driving—aerodynamic drag has the greatest effect in increasing fuel use (An and Ross 1993). At lower travel speeds, engine and tire friction, air-conditioning, and other accessories have a relatively larger effect. If vehicles are subject to frequent braking, idling, and acceleration, fuel use is increased even more (An et al. 1993, 4).

Given these influences, traffic flow measures that seek to moderate travel speeds by lowering top cruising speeds and minimizing repeated acceleration and braking could be expected to increase fleet fuel efficiency. It was in recognition of this relationship that Congress passed the nationwide 55 miles per hour speed limit as part of the Emergency Highway Energy Conservation Act of 1974.[15] Lower cruising speeds—that is, speeds 35 to 45 miles per hour—are associated with higher miles per gallon. However, the overall contribution of the national 55-mile-per-hour speed limit, per se, in reducing demand for petroleum has proved difficult to quantify. The higher fuel prices and spot supply shortages preceding and following its enactment caused drivers to slow down as a means of conserving fuel. At the same time, the rapid conversion to smaller and more fuel-efficient vehicles had a large effect on petroleum consumption.

More recently, speed limits have been promoted as safety measures, and their fuel-saving benefits have been downplayed. Whereas 20 years ago a major concern of state and local highway agencies was finding ways to save fuel, a major concern today is finding ways to alleviate traffic congestion. Measures to reduce traffic congestion are sometimes promoted as having fuel-saving and emission-reduction benefits by reducing stop-and-go traffic. Common and inexpensive measures taken by highway agencies to smooth traffic flow include synchronized traffic lights, reversible travel lanes, left-turn signals, on-street parking restrictions during peak hours, and ramp metering (Deakin 1993). Higher-cost measures can range from improvements in the layout and physical condition of existing roadways to the construction of new travel lanes on existing routes and the addition of new roads.

Although the prime motivation behind these measures is to reduce congestion, their proponents often point to reduced petroleum use and emissions as important side benefits. On the other hand, opponents of highway enhancements often argue that such efforts have transitory effects and do little to reduce motor vehicle emissions and fuel use largely because the roads fill up again with even more vehicles and traffic flow again begins to decline. They contend, for instance, that the additional highway capacity will spur further residential and commercial development in the areas served.

In light of this debate, a Transportation Research Board (TRB) study committee recently examined the effect of highway capacity improvements on motor vehicle travel, energy use, and emissions (TRB 1995). The committee found that the relationships among highway capacity, energy use, and emissions are highly complex because of secondary effects on travel demand (TRB 1995, 7). Evidence was found that incremental traffic control measures, such as synchronized timing of traffic lights, channelization of turn lanes, and ramp metering, could increase and smooth traffic flow without having a significant effect in generating additional commercial and residential development and associated motor vehicle use (TRB 1995, 162). Other studies have found that when implemented together, measures that improve traffic flow can reduce travel times in congested urban areas (Downs 1992, 38; Deakin 1993; OTA 1994, 246). How these improvements would translate into reduced fuel consumption and emissions remains unclear. Because such measures apply mainly to congested areas during peak travel times, their marginal effect on total motor vehicle fuel use and emissions is probably small. As discussed next, intelligent transportation systems, which have the potential to change dramatically the way motor vehicles are driven and used, could have a much broader influence on motor vehicle fuel use and system efficiency.

Intelligent Transportation Systems

During the past decade, interest has grown within the United States and abroad in the application of advanced computer, electronics, and communications technologies as a means of improving transportation traffic efficiency and safety. ITS is the collective term often used to refer to these systems.

ITS encompasses a wide spectrum of technologies and systems that, if successful in increasing traffic flow efficiencies and highway capacity, could have a profound influence on fuel use throughout the transportation system. Examples of ITS elements already in operation include computer-controlled traffic signal systems and centralized traffic monitoring and control centers. More advanced technologies being tested and explored include in-vehicle navigation systems that will provide motorists with real-time routing information and automatic vehicle control systems that will assist drivers in avoiding collisions and in operating vehicles at closer spacings and more consistent speeds (e.g., enabling more effective use of cruise-control technologies).

The ultimate effect of ITS on motor vehicle fuel efficiency and fuel use remains speculative. By increasing the capacity of the highway system and the ease of travel, ITS could substantially increase traffic volume and travel, which would presumably increase total fuel use. On the other hand, more efficient and safer travel could reduce fuel use per mile and facilitate the use of new (and perhaps smaller) vehicle types and concepts. For instance, elements of ITS have been promoted as a means of facilitating ridesharing, implementing congestion pricing, automating bus lanes, and improving transit and paratransit services (see Box 3-4) (Cervero 1992; Ostria and Lawrence 1994).

A number of operational tests of advanced ITS systems are under way in the United States and in Europe and Japan. The 1991 Intermodal Surface Transportation Efficiency Act called for the Federal Highway Administration to spend significantly more on research and demonstration of these systems. Current federal R&D spending for ITS activities is on the order of $200 million per year. In general, however, most of the automated vehicle control systems envisioned as part of ITS are not likely to be deployed on a large scale for many decades. At this stage, projections of how these systems will evolve and influence motor vehicle travel are largely conjectural; hence, confident predictions of effects—positive or negative—on future motor vehicle petroleum use and CO_2 emissions are not yet possible.

Mandates for the Supply of Fuel-Saving Vehicles

A supplier-oriented approach to increasing vehicle fuel economy is to require vehicle manufacturers to sell more fuel-efficient vehicles. Since 1975 the United States has taken such an approach through the federal Corporate Average Fuel Economy (CAFE) program. Adopted in response to the oil supply shocks of the 1970s, the CAFE program sets minimum mile-per-gallon requirements for automobile manufacturers based on total vehicle sales (though with significantly different requirements for passenger cars and vehicles classified as light trucks). Related programs that are still in place include the federal requirement that automobile dealers display vehicle fuel-economy labels on new vehicles for sale and provide consumers with a guidebook containing information on fuel-economy costs and savings (Box 3-6). The latter require-

Box 3-6

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Enhancing Consumer Education and Information by Fuel-Economy Labeling

Among the most lasting provisions of the 1975 Energy Policy and Conservation Act was the requirement that automobile dealers post fuel-economy labels on new vehicles and provide prospective buyers with gasoline mileage guides. The intent of this provision was to increase consumer awareness of fuel efficiency when shopping for new vehicles and to provide buyers with objective information for factoring fuel costs into purchase decisions.

In 1981 the Department of Energy conducted a major evaluation of the information and labeling programs (McNutt and Rucker 1981). On the basis of customer surveys, the agency found that more than 70 percent of purchasers were aware of fuel-economy labels and that about 50 percent used the information for comparing models. A follow-on study in 1982 found even higher rates of label awareness and use by consumers (Pirkey 1982). Even though fuel prices were declining at the time, the survey indicated that the information contained on the labels was being used by consumers in making decisions. The studies concluded that although the net effect of mile-per-gallon labeling on vehicle purchase decisions and overall fleet fuel efficiency may be modest, such information is inexpensive to provide and often useful to consumers in informing their decisions.

In light of the lower petroleum prices that have prevailed since the mid-1980s—after these studies were conducted—it is likely that consumer preferences have changed. Newer studies to determine the informational value of these programs, as well as of alternative programs, are presumably needed.

ments are examples of demand-oriented measures, aimed at fostering greater consumer interest in and awareness of fuel-saving vehicles and their benefits. The CAFE program, on the other hand, is supply-oriented, designed to compel automobile manufacturers to produce less fuel-intensive vehicles while giving them some latitude to vary fuel-economy characteristics by model. When enacted, the program called for automobile manufacturers to increase their sales-weighted fleet fuel economy (for passenger cars) from under 16 miles per gallon in 1975 to 27.5 miles per gallon by 1985 and thereafter.

The extent to which CAFE standards have contributed to rising passenger car fuel economy in the United States remains controversial. After their introduction in the late 1970s, significant gains were made in new-car average fuel economies, which rose from 18 miles per gallon in 1978 to 27.5 miles per gallon by 1985, an average increase of more than 6 percent per year (National Research Council 1992a). During this period, however, gasoline prices rose sharply, generating increased consumer demand for, and industry supply of, more fuel-efficient vehicles. Indeed, the volatility in motor fuel prices during the late 1970s and early 1980s created the enabling environment for higher fuel-economy standards to be adopted. Because the early increases in federal fuel-economy standards occurred against a backdrop of unstable fuel prices, it is difficult to isolate the effect of the CAFE program per se on the overall gains in fuel economy during this period.

During the 1980s, however, fuel prices dropped precipitously. Presumably, it is during periods of declining fuel prices (absent offsetting tax increases) that fuel-economy standards are intended to have their strongest effect, compelling automobile manufacturers to offer more fuel-efficient vehicles even as consumer interest in this quality fades. Indeed, average new-car miles per gallon continued to rise during the late 1980s, a period characterized by falling oil prices and generally declining consumer interest in fuel economy (National Research Council 1992a). From 1982 to 1990, federal fuel-economy standards—adjusted in legislation and regulations several years earlier—were elevated from 24 miles per gallon to 27.5 miles per gallon, whereas average new-car fuel economy rose from 26.6 to 28 miles per gallon. During the past several years, however, the CAFE fuel-economy standards and the fleet fuel-economy averages have remained relatively flat, suggesting that the most important influence of the standards today may be in preventing a decline in fleet fuel economy. Even this stabilizing effect has been weakened, however, because of increasing demand for minivans, sport utility vehicles, and other vehicles classified as light trucks and subject to significantly lower fuel-economy standards. It is often argued that this dual classification scheme has diluted the influence of the CAFE program and undermined its intent.

Although few doubt that the federal fuel-economy standards have led to reduced petroleum use, the magnitude of this effect is the subject of debate. One reason is that motorists may respond to higher fuel economy by driving more, forfeiting some of the potential fuel savings. This response, often referred to as the "rebound effect" or "take-back effect," stems from the fact that on a per-mile basis, vehicles offering higher fuel economy have lower fuel costs. In this respect, the marginal cost of driving an additional mile is lowered, leading some motorists to drive more miles. Although most researchers recognize the existence of such an offsetting effect, estimates of its importance vary widely (DOE 1996c, 5–13). The estimates range from a 10 to a 50 percent offset in fuel savings, with 20 percent representing the middle of the range (OTA 1994, 156; Nivola and Crandall 1995; DOE 1996c).

Perhaps the most controversial aspect of the CAFE program concerns the extent to which periodic adjustments in the fuel-economy standards are achievable and beneficial. The adjustments require complex determinations about the technical feasibility of higher standards, their safety implications (i.e., influence on vehicle size), and cost effects. Without the strong financial incentives for fuel economy that provided the opening for CAFE standards 20 years ago, the periodic determinations have become increasingly contentious and controversial. Some proposed ways to complement and preserve the intent of the CAFE program while addressing some of its shortcomings are discussed next and in Box 3-7.

Incentives To Boost Consumer Demand for Fuel Efficiency

In the absence of higher fuel prices that shift demand toward more fuel-efficient vehicles, various schemes have been adopted or proposed to boost consumer interest in fuel efficiency. Included among these

Box 3-7

Trading Fuel-Economy and Emissions Credits

Currently under the CAFE program, automobile manufacturers can accumulate credits to cover compliance shortfalls from previous or future years. The law does not, however, permit those companies to sell their exceedances to other manufacturers who fall below the standards. Such trading currently occurs to some extent through vehicle "rebadging," whereby manufacturers sell vehicles under their own brand name that were produced by another manufacturer. It is often argued that allowing such trading would open and simplify this process and produce a more cost-efficient program, for instance, by enabling manufacturers of mostly fuel-efficient vehicles to benefit from their excess production by banking and selling emission credits to makers of fuel-intensive luxury and recreational vehicles (National Research Council 1992a, 184; Sperling 1995, 120–131). Financial rewards would therefore be provided to producers of fuel-efficient technologies, whereas producers of fuel-intensive products would no longer be enticed to engage in rebadging or other less efficient means of minimizing their compliance costs.

Some researchers have proposed that automobile manufacturers be given CAFE credits for programs that have broader effects on fuel efficiency and carbon emissions (Sperling 1995, 128–131). Experiments by energy and utility companies with older vehicle buy-back programs offer a possible model for extending CO_2 emission credits to outside consumers and industries. By purchasing or selling emission credits from other industries, such as electric utilities, automobile manufacturers could adjust their fleet fuel economy averages in the most cost-efficient manner while having a net positive effect on total CO_2 emissions. Likewise, automobile manufacturers and oil companies could buy and sell credits from producers of low-carbon fuels and technologies, creating financial incentives for the latter to increase research and production.

Provided they can be simply and inexpensively administered, tradable credit schemes are often favored by economists as a means of instilling flexibility and market incentives into regulatory programs

(Cantor et al. 1992). Indeed, the general concept of emissions trading as a means of slowing and eventually stabilizing CO_2 buildup is now being explored as part of a pilot program to jointly implement the goals of the international Framework Convention on Climate Change. Emissions trading in this broader context would enable developed nations to purchase CO_2 emission credits from undeveloped nations, providing the latter with cash or fuel-efficient technologies. Presumably, for such a market-based strategy to succeed, participation by the U.S. transportation sector would be important, although the mechanisms for doing so in this decentralized sector have yet to be seriously explored.

demand-oriented measures are so-called "gas-guzzler" taxes (currently in place), proposed fee and rebate programs, and vehicle excise and registration taxes based on vehicle weight, engine size, and other attributes associated with fuel efficiency. Programs to accelerate the retirement of older high-pollution vehicles have also been attempted in some areas and may have application in discouraging the use of fuel-intensive vehicles.

The imposition of higher vehicle fees or surcharges on fuel-intensive vehicles has been a policy in many European countries and to a limited degree in the United States. Vehicle sales taxes and registration fees in a number of European nations, for instance, fall disproportionately on the least fuel-efficient vehicles since they ramp upward with vehicle weight, engine displacement, and other characteristics often associated with poorer fuel economy. Denmark and Norway, for instance, impose value-added taxes that tend to reduce the size of vehicles purchased (Schipper and Eriksson 1995, 223–224). Austria exempts the smallest and most fuel-efficient vehicles from sales taxes while imposing higher taxes on models offering low fuel economy (Schipper and Eriksson 1995).

A somewhat related effort to link vehicle taxes to fuel efficiency is the gas-guzzler tax in the United States. Since 1979 the federal government has imposed a tax on the retail price of new passenger cars that test below a specified fuel-economy threshold, currently set at 22.5 miles per gallon for passenger cars. The tax varies depending on the extent to which the vehicle falls below this level; for instance, new passenger cars with a fuel-economy rating of 15 miles per gallon are taxed $4,500, whereas those with a fuel-economy rating of 22 miles per gallon are taxed $1,000.

According to DeCicco and Gordon (1995), the federal gas-guzzler tax has been effective in raising the fuel efficiency of the traditionally least-efficient luxury vehicles. They maintain, however, that the tax has had little effect on average fleet efficiency, since most models have fuel-efficiency ratings well above the range affected by the tax. They point out that although the federal tax creates a monetary disincentive for the purchase and production of vehicles offering very low fuel economy, it does not create incentives for the purchase of models providing very high fuel economy (well above the tax threshold).

To provide such incentives, some analysts have proposed various fee and rebate programs (often called "feebates") whereby a higher tax is imposed on fuel-intensive vehicles and the receipts are used to offer rebates to buyers of fuel-efficient vehicles (DeCicco et al. 1992; OTA 1994, 159–162; Davis et al. 1995). Denmark is considering the adoption of such an incentive program. A DOE study concludes that various combinations of fuel-economy fees and rebates would improve fleet (on-road vehicle) fuel economy by 10 to 15 percent within 20 years of implementation, reducing fuel usage by slightly less (Davis et al. 1995, xviii). Not examined, however, is how vehicle size, design, and utility would be affected by such programs.

Other demand-oriented measures that offer potential for increasing fleet fuel economy include inducement for the retirement and scrapping of inefficient vehicles through the provision of accelerated capital depreciation allowances (especially for commercial fleet vehicles), vehicle buy-back programs, and credits toward the purchase of fuel-efficient vehicles. To date, most measures of this type have been targeted at heavy-polluting vehicles rather than at fuel-intensive ones. In a demonstration program, the Union Oil Company of Los Angeles paid $700 to owners of pre-1970 vehicles as a means of reducing emissions causing local air pollution (OTA 1992). Although such buy-back programs are usually designed to reduce local air pollution (they are approved for use by the 1990 Clean Air Act Amendments), their design could presumably be modified to target the retirement of fuel-inefficient vehicles as well.

Besides cost, the effectiveness of all such programs will depend on the extent to which retirement can be accelerated, how intensively the retired vehicles would have been driven, and how their fuel efficiency (and pollution characteristics) compares with that of the newer vehicles that would replace them (Hsu and Sperling 1994). Also of concern is whether these "retired" vehicles are resold and used elsewhere (abroad) or how they are disposed of. In general, longer-lived vehicles offer many advantages in reduced demand for new vehicles and the costs and environmental effects associated with new vehicle production. Because vehicles are becoming more durable and remain in operation longer, programs that encourage earlier retirement (such as accelerated tax depreciation allowances for commercial fleets) may be accompanied by unintended results (e.g., resale and reuse of vehicles abroad) such as those identified above.

Measures To Reduce Fuel-Intensive Large-Truck Travel

Medium- and heavy-duty trucks, predominantly freight-carrying and service-oriented vehicles, account for 7 percent of annual miles traveled and about 20 percent of petroleum consumed by highway vehicles in the United States (FHWA 1995, Table VM-1). Although the average miles per gallon of the large-truck fleet has increased in recent years, medium- and heavy-duty trucks average only about one-fourth as many miles per gallon (of diesel fuel) as gasoline-powered passenger cars (see Chapter 2, Figure 2-7). Hence, opportunities for saving fuel in the trucking and freight sectors may warrant serious attention as part of a comprehensive strategy to reduce petroleum use and CO_2 emissions. Because miles traveled by trucks have grown faster than travel by car, the influence of the freight sector on motor fuel use and emissions has grown, as has its importance as a source of fuel savings.

Probably the most commonly discussed approach to reducing energy consumption in freight is shifting truck traffic to rail, thereby reducing the total number of large trucks on the road. This approach may appear attractive since freight-carrying trucks consume nine times more fuel per ton-mile than does rail transport (Davis 1995, 2–24). Proposals for improving freight-sector fuel efficiency have ranged from increasing excise taxes on diesel fuel to providing subsidies for the use of lower-energy-intensity modes, such as rail and water transport. Stricter regulations governing vehicle fuel economy and other related characteristics, such as truck size and weight, have also been proposed.

Many such proposals, however, prove more complicated when all of their potential ramifications are considered. For example, restriction of truck size and weight may succeed in diverting some shipments to other modes, such as rail, but is likely to affect mainly long-haul shipments of high-density commodities, accounting for only a small portion of truck traffic. The fuel savings resulting from this diversion, however, may be largely or entirely offset by the reduced fuel efficiency of smaller trucks that would remain on the road. As a practical matter, many truck shipments are not well suited to alternative modes of transport. Trucks are also essential for short-haul freight pickup and delivery operations, including the initial and final movements of most goods moved long distance by water and rail. Consequently, more restrictive truck size and weight limits could cause many of these shipments to be moved in a larger number of smaller trucks, each using more fuel per unit of cargo moved.

Indeed, recent examinations of the possibilities for reducing energy consumption in the freight sector have concluded that the potential for mode shifts, induced by either price or regulatory mechanisms, is limited. The constraints reflect the different characteristics of the cargo moved by each freight mode and shipper and customer operational needs. The constraints were identified in a recent assessment by O'Rourke and Lawrence (1995), who pointed out: "The extent to which truck traffic can be diverted to other modes is . . . uncertain. Any analysis of freight movements must take into account that transportation and logistical decisions are made in a complex business environment where service, delivery time, and inventory management are important considerations for choice of mode. Price comparisons between modes can also be misleading since the type of freight hauled by each mode often differs."

Likewise, a 1994 Office of Technology Assessment study concluded that the amount of truck traffic that is a strong candidate for diversion to other transport modes is likely to be too small to have an appreciable effect on total transportation energy use (OTA 1994, 249). These findings suggest that as with passenger cars, if the intent is to reduce fuel use and CO_2 emissions from truck travel, more direct pricing measures and technology remain the most promising course. The latter options are discussed elsewhere in this chapter.

Efforts To Further Development of Fuel-Saving Technologies

During the 1970s, when fuel prices rose sharply, most of the early gains made in fleet fuel economy stemmed from a shift in the type of vehicles purchased toward lighter vehicles. As mentioned in Chapter 2, other gains followed as a result of changes in vehicle technologies, designs, and materials, such as expanded use of plastic body components, aerodynamic designs, front-wheel drive, and fuel-injection systems. Because petroleum prices have been stable or declining in recent years, motorists have not been demanding further gains in vehicle fuel economy, providing little incentive for automobile manufacturers to explore and adopt new fuel-saving designs and technologies.

Opportunities to further enhance fuel economy exist. Some of the easiest solutions, such as sharply reducing vehicle mass, are not as practical as they were 20 years ago (when passenger cars were significantly heavier than they are today). Nevertheless, since only a fraction of the energy carried in gasoline is ultimately converted to the mechanical energy that propels the vehicle, measures to reduce conversion inefficiencies may yield further gains in vehicle fuel economy (DeCicco and Ross 1994). Apart from additional reductions in vehicle mass, opportunities range from curtailing energy losses from aerodynamic drag and braking to overcoming losses in the vehicle drivetrain and engine combustion process (DeCicco and Ross 1994). A 1992 National Research Council study estimated that new passenger car fuel economies could be elevated by about 2 percent per year over a decade-long period; vehicle performance would not be significantly degraded, but vehicle prices would rise by an average of $500 to $1,250 (National Research Council 1992a). It was noted that higher fuel-economy gains are technically achievable, but the associated costs—in terms of reduced vehicle performance and higher price—could lessen demand by consumers.

Consumer acceptability with regard to fuel economy and the factors that influence it are issues that warrant greater attention. A better understanding of how fuel-saving designs, technologies, and materials are likely to change vehicle prices, operating costs, and performance attributes and how such changes will be met by consumers could provide guidance for automobile manufacturers, researchers, and government regulators in setting fuel-economy goals and inducements.

In many respects, the circumstances surrounding the development of diesel-powered passenger cars exemplify how the introduction of fuel-saving technologies, even for relatively proven concepts, can be complex in practice and involve many interrelated cost, engineering, and environmental issues. Diesel passenger cars are already more energy efficient than gasoline-powered vehicles, offering 20 to 30 percent more miles per gallon (IPCC 1996b, 692). Thus, even though each gallon of diesel fuel contains 5 to 10 percent more carbon than gasoline, this fuel efficiency advantage promises net reductions in end-use CO_2 emissions (see Appendix A).[16] Diesel engines, however, emit more NO_x and particulates, both of which are important sources of air pollution and adverse environmental effects. Diesel passenger cars are popular in Europe (in large part because of their higher fuel efficiency as well as the history of lower fuel taxes for diesel fuel than gasoline), and research is under way in the United States and abroad to overcome some of their disadvantages, for instance, through the use of lean-burn catalysts, better direct fuel-injection systems (to further reduce fuel use per mile), and particulate filters and traps (IPCC 1996b, 692). Although this research is advancing, many more years may be required before an acceptably priced and sufficiently clean diesel passenger car becomes available for popular use in the United States.

Aiming to accelerate research, development, and implementation of fuel-saving technologies, the federal government and major U.S. automobile manufacturers have been working since 1993 to develop an affordably priced and consumer-acceptable "new-generation" vehicle. This joint venture, known as the Partnership for a New Generation of Vehicles (PNGV), is seeking to develop a new type of passenger car that is equivalent in price, function, and performance to popular mid-size passenger cars but has up to three times the fuel economy. This R&D program is discussed later in the chapter under the options for spurring the development and introduction of vehicles emitting low amounts of carbon and other greenhouse gases.

Illustration of Effect of Raising Conventional Vehicle Fuel Economy on CO_2 Emissions

As discussed above, various means exist for increasing motor vehicle fuel economy, each associated with different economic, political, and technical issues related to implementation and eventual success in reducing motor vehicle petroleum use and CO_2 emissions. Although it is not possible here to examine these complex and numerous issues, it is possible, for purposes of demonstration, to make some rough projections of how steady gains in vehicle fuel economy would influence long-term trends in motor vehicle petroleum use and CO_2 emissions.

Figure 3-3 shows projections of how growth in new-vehicle (all vehicle types) fuel economy of 1.5 percent per year would affect motor vehicle travel and petroleum use over several decades. The scenario assumes that as a result of this continual increase, average miles per gallon of the fleet gradually increases over the entire period. For the entire period, the average annual rate of fuel-economy growth in the entire fleet would be slightly lower than 1.5 percent.[17] This growth in fleet fuel economy is about one-third the annual rate of growth achieved in the U.S. motor vehicle fleet during the mid-1970s through the 1980s (see Chapter 2), following two major petroleum price increases and the advent of federal fuel-economy standards. From a present fleet average of 16.9 miles per gallon, a 1.5 percent annual increase in new-vehicle fuel economy would lead to a fleet average of 21 miles per gallon by 2020 and 28 miles per gallon by 2040. This of course assumes a transition period. In the early years, the fleet average would move up slowly as newer vehicles are gradually introduced into the fleet and older vehicles are slowly retired. The calculations and the assumptions used in their development are presented in Appendix A.

Factored into this scenario is an assumption about the stimulative effect of higher fuel economies on motorist demand for travel, referred to above as the rebound effect, caused by a significant reduction in per-mile fuel costs. Essentially, the scenario assumes that for every 1 percent increase in vehicle fuel economy (and therefore 1 percent decline in fuel

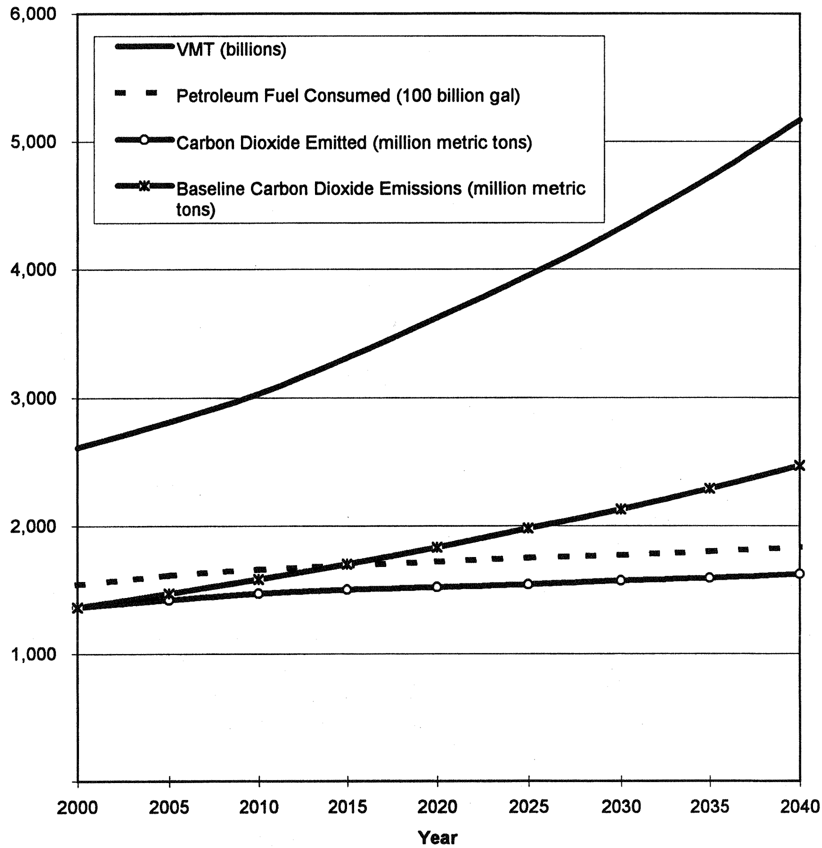

Figure 3-3 Scenario assuming rising fuel economy of new vehicles: resultant trends in vehicle travel, petroleum use, and carbon dioxide emissions, 2000 to 2040. (See Appendix A for assumptions and calculations.)

cost per mile), miles of travel by the affected vehicles increases 0.2 percent from the level of travel otherwise expected. This ratio falls roughly in the middle of most estimates of the fuel-economy rebound effect.

Taken together, these assumptions imply that rising new-vehicle fuel economy on the order of 1.5 percent per year would reduce petroleum consumption and resultant CO_2 emissions by about 15 percent after 20 years and 35 percent after 40 years. This is relative to the baseline trend, which projects an 80 percent increase in CO_2 emissions from 2000 to 2040 (Figure 3-3).

The assumption of a constant rate of increase in new-vehicle fuel economy is simplified for the purpose of illustration. A constant percentage rate of growth in fuel economy is improbable. Nevertheless, when considering a time frame of several decades and a tremendous potential for technological change, the overall magnitude of the fuel-economy change depicted in the scenario appears plausible.

Higher Petroleum Fuel Prices

Perhaps the most direct means of promoting energy conservation—and curtailing CO_2 emissions—is to raise the cost, or price, of using carbon-rich fossil fuels such as gasoline. Higher gasoline prices cause people to reduce consumption by changing travel behavior and technologies in a variety of ways over both the short and longer terms.

In the near term, higher gasoline prices cause motorists to forgo or shorten trips for shopping, recreation, entertainment, and other discretionary activities. As time passes and response options increase, individuals may alter their commuting patterns and increase vehicle occupancy rates, for instance, by substituting carpooling, transit, and work at home for single-occupant travel. Sustained higher prices also encourage motorists to reduce their use of or to retire fuel-intensive vehicles and demand more fuel-efficient models. The magnitude of the latter effect will depend on the size and permanence of the price increase, as well as the cost and the technical capability of vehicle manufacturers to meet the demand. Increased demand will spur manufacturers to invest more in research to develop and produce the fuel-efficient models needed to meet consumer demand. Sustained increases in prices (over many years) will also doubtless influence people's decisions about where to live relative to where they work, shop, and socialize.

Evidence of Demand Responses to Higher Fuel Prices

That a variety of fuel-saving responses are triggered by higher fuel prices is less controversial than the specific timing and magnitude of the responses, which have been the subject of considerable research and debate during the past two decades. Various studies have sought to determine the price elasticity of demand for motor vehicle fuel, that is, the percentage by which the quantity of fuel used will decline in response to each 1 percent rise in price. The studies, many conducted in the 1970s and 1980s following the oil supply shocks, have produced an array of elasticity values measuring both the short- and longer-term effects of changes in the price of gasoline on demand.

As might be expected, gasoline demand is found to be least sensitive to changes in price in the short term, because motorists can respond to higher prices primarily by reducing discretionary travel. Studies (mainly of the private passenger car market) have found short-term price elasticities ranging from as low as −0.05 to higher than −0.5 (Dahl 1986; Goodwin 1990; DeCicco and Gordon 1995; Nivola and Crandall 1995, 44; DOE 1996c, 5–13; Espey 1996). An elasticity of −0.5 means that a 10 percent increase in the price of gasoline would yield a 5 percent reduction in consumption; an elasticity of −1 means that a 10 percent price increase would yield a 10 percent reduction.

The studies indicate that initial reductions in gasoline consumption are likely to stem primarily from reduced motor vehicle driving as a response to higher prices. Over the longer term, however, about half the decline in gasoline use will be attributable to increased demand for fuel-efficient vehicles and the resultant growth in fleet fuel economy. The reason is that as time passes and gasoline prices remain high, motorists will not only change their discretionary travel patterns but will also purchase more fuel-efficient vehicles, move to locations closer to where they work and shop, and find alternative means of transportation. They may also demand substitute fuels.

Because of substitution opportunities, demand for gasoline is more sensitive to price changes over longer time horizons. Hence, estimates of longer-term price elasticities (in response to enduring changes in prices) tend to be higher than those of short-run elasticities. Estimates cited in the literature range from as low as −0.2 to higher than −1 (DeCicco and Gordon 1995; Nivola and Crandall 1995, 44; DOE 1996c, 5–13; Espey 1996). A review by Espey (1996) of more than 40 studies containing price-elasticity estimates revealed an average elasticity value of −0.53.

As a metric for estimating the effect of fuel prices on fuel usage over time, longer-term elasticity values are most relevant since they are more likely to account for gradual changes in fleet fuel efficiency, land use, and other long-run substitution responses by consumers. Yet how closely past patterns of price responses are likely to correspond to future trends over even longer time horizons (on the order of decades) is uncertain. Most measurements of long-term price elasticities have been computed over relatively brief time horizons, encompassing several years (in some cases months) rather than many decades. Moreover, during the 1970s and early 1980s (when many of these elasticities were estimated), motorist responses to higher gasoline prices were aided by the relatively simple and inexpensive improvements that could be made in vehicle fuel economy, especially reductions in vehicle weight (through changes such as front-wheel drive). Further advances in vehicle fuel efficiency might prove more difficult and costly. On the other hand, continued advances in motor vehicle and fuel technology, as well as travel substitutes such as telecommunications, as discussed earlier, may greatly expand response options, causing fuel demand to become even more sensitive to changes in fuel price.[18]

Fuel Taxes To Deter Petroleum Use and Spur Demand for Alternatives

Higher taxes on gasoline and diesel fuel are the principal means by which governments can raise fuel prices to engender such a broad set of fuel-conservation responses. Fuel taxes also have the advantage of being straightforward to devise and administer, proving a dependable source of government revenue. In the United States, fuel taxes are imposed primarily as a means of funding the highway system. Currently, the combined federal, state, and local levies on gasoline in the United States range from approximately \$0.25 to \$0.50 per gallon (the weighted average is approximately \$0.35), accounting for about one-third of the price paid for gasoline at the pump in most locations (FHWA 1995, Table MF-205).[19]

By comparison, motor fuel taxes are much higher in most other industrialized nations, and the revenues generated by them are used for more varied purposes. Figure 3-4 shows gasoline taxes in U.S. dollars in

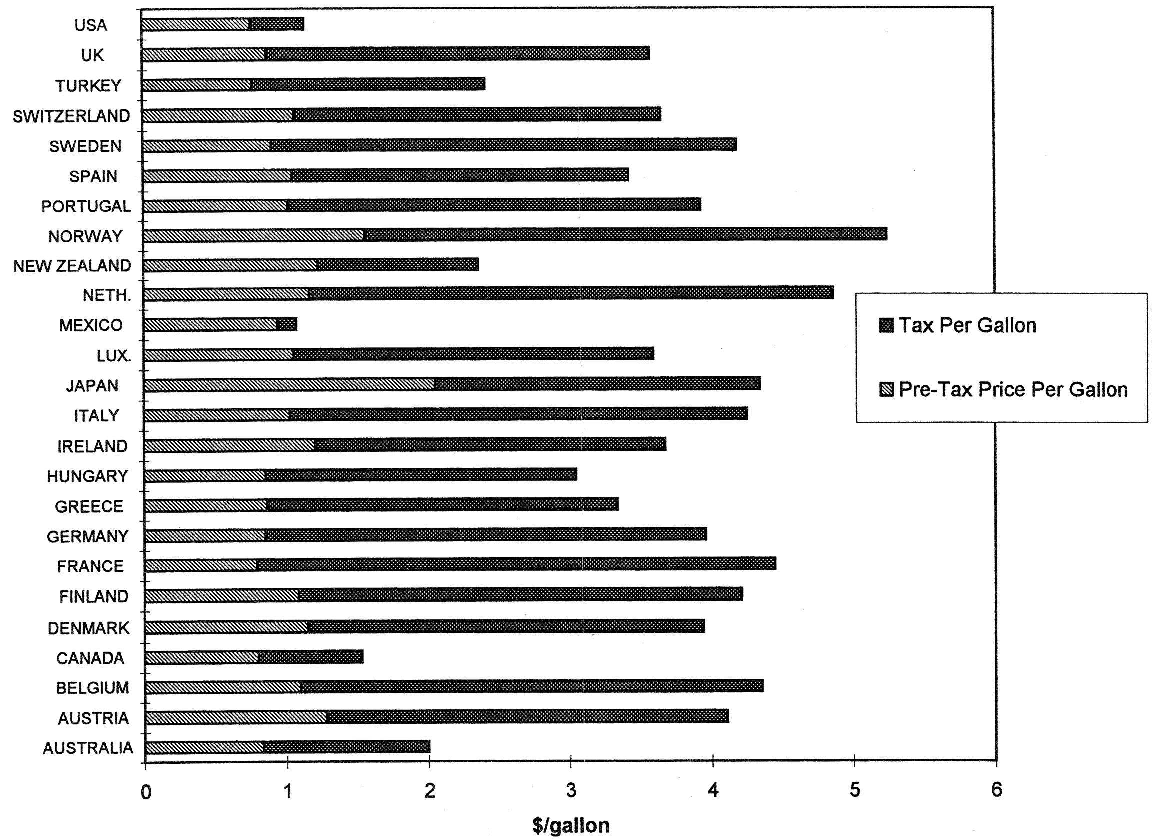

Figure 3-4 Gasoline tax and retail prices in industrialized nations, 1995 (compiled by the International Energy Agency).

Canada, Japan, and some other industrialized countries. Most of these countries have imposed high fuel taxes for many decades, often predating concerns over air pollution, noise, traffic congestion, and other side effects of highway transportation (Nivola and Crandall 1995, 57). Though several Scandinavian countries have recently instituted a motor fuel tax on the basis of fossil carbon content, the central function of most fuel taxes in Europe, as in the United States, is to raise revenue rather than to conserve gasoline and control adverse environmental effects (Schipper and Eriksson 1995, 218).

As concern over emissions of CO_2 and local air pollution has grown, greater attention has been given to the notion of using the fuel tax as an instrument for regulating petroleum consumption. During the 1970s, higher motor fuel taxes were considered—though seldom implemented in the United States—as a means of reducing demand for petroleum, particularly from foreign oil sources. More attention has been given in recent years to using fuel taxes to reduce CO_2 emissions by linking the tax to fossil carbon content.

Exactly how such a carbon tax would affect the mix of fuels used in transportation is unclear, at least over the long term. Like a traditional fuel tax imposed on gasoline or diesel fuel on the basis of volume, a carbon-based tax that raises the price of petroleum would reduce petroleum demand and thus reduce CO_2 emissions. It would also increase interest in the use of other available or emerging fuels (and associated vehicle technologies) that would raise energy efficiency and reduce total energy costs. Thus diesel fuel, natural gas, and alcohol and gasoline blends—each of which is a known technology and can provide additional fuel economy or carbon reduction benefits compared with gasoline—might become more popular as a result of either a traditional fuel tax or a carbon-based tax.

What a fossil carbon tax is much more likely to generate, over time, is greater consumer and supplier interest in energy sources that produce very low net carbon or none at all. As discussed in the next section, many very low- and zero-carbon energy technologies are still in their technical infancy; hence, a carbon tax probably would not prompt a rapid switch to radically different vehicle technologies and energy sources. By skewing consumer demand in favor of such change, however, the carbon tax, depending on its size and structure, could expedite this transition.

Illustration of Effect of Raising Fuel Prices on CO_2 Emissions

Higher petroleum prices evoke two important responses of motorists that lead to reduced fuel consumption: they cut back on travel and they demand more fuel-efficient technologies. A third potential influence of higher fuel prices, especially if prompted by a tax targeted at fossil carbon content, is to spur consumer interest in, and subsequent supplier research on, alternative energy sources and transportation technologies.

Figure 3-5 demonstrates how annual increases averaging 3 percent in petroleum (gasoline and diesel fuel) prices could influence trends in motor vehicle travel and fleet average fuel economy, ultimately affecting growth in CO_2 emissions. A 3 percent annual increase in petroleum prices would result in a price that is about \$1 higher than the current gasoline price (which averages \$1.35 per gallon) by 2020 and about \$3 higher by 2040. It is assumed that the long-run price elasticity of demand for petroleum is −0.4. This figure, which falls in the middle of elasticity estimates found in the literature cited earlier, implies that for every 1 percent increase in fuel prices, fuel consumption declines by roughly 0.4 percent. It is further assumed that half this response is the result of reduced travel by motorists and the other half stems from increased fleet fuel economy. In other words, a 10 percent increase in petroleum prices—equivalent to a 10 percent increase in per-mile fuel costs—causes miles traveled to fall by 2 percent and fleet fuel economy to grow by 2 percent, causing a 4 percent net reduction in total fuel consumption.

This scenario demonstrates that changes in petroleum prices can have a large influence on petroleum demand. The projections developed here show that the amount of petroleum used by motorists after 20 years would be about 15 percent lower than under the baseline scenario. After 40 years, petroleum consumption would be about 35 percent lower than under the baseline scenario (Figure 3-5). Fleet fuel economy would rise 25 percent (from 16.9 to 21.5 miles per gallon) in relation to the constant fuel-economy levels in the baseline scenario. Meanwhile, total motor vehicle travel would be about 20 percent lower than under the baseline scenario.

Not considered in this simplified scenario are the many economic, political, and social implications of rising fuel prices and their effects on

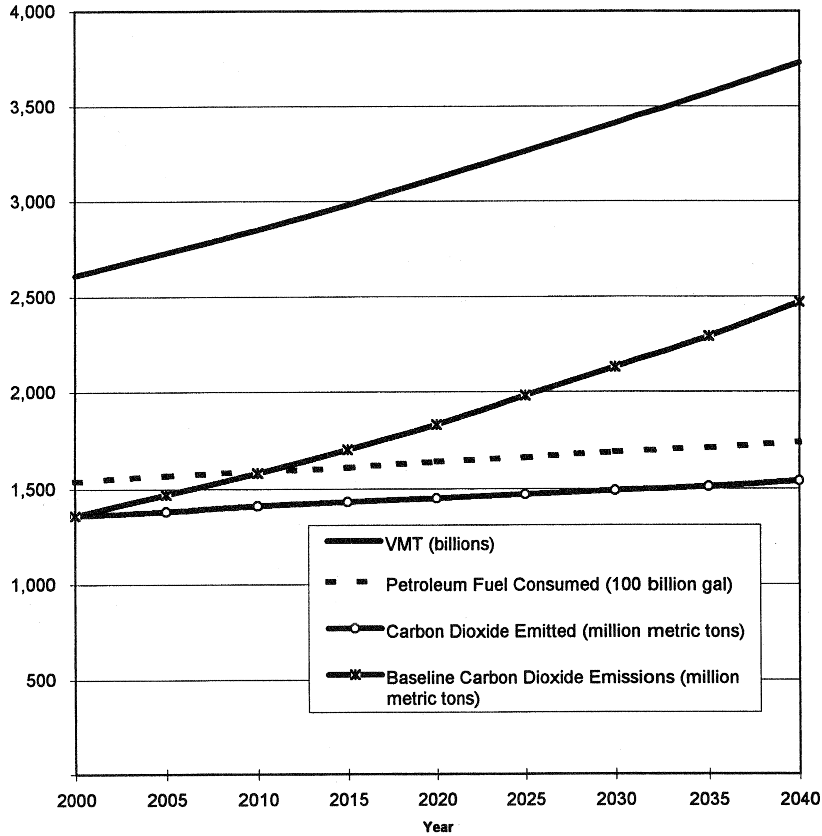

Figure 3-5 Scenario assuming policies to raise motor fuel prices: resultant trends in vehicle travel, petroleum use, and carbon dioxide emissions, 2000 to 2040. (See Appendix A for assumptions and calculations.)

travel and vehicle technology. Nor are the means of achieving these higher prices considered (e.g., whether through tax policy or supply and demand forces). Warranting consideration in the event of rising petroleum prices—prompted by either energy taxes or market forces—is the extent to which motorists would switch to alternative fuels in addition to (or instead of) improving vehicle fuel efficiency and reducing travel. Alternative energy sources, depending on their composition, energy output, and production processes, may or may not produce significantly less CO_2 than traditional petroleum motor fuels. In this regard, a graduated energy tax based on fossil carbon content or greenhouse gas emissions would offer more incentive for motorists to demand and suppliers to develop vehicle technologies low in fossil carbon emissions.

Development of Vehicles Emitting Low Amounts of CO_2 and Other Greenhouse Gases

Because of the sharp growth in motorized transportation that is occurring around the world, improvements in conventional motor vehicle fuel economy may not provide the global reductions in CO_2 necessary to limit greenhouse gas buildup. Hence, conversion to new vehicle propulsion technologies and energy sources may become necessary. The need for such a conversion will become clearer as the risk, timing, and magnitude of greenhouse gas buildup and its consequences become better understood. An accelerated conversion may not be required. On the other hand, should the need to control greenhouse gas emissions become more urgent, the early progress made in the research, development, and demonstration of low-emission technologies may prove invaluable in enabling a faster and smoother transition.

Table 3-3 identifies several vehicle propulsion technologies that have the potential to emit significantly less CO_2 and other greenhouse gases than conventional gasoline- and diesel-powered vehicles. These technologies involve radical changes in engine design and fuels, encompassing battery, fuel cell, hydrogen, and biofuel systems. Growing concern about greenhouse gas emissions, as well as urban air pollution and energy security, has prompted greater interest in their exploration and development.

The review in this section is not intended to be comprehensive. Not considered, for example, are several alternative fuels that have been the subject of research, public subsidy, and niche applications during the past two decades, including vehicles fueled by compressed or liquefied natural gas, liquefied petroleum gas, and petroleum and alcohol blends (e.g., gasoline mixed with grain-derived ethanol or methanol). Even compared with vehicles using reformulated gasoline and diesel fuel, some of these alternatives still offer advantages in reducing emissions of

Table 3-3 Promising Technologies To Reduce Greenhouse Gas Emissions from Motor Vehicle Transportation: Examples of Environmental, Cost, and Technical Issues

Power Train or Fuel	Vehicle Emissions of CO_2 and Other Pollutants	Fuel Cycle Emissions of CO_2	Technical and Market Barriers
Electric drive using battery	None	Depend on electricity source; if battery recharged with electricity generated by carbon-rich fossil fuel (such as coal), emissions higher than with hydroelectricity, other nonfossil sources, or lower-carbon fossil fuels such as natural gas	Battery size, durability, and storage capacity need to be significantly developed in order to improve vehicle range, reduce production costs, and enable application in larger vehicles such as trucks; other performance issues, such as energy loss during cold weather, recharging time, and poor acceleration, need to be addressed; smaller electric vehicles with limited range may be used for neighborhood travel until battery shortcomings are overcome; sequestration of carbon emissions may be option for electric power plants that use carbon-rich fuels, although many technical, environmental, and economic issues need to be addressed

(*continued on next page*)

Table 3-3 (*continued*)

Power Train or Fuel	Vehicle Emissions of CO_2 and Other Pollutants	Fuel Cycle Emissions of CO_2	Technical and Market Barriers
Hybrid electric drive and ICE	CO_2, NO_x, VOCs, and particulates reduced relative to conventional vehicles, mainly because of increased fuel economy; size of reduction will depend on changes in driving cycle, vehicle size, type of fuel used, engine design, and other factors	CO_2 and VOCs emitted during petroleum extraction, refining, and distribution; emissions of CO_2, NO_x, and other pollutants from electricity production will depend on type of electric storage device used in vehicle and whether charged with electricity generated by carbon-intensive fuels (issues same as above)	More complex and costly because of redundant drives; alternative types of hybrid systems—differing in electric storage and fuel combustion units—at different stages of development
Electric drive fuel cell or ICE vehicle using hydrogen	Electric drive fuel cell vehicle: none ICE vehicle: very low emissions of CO_2, particulates, VOCs, and CO, mainly by engine lubricants; NO_x emitted during high-temperature combustion process	Nonfossil sources of hydrogen, such as nuclear, solar, or biomass, can lead to zero carbon emissions; fossil sources of hydrogen will generate carbon emissions unless captured	Overall cost and size of fuel cell need to be reduced; safety of mobile hydrogen storage unit on board needs to be ensured; less costly, more dependable, and safer systems for hydrogen transmission and delivery also needed; low-carbon means of mass producing hydrogen must be developed further, including CO_2 sequestration methods

Fuel cell electric using chemical fuels reformed on board vehicle	Reduced CO_2 emissions relative to conventional ICE vehicles, mainly because of increased energy efficiency of fuel cell; zero emission of NO_x and particulates; VOCs emitted from chemical fuels, which may include methanol, gasoline, or other hydrocarbon fuels	Net greenhouse gas emissions depend on feedstock. Alcohol derived from cellulosic biomass has greatest potential for emission reduction (see below); alcohol derived from fossil sources would produce high carbon emissions unless sequestered; if gasoline or other hydrocarbon fuels are reformed, emissions will also depend on entire fuel production, transmission, and distribution cycle	Reformer and fuel-cell system size and cost need to be reduced; emissions and environmental issues related to methanol production from fossil fuel or biomass must be addressed (see below)
ICE using alcohol fuels derived from cellulosic biomass	CO_2 emissions largely offset by CO_2 absorbed from atmosphere by plants used as biomass feedstock; NO_x and VOCs emitted by high-temperature combustion process and fuel vapor	Some greenhouse gases emitted during biomass production and conversion to alcohols, but much less than in conventional processes that use energy-intensive starch and sugar crops for making alcohol fuels	Many economic issues remain concerning biofuel production processes; environmental and agricultural issues related to mass production of energy from crops must be addressed, although environmental effects promise to be less per unit of fuel produced than for corn-derived ethanol; vehicle cold-start performance must also be improved

Note: ICE = internal combustion engine; VOCs = volatile organic compounds.

greenhouse gases and conventional pollutants (as discussed in Box 3-8). The reductions, however, are often modest and could perhaps be equaled through further improvements in gasoline- and diesel-engine technologies, including vehicle fuel economy. The focus of this section is on longer-range technologies that could bring about much greater reductions in CO_2 and other greenhouse gas emissions.

The status of several low-emission technologies is described next, followed by discussion of several other efforts under way to spur low-emission technology development. A hypothetical scenario is then presented to illustrate how a conversion to low-emission vehicles could influence long-range trends in transportation emissions of CO_2. Appendix B provides some estimates of federal funding of alternative vehicle and fuel programs.

Box 3-8

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Alternative-Fuel Vehicles Now in Use and Greenhouse Gas Issues

According to DOE, there are nearly 400,000 alternative-fuel vehicles in operation (on the road) in the United States (DOE 1996d, 1–2). The majority of these vehicles (about 60 percent) are fueled by liquefied petroleum gas (LPG). Vehicles using compressed or liquefied natural gas (CNG, LNG) compose most of the remainder with fewer than 10,000 alcohol (methanol and ethanol) and electric vehicles in use. Most are in government or commercial fleets.

Research, development, and demonstration of many of these alternative fuel vehicles accelerated during the 1970s out of concern over the oil embargoes by the Organization of Petroleum Exporting Countries and U.S. dependence on foreign oil. Among the impediments to the widespread use of these alternative fuels is their low energy density relative to gasoline and diesel fuel, reducing vehicle operating range and interior space. The vehicles also tend to be more costly to manufacture and operate.

More recently, some of the alternative fuels have been promoted as a means of reducing emissions of pollutants detrimental to human health, such as NO_x, hydrocarbons, carbon monoxide, and particulates. In some cases, they also have advantages over conventional motor vehicles in terms of greenhouse gas emissions. Natural gas, for instance, has lower CO_2 emissions because it is less carbon-rich than petroleum. Another advantage of natural gas is that it is abundant and affordable to produce and an extensive infrastructure system is already in place for its supply and distribution. A disadvantage of natural gas fuel—which consists mostly of methane—is that it is itself a greenhouse gas; hence, leakage of fuel during production, distribution, and use is a concern. Another practical disadvantage is that on-board fuel storage units (even those capable of handling CNG) occupy considerable volume, which increases vehicle size and cost.

To the extent that they are denser in energy than gaseous fuels, the alcohol fuels (ethanol and methanol) are sometimes viewed as more practical alternatives. Few such vehicles are in operation, however. The wide-scale use of alcohol fuels raises a number of economic and environmental issues, including consequences of fertilizer use. Some of the fuels, particularly methanol, pose safety and toxicity hazards. There are also a variety of emission trade-offs that warrant consideration. For example, the extent to which these alcohol fuels would confer net emission benefits for both local air pollutants and greenhouse gases would depend on how they are produced. If coal is used as the feedstock for methanol, greenhouse gas emissions could increase significantly. Because production of ethanol from corn and food crops is energy intensive (using fossil fuel), net greenhouse gas reductions could be small. As discussed later in the text, ethanol can be produced from cellulosic sources—such as wood—that produce much lower net emissions of carbon. The latter sources have the potential to emit much less greenhouse gases than the conventional ethanol produced from grains.

Status of Some Low-Emission Technologies

Electric-Battery and Hybrid Vehicles

At present, the low-emission technology in the most advanced stage of development is the electric-battery vehicle, already in use on a limited basis.[20] Provided that they are recharged with electrical energy from low-emission nuclear, solar, and hydroelectric sources, these vehicles have the potential to produce extremely low emissions of CO_2. The restricted driving range of battery-operated vehicles and their high price have limited their market penetration (IPCC 1996b, 699).

These limitations have led some to propose a new vehicle type for near-term applications of the battery technology: local or neighborhood-oriented vehicles. Smaller electric-battery vehicles, for instance, would be used as urban cars in multicar households, supplemented by a larger internal combustion engine (ICE) vehicle that could be used on longer trips (Sperling 1994; Stein et al. 1994). For more general use of electric-battery vehicles, a lower-cost and longer-lived battery would be required (IPCC 1996b, 590–600). Among the efforts under way to improve battery technology are those sponsored by the Advanced Battery Consortium, a public-private partnership. The consortium is seeking to reduce the cost and improve the energy storage, durability, and power capabilities of electric-vehicle batteries.

Under present circumstances, the net reduction in CO_2 emissions from a fleet of battery-powered vehicles would vary significantly by location within the country. In areas where a large share of electricity generation plants are powered by coal, as in the Midwest, the CO_2 savings might be low or negative, whereas in areas such as the Pacific Northwest that are served by hydroelectric plants, the savings could be larger (DeLuchi 1991; IPCC 1996b, 590). To address this problem (and that of CO_2 emissions from power plants generally), some researchers have been examining ways to sequester the CO_2 emitted by power plants burning fossil fuel, for instance, by pumping the emissions from coastal power plants through pipelines to the deep oceans or by storing the emissions in vacant oil and gas wells or saline aquifers (IPCC 1996b, 597). Determining how best to capture and store (sequester) CO_2 will require considerable research to understand and overcome the technical, environmental, and cost issues involved. Carbon sequestration methods might also be used for several of the other technologies and fuels (including hydrogen production) reviewed in this section.

An alternative to battery-powered electric vehicles—one with earlier market potential—is the electric hybrid, which incorporates some form of ICE and an electric storage device. For instance, electricity storage and generation can be accomplished through smaller batteries, flywheels, ultracapacitors, or other means. The supplemental engine could be fueled by petroleum, diesel, other hydrocarbon fuels, or alcohols. Gas turbine technologies might also substitute for the ICE. Use of these carbon-based fuels would produce CO_2 emissions, though in much smaller quantities than conventional ICE vehicles. The extent to which the electric drive would produce greenhouse gas emissions would depend on the electricity fuel source, engine type, and drive design.

Hybrids, which have been developed in prototype, would overcome the range, power, and other performance disadvantages of pure battery-powered vehicles. Because of the dual propulsion systems, these vehicles would be more complex to design and would cost more than conventional vehicles; however, they would offer significantly higher fuel economy and thus the prospect of large reductions in CO_2 emissions. As discussed below, the PNGV research program has been examining diesel-electric hybrids (among other technologies) as a means of substantially increasing vehicle fuel economy.

Hydrogen and Fuel Cell Vehicles

Hydrogen used in an ICE or to generate electricity in fuel cells has long been recognized as a potentially important fuel for reducing carbon emissions. Both types of vehicles—with a hydrogen-fueled ICE or fuel cell—would offer dramatic reductions in CO_2 emissions; the latter would also produce virtually no conventional pollutants (e.g., particulates, NO_x). Because they generate energy through electrochemical reactions (transforming oxygen and hydrogen into water), fuel cells are much more efficient energy converters than ICEs. With hydrogen as the fuel source, their primary emission is water vapor. The hydrogen ICE would emit NO_x (created during the high-temperature combustion process) and small amounts of hydrocarbons and particulates produced by engine lubricants.

The extent to which these vehicles can reduce net greenhouse gas emissions will depend largely on the source of hydrogen. Options for producing hydrogen include chemical processing of natural gas, coal, or biomass (Williams 1994a; Johansson et al. 1996). A by-product of hydrogen produced in this way is CO_2, both from the hydrocarbon feedstock and the energy required for chemical processing. Presumably, many of these carbon emissions would need to be sequestered to minimize atmospheric emissions (Williams 1996). If carbon-rich coal is the feedstock, effective sequestration would be essential. Some analysts have ventured that hydrogen will one day be mass produced without carbon by-products by electrolytically splitting water using solar power and other renewable and low-carbon sources of feedstock electricity, such as nuclear, wind, or hydroelectric power (Sperling 1995, 90; Williams 1994a; Greene 1996, 260).

A number of technical barriers must be overcome if hydrogen is to be used in a mobile vehicle, whether powered by a fuel cell or an ICE. These barriers include the need to develop systems for ensuring the safe long-distance transmission and delivery of hydrogen. Likewise, safe and leakproof means must be developed for storing enough hydrogen on board the vehicle for an acceptable driving range. One way to avoid long-distance transmission of this fuel is by producing it at or near refueling stations, for instance, by processing methanol, natural gas, gasoline, and other chemicals. Alternatively, these materials can be processed on board the vehicle using a reformer. In either case, fuel efficiency is reduced and CO_2 is produced by both the reformation process and production of the chemical fuel, offsetting a portion of the greenhouse gas savings (depending on the chemical fuel). Prototype fuel cell vehicles with on-board reformers have been developed, but smaller, more durable, and more affordable fuel-processing systems are needed.

Because of these and other technical obstacles, many analysts believe that hydrogen-based vehicles will require many more years of research and development for use in transportation. Nevertheless, the prospect of the substantial reductions in greenhouse gas emissions and other pollutants offered by hydrogen is a compelling reason for further research and development.

Biomass-Fuel Vehicles

A fuel source that has been the subject of increasing interest in recent years is renewable biomass that can be produced with minimal fossil fuel. Of particular interest is the production of ethanol and methanol from advanced processes using cellulosic biomass. These alcohol fuels offer the potential for use in ICEs in pure form, in mixtures with other fuel (such as gasoline), in hybrid vehicles, or as a chemical fuel for reformation in fuel cell vehicles (DeCicco and Lynd 1995).

The advantage of these fuels is that production of their feedstock is not as carbon- or land-intensive as grain crops. Most alcohol fuels used in transportation are derived from corn and other starch or sugar crops that require significant amounts of energy for crop production. However, alcohol fuel produced from certain types of cellulosic sources—from wood, grasses, and wastes—involves fundamentally different farming and production processes and much lower net carbon emissions (Lynd et al. 1991; Wyman et al. 1993). Because wood and grass resources are renewable and store vast amounts of carbon, most of the CO_2 emitted during the use of cellulosic biofuel could be offset by the additional CO_2 removed from the atmosphere by the renewable wood and grass crops used as feedstock.

An important consideration in the development of biofuels is the environmental and agricultural effect of feedstock production, for instance, on use of forest-, range-, and farmland; soil fertility; food production; and water resources (Williams 1994b).[21] Because more cellulosic crops can be produced per unit of land (and on more marginal farmland) and with less energy input than can sugar or starch crops, they offer the potential for reduced environmental effects relative to the alcohol fuels that are currently produced for mixing with gasoline. If they are used as a more general replacement for gasoline, however, the scale of cellulosic crop production would be much larger than is currently the case for corn and other starch and sugar crops. Assessing the environmental effects of starch and sugar crop production is complex; these effects will warrant more attention as these fuel sources are developed.

DOE's National Renewable Energy Laboratory, which has chosen cellulosic-derived ethanol as a high priority for research, is beginning to examine the environmental issues surrounding energy crop production as well as a variety of other technical and economic issues (Graham et al. 1995; Riley and Tyson 1994; McNutt et al. 1996).

Other Efforts To Spur Low-Emission Technology Development

Though recently amended, the most significant U.S. effort to encourage the development and use of low-carbon technologies is under way in California. In 1990, the California Air Resources Board instituted a requirement that major automobile manufacturers begin selling so-called zero-emission vehicles (ZEVs) in California by 1998.[22] New York and Massachusetts have adopted similar ZEV requirements. To spur demand for new technologies and fuels, several states, led by California, also offer tax and rebate incentives for private and commercial use of very-low-emission vehicles and inducements or requirements for government agencies to use alternative-fuel vehicles in their fleets (DOE 1996d, 31–33).

The California ZEV mandate targets air pollutants rather than CO_2. As a practical matter, however, the mandate for early production of ZEVs was tantamount to requiring the mass production of electric-battery vehicles, whose potential effect on greenhouse gas emissions is large in California but elsewhere depends on the source of electricity and whether it is carbon-intensive.

The longer-term intent of the California mandate—as is befitting its performance-oriented design—is to generate greater automobile manufacturer interest in a variety of electric-drive technologies. Proponents of such performance-oriented mandates argue that they provide the incentive for R&D, the latitude to explore other technologies, and more certainty about the future. This technology-forcing approach focuses the task of R&D on the private sector. Opponents of this approach argue that if the performance standards are unrealistic in recognizing technological constraints, leading to impractical time frames for research, development, and deployment, they can be costly to suppliers and consumers and—perhaps worse—can serve as a distraction, drawing attention away from other more valid options for controlling emissions.

Another general approach, which may or may not be coupled with supplier mandates, is to lend government support to the development of new technologies. Technology demonstration and deployment and customer incentives could be part of this approach. At a minimum, public-sector R&D can support private-sector initiatives by assisting with basic research on materials, structures, and scientific development generally. In the defense sector, the government has played a more collaborative role with the private sector in supporting basic as well as applied research. Aspects of this approach, particularly with respect to applied R&D, have recently been adopted for the automotive sector through the Advanced Battery Consortium (discussed earlier) and the PNGV research program.

The goals of the PNGV program are among the most ambitious of any R&D activity under way. PNGV seeks to develop a new passenger car that is comparable with current vehicles in performance and price while achieving up to three times the fuel economy. Although reducing CO_2 emissions is not the explicit goal of PNGV, such a large improvement in fuel economy would yield substantial reductions in CO_2. It would also require significant changes in vehicle technology. Because another National Research Council panel is reviewing the PNGV program (National Research Council 1994, 1996, and 1997), its goals and accomplishments were not examined in this study. It is important to note, however, that the PNGV program is under a tight deadline to develop a concept vehicle by 2000. The deadline has influenced the kinds of technologies being explored, particularly limiting the consideration of technologies requiring much longer development, such as the fuel cell. Hence, one of the recommendations of the Research Council review of the PNGV program is that complementary capabilities be explored to further the development of longer-range technologies that cannot meet the more ambitious prototype deadlines (National Research Council 1996 and 1997).

Finally, another area in which public-sector support may be valuable is in stimulating the exploration and development of infrastructure required to support alternative-fuel vehicles, which may differ significantly from that now in place for conventional vehicles. For instance, if new technologies require radically different energy production, transmission, and distribution systems, as is likely for fuel cells, the early exploration of these needs may be valuable in overcoming obstacles to private-sector development and technology deployment. The need for such a complementary program was also identified in the Research Council review of the PNGV program.

Illustration of Effect of Low-Emission Technologies on CO_2 Emission Trends

Given the many uncertainties involved in development of low-emission technologies, there is no good way to project how effective the types discussed here (or others) could be in reducing CO_2 emissions during the next several decades. Perhaps the best that can be done is to make some general projections of how long it might take for new technologies to be developed and introduced into the fleet and of how much they will lower emissions of CO_2 and other greenhouse gases on a per-vehicle or per-mile basis.

Figure 3-6 demonstrates how CO_2 emissions might be reduced following the development of and gradual conversion to very-low-emission vehicles. The hypothetical scenario, which is developed in Appendix A, assumes that these new vehicles emit only one-third as much CO_2 (or other greenhouse gas equivalents) per mile as conventional (baseline) vehicles. Starting in 2010, the new vehicles are introduced into the fleet, so that by 2020 they account for 5 percent of total VMT. Their popularity quickly grows as the technologies become more mature and consumer familiarity increases. Thus, by 2030 they account for 20 percent of VMT, rising to nearly half of all VMT by 2040.

The purpose of this scenario is to illustrate graphically that the development and introduction of new technologies—even with fairly aggressive assumptions about effectiveness in reducing CO_2 emissions and introduction—may require several decades to bring CO_2 emissions back to present levels. Most evident are the years of lead time required for low-emission technology development and the lags that are likely in expanding consumer acceptance and use. Although this is only one of many plausible scenarios, it portrays the importance of early research, development, and demonstration.

International Efforts to Reduce CO_2 Emissions

The discussion thus far has focused almost exclusively on opportunities for reducing the contribution of the U.S. transportation sector to green-

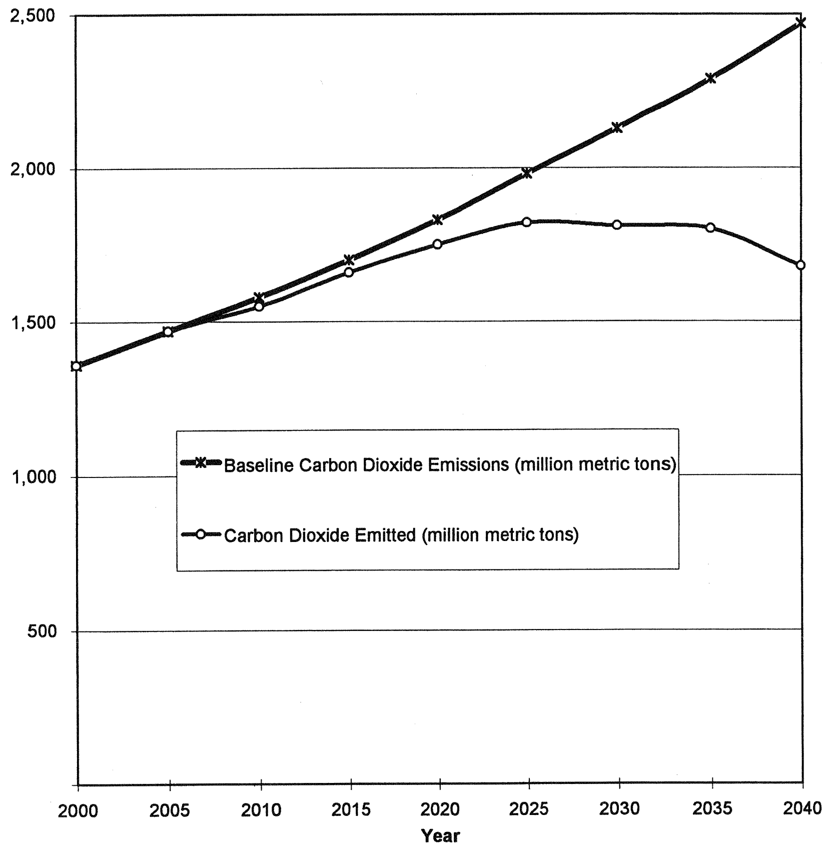


Figure 3-6 Scenario assuming policies to develop and introduce vehicles offering very low emissions: resultant trends in carbon dioxide emissions, 2000 to 2040. (See Appendix A for assumptions and calculations.)

house gas buildup. Inasmuch as CO_2 buildup is a global concern, possible actions to reduce greenhouse gas buildup must be considered in an international context and across economic sectors (National Research Council 1992b, 66–67). Indeed, since no individual nation can undertake meaningful abatement on its own, international cooperation is essential.

Developing such a cooperative framework for controlling greenhouse gas buildup and climate change was a focal point of the 1992 United

Nations Conference in Rio de Janeiro, Brazil. The Rio conference led to an international climate change treaty (known as the Framework Convention on Climate Change) that has been ratified by more than 150 nations. The stated objective of the Framework Convention is to "achieve . . . stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (DOE 1995, 8; United Nations 1992). Under the auspices of the Framework Convention, efforts are under way to develop and promote cooperative means of curbing greenhouse gas emissions in the most cost-effective and politically acceptable manner across nations and economic sectors. Recently (in remarks before the Second Conference of the Parties Framework Convention on Climate Change in Geneva) U.S. Undersecretary of State for Global Affairs Timothy E. Wirth announced U.S. intentions that negotiations continue, focusing on "an agreement that sets a realistic, verifiable, and binding medium-term emissions target."[23]

So far, however, progress in curbing CO_2 emissions has proved elusive, in large part because the activities and products that generate CO_2 are so pervasive, leading to controversy about who should take action and how. Whereas international cooperation is essential, it is widely recognized that if reductions in CO_2 and other greenhouse gas emissions are to be pursued in the most efficient manner, each nation and economic sector may warrant different emission reduction strategies. Emphasis would be placed, for instance, on reducing emissions from those nations and sectors in which the cost of doing so is lowest (National Research Council 1992b, 48; IPCC 1996c). According to this approach, some sectors—perhaps even the transportation sector—could help reduce emissions from others. For example, motorists could help pay for the conversion of coal-powered electricity plants to natural gas or contribute funds to cover the cost of sequestering carbon through reforestation or forest preservation programs (National Research Council 1992b; IPCC 1996c). Likewise, if strategies to reduce CO_2 and other greenhouse gases prove more costly and difficult to accomplish in other sectors, they may be better suited to assisting in the reduction of emissions from the transportation sector.

Signatories to the United Nations' Framework Convention on Climate Change are in the process of developing such cooperative mechanisms through what is often referred to as "joint implementation." The Framework Convention and its support for joint implementation have spawned numerous proposals for multilateral mechanisms, ranging from tradable emission credits and international carbon taxes to collaborative research, development, and technology transfer programs (IPCC 1996c). Some of these joint implementation proposals and mitigation measures (e.g., carbon sequestration) are now being examined for application in pilot programs. If such international actions are explored more fully and eventually implemented, the U.S. transportation sector will likely be affected and have an important role in ensuring their success. Developing institutional arrangements for the participation of the U.S. transportation sector in these efforts could prove valuable.[24]

SUMMARY AND ASSESSMENT

The CO_2 emitted by human activities is causing concentrations of this important greenhouse gas to accumulate in the atmosphere. The buildup of greenhouse gases has become an international concern because of the potential for warming of the earth's surface and resultant disruptions in global climates and other natural processes and systems. Although a great deal of uncertainty remains about the magnitude, mix, and timing of these potential effects, as well as their ecological, social, and economic ramifications, the possibility exists that the repercussions will be large and long lasting.

CO_2 contributes more than half of the enhanced warming believed to be caused by greenhouse gas buildup. Because rising concentrations of CO_2 in the atmosphere can persist for hundreds of years, the enhanced warming may be long lasting. The prospect that CO_2 emissions will have such a prolonged effect is of additional concern because this greenhouse gas is emitted by so many human activities, transportation being among the foremost and fastest-growing.

Transportation is fueled predominantly by petroleum, a fossil fuel rich in carbon that forms CO_2. The U.S. transportation sector, through its use of petroleum, is the source of about 5 percent of the annual CO_2 that is building up in the atmosphere through human activities. No other energy-use sector in the United States or elsewhere contributes a substantially larger share of global CO_2 emissions. Perhaps no other sector faces as complex a challenge in curbing these emissions.

Policy makers and the general public are not yet prepared to take decisive action to curtail CO_2 emissions. Further scientific evidence and understanding of the implications of acting, including the cost of alternative policies, are needed. The review of possible options in this chapter suggests that if the need to curb CO_2 emissions from the U.S. transportation sector becomes more compelling, there will be no easy, fast, or certain means. In other words, there are no panaceas for reducing CO_2 and other greenhouse gas emissions from transportation. Failure to acknowledge this reality can lead to overly optimistic expectations about the prospects for quickly changing transportation patterns and technologies should such changes be warranted. On the other hand, inordinate emphasis on the magnitude of the challenge may discourage the early and constructive actions that will be necessary for progress. A real but achievable challenge is to enable transportation to fulfill its economic and social functions in providing mobility while controlling negative effects such as greenhouse gas emissions.

The transportation system is inextricably linked to slowly changing land use patterns, large and durable infrastructure systems, and a host of well-established patterns by which individuals have organized their daily activities and habits. Making significant changes in these systems in the short to medium term—that is, in one or two decades—would be especially demanding. The potential is much greater for making changes over longer time frames, provided that preparatory steps are taken soon. This review suggests that if large reductions in emissions become necessary, deferral of the initial steps will make the task more difficult, and valid options to curb emissions will dwindle. Further growth in population and motor vehicle travel raises the possibility that future efforts to roll back transportation emissions will be increasingly difficult and disruptive.

Options for reducing motor vehicle emissions of CO_2 consist of measures to slow growth in automotive travel, raise vehicle fuel efficiency, increase petroleum fuel prices, and further the development and introduction of technologies that promise much lower emissions of CO_2 and other greenhouse gases. Table 3-4 identifies some specific policy

Table 3-4 Various Options for Reducing CO_2 Emissions from U.S. Motor Vehicle Transportation: Example Policy Options, Scenarios, and Key Uncertainties and Research Needs

			Plausible Change in CO_2 Emissions Relative to Baseline Growth (%)			
Broad Strategy	General Policy Options	Hypothetical Scenarios[a]	After 20 years (2020)	After 40 years (2040)	Key Uncertainties	Research and Implementation Needs
Reduce demand for motor vehicle travel	Integrate on regional basis planning of land use and transport services and infrastructure development Create more inducements for ridesharing and telecommuting Raise vehicle sales and registration fees Charge more for highway use and parking	Annual growth in national VMT 20 percent lower than baseline growth rate as result of new development patterns and widespread implementation of transportation demand management measures	−5 to −10	−10 to −20	Effects of ridesharing inducements in generating more travel from more dispersed land use patterns Effect of road pricing in diverting travel to other roads and time periods Extent to which denser land use patterns and transit investments influence total motor vehicle travel	Overcoming jurisdictional and institutional barriers to coordinated planning of land use and transport infrastructure investments Developing alternative community designs and land use patterns that reduce travel and are acceptable to the public Devising political institutions to implement regional road pricing and other travel demand management measures Overcoming public opposition to restraints on motor vehicle travel

(*continued on next page*)

Table 3-4 *(continued)*

Broad Strategy	General Policy Options	Hypothetical Scenarios[a]	Plausible Change in CO_2 Emissions Relative to Baseline Growth (%): After 20 years (2020)	After 40 years (2040)	Key Uncertainties	Research and Implementation Needs
Raise conventional vehicle fuel economy	Enhance traffic flow through more efficient highway operations and development and deployment of intelligent transportation systems Institute monetary incentives for fuel economy such as feebates and higher "gas-guzzler" taxes Require or provide incentives for automobile manufacturers to supply vehicles with higher fuel economy Aid industry in the development of fuel-saving technologies	Average fuel economy of new vehicles (all types) grows average of 1.5% per year, representing near-doubling from existing levels by the middle of next century	−10 to −20	−30 to −40	Degree to which improving traffic flow and reducing congestion increase travel demand Effect of higher vehicle fuel economies on spurring travel (e.g., rebound effect) Extent to which growth in truck traffic will contribute to rising CO_2 emissions and how to manage this contribution most efficiently	Generating consumer interest in fuel economy with complementary market incentives Determining more effective means of eliciting supplier interest in development of fuel-saving technologies Reducing various cost, performance, safety, and environmental effects associated with specific fuel-saving technologies Establishing the most appropriate government role in furthering R&D of fuel-saving technologies

Raise energy prices to restrain travel demand and spur technological change	Increase fuel taxes (e.g., higher gasoline tax) Institute carbon tax	Petroleum prices rise an average of 3% per year, up about \$1 per gallon by 2020 and about \$3 per gallon by 2040 compared with current prices	−10 to −20	−30 to −40	Long-term travel and fuel-efficiency responses by consumers to higher fuel costs Effect of fuel tax or carbon-content tax in skewing consumer and supplier interest in favor of low-carbon-emitting technologies	Generating public interest in controlling petroleum use and greenhouse gas emissions Implementing measures to minimize economic and social disruption from higher energy costs Overcoming political impediments to fuel tax increases
Further development and use of very-low-emission technologies	Support R&D exploring and advancing zero-emission technologies Provide incentives or require industry to develop and introduce low-emission vehicles Institute carbon tax and other consumer-oriented inducements (e.g., tax exemptions) for purchase of low-emission vehicles	Share of vehicle fleet consisting of low-carbon emitting vehicles—those producing two-thirds less CO_2 per mile than current vehicles—grows gradually to account for nearly half of fleet VMT by 2040.	0 to −5	−25 to −35	Time horizon for development and commercialization of new technologies Cost and performance effects of new technologies Cost-competitiveness relative to other higher-emission technologies	Determining the most appropriate government role in furthering R&D of low-emission technologies Researching long-range infrastructure, safety, environmental, and economic effects and needs of promising technologies

[a]The scenarios are presented in the text and detailed in Appendix A.

measures reviewed in this chapter together with illustrative projections of changes in long-range emission trends. This assessment suggests the following summary points:

- Measures aimed at restraining motor vehicle travel offer the potential for some early but modest reductions in CO_2 emissions. More significant reductions would require fundamental changes in land use and other factors influencing travel behavior. Such changes would require many decades of concerted effort and public support.
- Increasing vehicle fuel economy through consumer inducements, fuel-economy standards, and advances in fuel-saving technology offers the potential to counter growth in petroleum consumption and CO_2 emissions caused by increasing travel demand. Increases in fleet fuel economy on the order of 1 to 2 percent per year have been achieved in the past. These improvements subsided, however, when fuel prices stabilized and began to decline. Successful strategies aimed at achieving higher vehicle fuel economies will require complementary actions to elicit stronger consumer interest in fuel economy as a valued attribute.
- The achievement of significant reductions in CO_2 emissions will likely require a combination of changes in travel behavior and vehicle technology. Higher fuel prices influence these two factors by reducing travel demand and prompting motorist interest in vehicle fuel economy. Higher fuel prices caused by a tax based on fuel carbon content are even more likely to boost consumer and supplier interest in low-emission technologies.
- The advent of radically different transportation vehicles and fuels that produce much lower levels of CO_2 may eventually cause an absolute decline in CO_2 emissions from transportation. There is genuine risk, however, in treating such an outcome as inevitable, especially given the numerous institutional, cost, and infrastructure barriers to technology development and deployment. Early measures to address these potential impediments may prove valuable to furthering the development and introduction of low-emission technologies.

Each of the strategies discussed in this chapter is associated with technical, political, and economic uncertainties, many of which are mentioned in Table 3-4. Currently there is a lack of, and a need for, policy research to explore some of these issues and to develop information on the cost-effectiveness of various options and strategies. Until a good number of these uncertainties are settled or better understood, policy makers and the public are likely to remain inadequately informed about the most appropriate courses of action.

NOTES

1. The IPCC was established jointly in 1988 by the United Nations Environmental Program and the World Meteorological Organization (WMO) to assess available scientific information on climate change, associated environmental and socioeconomic impacts, and response options. Consensus IPCC evaluations are widely viewed as representing the prevailing scientific judgment about greenhouse gas buildup and its potential consequences.
2. Some of these manmade compounds, especially the CFCs, are threats to the earth's protective ozone layer, while also acting as greenhouse gases.
3. Because of the relative abundance of CO_2 in the atmosphere, additional accumulations actually have an increasingly smaller—though still significant—heat-trapping effect. By comparison, emissions of greenhouse gases such as N_2O that are much less plentiful in the atmosphere have greater heat-trapping potential, at least in the near term. The overall effect of individual greenhouse gases emitted into the atmosphere depends on their concentrations and life spans. If anthropogenic emissions of greenhouse gases were to cease today, the atmospheric concentrations of many shorter-lived gases would return to balance in a matter of years, whereas it is theorized that CO_2 concentrations would take many centuries to reach their natural balance.
4. This gram-per-mile calculation corresponds well with other estimates. DeLuchi (1991), for instance, calculates that light-duty vehicles averaging 30 miles per gallon emit about 345 grams of CO_2-*equivalent* emissions per mile, not including emissions of CO_2 and other greenhouse gases occurring as a result of the production and distribution of motor vehicles and fuels. This estimate differs from that developed here since it includes only light-duty vehicles and assumes fuel economies that are higher than current levels. Another difference is that it uses CO_2-equivalent measurements (using a 100-year time span) in order to include the effect of other greenhouse gases emitted by motor vehicles. When factoring in upstream CO_2-equivalent emissions from fuel extraction, production, and distribution, DeLuchi estimates that CO_2-equivalent emissions would average about 25 percent higher per mile, or 430 grams per mile.
5. The U.S. Department of Transportation's Bureau of Transportation Statistics also estimated that motor vehicles emitted about 1,200 to 1,300 million metric tons of CO_2 in 1992 (DOT 1995, 78).

6. Fertilizer use amplifies the natural flux of nitrous oxide from soil.
7. Tropospheric aerosols are increasingly recognized as having an important role in counteracting some greenhouse warming, especially in the regions where they are concentrated (IPCC 1996a, 4).
8. There is evidence that tropospheric ozone concentrations in the Northern Hemisphere have increased since preindustrial times, largely as a result of fossil fuel combustion. Their effect on global warming, however, is not yet well characterized (IPCC 1996a, 4).
9. Estimates of the contribution of deforestation to CO_2 buildup vary from 10 to 45 percent (IPCC 1996a, 17; IPCC 1996b, Chapter 24).
10. It is important to make a distinction between biomass fuels that contain "cycle" carbon and those that are rich in, or are produced with energy that contains, "fossil" carbon. The former do not cause a net increase in CO_2 levels in the atmosphere since the biomass feedstock absorbs CO_2. The latter do cause an increase, for reasons explained earlier. This distinction is raised again later in the chapter in the discussion of biofuels.
11. Implied is that the carbon tax will be applied at all stages of energy products, so that, for instance, the price of electricity derived from carbon-rich coal would rise relative to the price of electricity derived from low- or zero-carbon sources.
12. Experiences of other countries with some policy measures are discussed in this section, especially in cases where U.S. experience is limited. The committee recognizes that differences in economic, political, and social circumstances among countries and regions of the world will make foreign experiences more or less applicable to the United States.
13. Federal law exempts from income tax obligation the first $155 per month in employer-provided parking benefits.
14. The marginality problem recognizes that most development of the last 30 to 40 years has been dispersed, that new community designs emphasizing transit and nonmotorized travel are most likely to be adopted only in new developments at the periphery of established communities or in emerging metropolitan areas, and that new developments would therefore have to be far denser to raise the average density of a metropolitan area.
15. Before the law was passed, several studies predicted large fuel savings as a result of lower freeway speed limits. DOT, for instance, estimated that 200,000 barrels of petroleum—or about 3 percent of daily demand—would be saved each day by setting the maximum speed limit at 55 miles per hour (French and Bishop 1973).
16. Again, "upstream" emissions are not considered. These may be lower for diesel engines (DeLuchi 1991).
17. The annual rate of growth in fuel economy for the entire fleet would average 1.35 percent per year according to scenario calculations. This rate is slightly lower than that for new vehicles because of the time required for new vehicles to filter through the fleet.
18. In addition, many fuel price elasticities were calculated during a period when the fuel economy standards of the CAFE program had begun to take effect, influ-

encing travel demand and the fuel-efficiency characteristics of the fleet (DOE 1996c, 5–14).

19. State and local governments have a long history of using fuel taxes to pay for highway improvements. Such taxes were introduced in most states before World War II to fund highway paving programs. The practice of dedicating fuel taxes to highway projects was formalized in federal policy with the advent of the federal-aid user-financed Highway Trust Fund in 1956.
20. DOE estimates that about 4,000 electric vehicles (mostly battery powered) are used on roads in the United States (DOE 1996d, 14).
21. For an interesting and thorough review of these issues and ways of making biomass environmentally attractive, see the discussion by Williams (1994b).
22. The requirement originally called for major automobile manufacturers selling cars in California to increase sales of ZEVs to 2 percent of total in-state sales of light-duty trucks and passenger cars in 1997. This figure was slated to rise to 5 percent in 2001 and 10 percent 2 years later. In March 1996, the 2 and 5 percent requirements were suspended. In its place, major automobile manufacturers are to place up to 3,750 advanced battery ZEVs in California by 2001. The 10 percent requirement for 2003 was retained.
23. U.S. Department of State Dispatch, July 22, 1996, Vol. 7, No. 30, page 377.
24. Ford Motor Company, for instance, is supporting joint efforts by the Massachusetts Institute of Technology and Qinghua University in China that are aimed at assisting China in utilizing coal and other natural resources in the most economically and environmentally beneficial manner (personal communication with representative of Ford Motor Company).

REFERENCES

ABBREVIATIONS

DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
IPCC	Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
OTA	U.S. Congress Office of Technology Assessment
SPARC	Stratospheric Processes and Their Role in Climate Change
TRB	Transportation Research Board
WMO	World Meteorological Organization

An, F., and M. Ross. 1993. Model of Fuel Economy and Driving Patterns. Presented at the 72nd Annual Meeting of the Transportation Research Board, Washington, D.C.

An, F.M., M. Ross, and A. Bando. 1993. *How to Drive to Save Energy and Reduce Emissions in Your Daily Trip.* RCG/Hagler, Bailly, Inc., Arlington, Va.; University of Michigan, Ann Arbor, 10 pp.

Anderson, J.P., and H.M. Howitt. 1995. Clean Air Act SIPs, Sanctions, and Conformity. *Transportation Quarterly,* Vol. 49, No. 3, Summer, pp. 67–79.

Berman, M. 1996. The Transportation Effects of Neo-Traditional Development. *Journal of Planning Literature,* Vol. 10, No. 4, May, pp. 347–363.

Button, K. 1993. *Transport, the Environment, and Economic Policy.* Edward Elgar Publishing Limited, Aldershot, U.K., 161 pp.

Cambridge Systematics, Inc. 1996. *Making the Land Use Transportation Air Quality Connection,* Volume 5: *Analysis of Alternatives.* 1000 Friends of Oregon, Portland, May.

Cantor, R., S. Henry, and S. Raynor. 1992. *Making Markets: An Interdisciplinary Perspective on Economic Exchange.* Greenwould Press, Westport, Conn.

Cervero, R. 1992. Futuristic Transit and Futuristic Cities. *Transportation Quarterly,* Vol. 46, No. 2, April, pp. 193–204.

Cervero, R. 1995. *BART@20: Land Use and Development Impacts.* Institute of Urban and Regional Development, University of California at Berkeley.

Cervero, R., and R. Gorham. 1995. Commuting in Transit Versus Automobile Neighborhoods. *Journal of the American Planning Association,* No. 2, Spring, pp. 210–225.

Cervero, R., and J. Landis. 1995. The Transportation Land Use Connection Still Matters. *Access,* No. 7, Fall, pp. 3–10.

Crane, R. 1996. Cars and Drivers in the New Suburbs: Linking Access to Travel in Nontraditional Planning. *Journal of the American Planning Association,* No. 1, Winter, pp. 51–65.

Dahl, C. 1986. Gasoline Demand Survey. *Energy Journal,* Vol. 7, Jan., pp. 67–82.

Dahlgren, J. 1995. Are HOV Lanes Really Better? *Access,* No. 6, Spring.

Davis, S.C. 1995. *Transportation Energy Data Book: Edition 15.* Report ORNL-6798. U.S. Department of Energy; Oak Ridge National Laboratory, Oak Ridge, Tenn.

Davis, W.B., Levine, M.D., Train, K., and Duleep, K.G. 1995. *Effects of Feebates on Vehicle Fuel Economy, Carbon Emissions, and Consumer Surplus.* U.S. Department of Energy, 143 pp.

Deakin, E.A. 1993. Policy Responses in the USA. In *Transport, the Environment, and Sustainable Development* (D. Banister and K. Button, eds.), E&Fix Spon, New York.

DeCicco, J.M., and M. Ross. 1994. Improving Automotive Efficiency. *Scientific American,* Dec. 1994, pp. 52–57.

DeCicco, J.M., and D. Gordon. 1995. Steering with Prices: Fuel and Vehicle Taxation as Market Incentives for Higher Fuel Economy. In *Transportation and Energy: Strategies for a Sustainable Transportation System* (D. Sperling and S. Shaheen, eds.), American Council for an Energy-Efficient Economy, Washington, D.C., and Institute for Transportation Studies, University of California, Davis.

DeCicco, J.M., and L. Lynd. 1995. *Combining Vehicle Efficiency and Renewable Biofuels to Reduce Light Vehicle Oil Use and CO_2 Emissions.* Presented at Transportation and

Energy Conference, Asilomar, Calif., July 31-August 2, Institute for Transportation Studies, University of California, Davis.

DeCicco, J.M, H.S. Geller, and J.H. Morril. 1992. *Feebates for Fuel Economy: Market Incentives for Encouraging Production and Sales of Efficient Vehicles*. American Council for an Energy-Efficient Economy, Washington, D.C.

DeLuchi, M. 1991. *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity*. Report ANL/ESD/TM-22. Center for Transportation Research, Argonne National Laboratory, Argonne, Ill.

Diamond, H., and P. Noonan. 1996. *Land Use in America*. Sustainable Use of Land Project, Island Press, Washington, D.C.

DOE. 1994. *Energy, Emissions, and Social Consequences of Telecommuting*. Report DOE-PO-0021.

DOE. 1995. *Emissions of Greenhouse Gases in the United States 1987–1994*. Report DOE/EIA-0573 (87–94). Energy Information Administration, Oct., 117 pp.

DOE. 1996a. *Annual Energy Outlook 1996: With Projections to 2015*. Report DOE/EIA-0383(96). Energy Information Administration.

DOE. 1996b. *International Energy Outlook 1996: With Projections to 2015*. Report DOE/EIA-0484(96). Energy Information Administration.

DOE. 1996c. *Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions: Lessons from Recent Literature*. Report DOE-PO-0047. Office of Policy and International Affairs, Chapter 5.

DOE. 1996d. *Alternative Fuel Vehicles Suppliers' Annual Report*. Washington, D.C.

DOT. 1993. *Transportation Implications of Telecommuting*. Transportation Systems Center, Cambridge, Mass., 219 pp.

DOT. 1994. *Transportation Statistics Annual Report*. Bureau of Transportation Statistics.

DOT. 1995a. *Transportation Statistics Annual Report*. Bureau of Transportation Statistics.

DOT. 1995b. *1995 Status of the Nation's Surface Transportation System: Condition and Performance*. Report to Congress.

Downs, A. 1992. *Stuck in Traffic: Coping with Peak-Hour Traffic Congestion*. Brookings Institution, Washington, D.C.; Lincoln Institute of Land Policy, Cambridge, Mass.

Espey, M. 1996. Explaining the Variation in Elasticity Estimates of Gasoline Demand in the United States: A Meta-Analysis. *The Energy Journal*, Vol. 17, No. 3, pp. 49–61.

FHWA. 1995. *Highway Statistics*. U.S. Department of Transportation.

French, A., and H. Bishop. 1973. *Analysis of Fuel Savings Through Reduced Speed Limits*. Report HHP-40. FHWA, U.S. Department of Transportation.

Gates, W. 1995. *The Road Ahead*. Viking Press, New York City.

Giuliano, G. 1995. The Weakening Connection Between Transportation and Land Use. *Access*, No. 6, Spring.

Gómez-Ibáñez, J.A., and K.A. Small. 1994. *NCHRP Synthesis of Highway Practice 210: Road Pricing for Congestion Management: A Survey of International Practice*. TRB, National Research Council, Washington, D.C.

Goodwin, P.B. 1990. A Review of New Demand Elasticities with Special Reference to Short- and Long-Run Effects of Price Changes. *Journal of Transport Economics and Policy*, Vol. 26, No. 2, pp. 155–170.

Graham, R.L., W. Liu, and B.C. English. 1995. *The Environmental Benefits of Cellulosic Energy at a Landscape Level.* Paper DE96008626. Presented at DOE Conference on Environmental Enhancement Through Agriculture, Boston, Mass., Nov. 16–17, 11 pp.

Greene, D.L. 1996. *Transportation and Energy.* Eno Transportation Foundation, Inc., Lansdowne, Va.

Helm, J.L., and S.H. Schneider. 1990. What to Do About CO_2. In *Energy: Production, Consumption, and Consequences* (J.E. Helm, ed.), National Academy of Engineering, National Academy Press, Washington, D.C.

Houghton, J. 1994. *Global Warming: The Complete Briefing.* Lion Books, Oxford, England.

Hsu, S., and D. Sperling. 1994. Uncertain Air Quality Impacts of Automobile Retirement Programs. In *Transportation Research Record 1444*, TRB, National Research Council, Washington, D.C.

IPCC. 1996a. *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report. Cambridge University Press, Cambridge, England, 572 pp.

IPCC. 1996b. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change—Scientific and Technical Analyses.* Contribution of Working Group II to the Second Assessment Report. Cambridge University Press, Cambridge, England, 878 pp.

IPCC. 1996c. *Climate Change 1995: Economic and Social Dimensions of Climate Change.* Contribution of Working Group III to the Second Assessment Report. Cambridge University Press, Cambridge, England, 448 pp.

Johansson, T.B., R.H. Williams, H. Ishitani, and J.A. Edmonds. 1996. Options for Reducing CO_2 Emissions from the Energy Supply. *Energy Policy*, Vol. 24, Oct.–Nov., pp. 959–1003.

Kelly, E. 1994. The Transportation-Land Use Link. *Journal of Planning Literature*, Vol. 9, No. 2.

Kessler, J. and W. Schroeer. 1995. Meeting Mobility and Air Quality Goals: Strategies That Work. *Transportation*, Vol. 22, Aug., pp. 241–272.

Lynd, L., J.H. Cushman, R.J. Nichols, and C.E. Wyman. 1991. Fuel Ethanol from Cellulosic Biomass. *Science*, Vol. 251, March 15, pp. 1318–1323.

May, A.D. 1994. Potential Next-Generation Technology. In *Special Report 242: Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion*, Vol. 2, TRB, National Research Council, Washington, D.C.

McNutt, B., and E. Rucker. 1981. *Impact of Fuel Economy Information on New Car and Light Truck Buyers.* U.S. Department of Energy.

McNutt, B., P. Bergeron, M. Singh, and K. Stork. 1996. *Making the Transition to Large Scale Ethanol Use in the U.S. Transportation Sector.* Paper DE96008397. Presented at DOE International Symposium on Alcohol Fuels, Sun City, South Africa, April 14–17, 17 pp.

Michalak, S., J. Spyridakis, M. Haselkorn, B. Goble, and C. Blumenthal. 1994. Assessing Users' Needs for Dynamic Ridesharing. In *Transportation Research Record 1459*, TRB, National Research Council, Washington, D.C., pp. 32–38.

NASA. 1995. *Scientific Assessment of the Atmospheric Effects of Stratospheric Aircraft*. Reference Publication 1381. Washington, D.C.

National Research Council. 1992a. *Automotive Fuel Economy: How Far Should We Go?* Commission on Engineering and Technical Systems, National Academy Press, Washington, D.C.

National Research Council. 1992b. *Policy Implications of Greenhouse Warming*. National Academy Press, Washington, D.C.

National Research Council. 1994. *Review of the Research Program of the Partnership for a New Generation of Vehicles*. National Academy Press, Washington, D.C.

National Research Council. 1996. *Review of the Research Program of the Partnership for a New Generation of Vehicles, Second Report*. National Academy Press, Washington, D.C.

National Research Council. 1997. *Review of the Research Program of the Partnership for a New Generation of Vehicles, Third Report*. National Academy Press, Washington, D.C.

Nelson, A., and T. Moore. 1993. Assessing Urban Growth Management. *Land Use Policy*, Oct.

Nivola, P.S., and R.W. Crandall. 1995. *The Extra Mile: Rethinking Energy Policy for Automotive Transportation*. The Brookings Institution, Washington, D.C., 180 pp.

Olson, D.J. 1994. Pricing Urban Roadways: Administrative and Institutional Issues. In *Special Report 242: Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion*, Vol. 2, TRB, National Research Council, Washington, D.C.

O'Rourke, L., and M. Lawrence. 1995. Strategies for Goods Movement in a Sustainable Transportation System. In *Transportation and Energy: Strategies for a Sustainable Transportation System* (D. Sperling and S.A. Shaheen, eds.), American Council for an Energy-Efficient Economy, Washington, D.C., and Berkeley, Calif.; Institute of Transportation Studies, University of California, Davis, 305 pp.

Ostria, S.J., and M.F. Lawrence. 1994. Potential Emission and Air Quality Impacts of Intelligent Vehicle-Highway Systems. In *Transportation Research Record 1444*, TRB, National Research Council, Washington, D.C., pp. 79–89.

OTA. 1991. *Changing by Degrees: Steps to Reduce Greenhouse Gases*. Report OTA-0–482. Washington, D.C., Feb., 354 pp.

OTA. 1992. *Retiring Old Cars: Programs to Save Gasoline and Reduce Emissions*. Report OTA-E-536. Washington, D.C., July, 42 pp.

OTA. 1994. *Saving Energy in U.S. Transportation*. Report OTA-ETI-589. Washington, D.C., July.

OTA. 1995. *The Technological Reshaping of Metropolitan America*. Report OTA-ETI-463. Washington, D.C.

Pietrzyk, M.C. 1994. Electronic Toll Collection Systems. In *Special Report 242: Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion*, Vol. 2, TRB, National Research Council, Washington, D.C.

Pirkey, D. 1982. *Assessment of Federal Fuel Economy Information Program.* U.S. Department of Energy.

Pisarski, A.E. 1996. *Commuting in America II: The Second National Report on Commuting Patterns and Trends.* Eno Transportation Foundation, Inc., Lansdowne, Va.

Pushkarev, B., and J. Zupan. 1977. *Public Transportation and Land Use Policy.* Indiana University Press, Bloomington.

Riley, C.J., and K.S. Tyson. 1994. Total Fuel Cycle Emissions Analysis of Biomass-Ethanol Transportation Fuel. Paper DE93018219. Presented at DOE International Symposium on Alcohol Fuels, Colorado Springs, Colo., Nov. 7–10.

Ritter, G., and S. Thompson. 1994. The Rise of Telecommuting and Virtual Transportation. *Transportation Quarterly,* Vol. 48, No. 3, pp. 235–248.

Rosenbloom, S. 1996. Future Travel Demand: The Impact of Current and Future Societal Trends. Presented at July 1996 meeting of Research and Technology Coordinating Committee (FHWA), Transportation Research Board, Washington, D.C.

Schipper, L., and G. Eriksson. 1995. Taxation Policies Affecting Automobile Characteristics and Use in Western Europe, Japan, and the United States, 1970–1990. In *Transportation and Energy: Strategies for a Sustainable Transportation System* (D. Sperling and S.A. Shaheen, eds.), American Council for an Energy-Efficient Economy, Washington, D.C., and Berkeley, Calif.; Institute of Transportation Studies, University of California, Davis.

Schneider, S.H. 1993. Degrees of Certainty. *National Geographic Research and Exploration,* Vol. 9, No. 2, pp. 173–190.

Seely, B.E. 1987. *Building the American Highway System: Engineers and Policy Makers.* Temple University Press, Philadelphia, Pa., 315 pp.

Shoup, D.C. 1994. Cashing Out Employer-Paid Parking: A Precedent for Congestion Pricing. In *Special Report 242: Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion,* Vol. 2, TRB, National Research Council, Washington, D.C.

SPARC. 1993. *Stratospheric Processes and Their Role in Climate Change.* SPARC Scientific Steering Committee, World Climate Change Research Programme, Verrieres-le-Buisson, France.

Sperling, D. 1994. Prospects for Neighborhood Electric Vehicles. In *Transportation Research Record 1444,* TRB, National Research Council, Washington, D.C.

Sperling, D. 1995. *Future Drive: Electric Vehicles and Sustainable Development.* Island Press, Washington, D.C., 175 pp.

Sperling, D., and S.A Shaheen (eds.). 1995. *Transportation and Energy: Strategies for a Sustainable Transportation System.* American Council for an Energy-Efficient Economy, Washington, D.C., and Berkeley, Calif.; Institute for Transportation Studies, University of California, Davis, 305 pp.

Stein, A.G., K.S. Kurani, and D. Sperling. 1994. Roadway Infrastructure for Neighborhood Electric Vehicles. In *Transportation Research Record 1444,* TRB, National Research Council, Washington, D.C.

Stone, J.R., A.M. Nalevenko, and G. Gilbert. 1994. Computer Dispatch and Scheduling for Paratransit: An Application of Advanced Public Transportation Systems. *Transportation Quarterly,* Vol. 48, No. 2, Spring, pp. 173–184.

TRB. 1994. *Special Report 242: Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion,* Vol. 1. National Research Council, Washington, D.C.

TRB. 1995. *Special Report 245: Expanding Metropolitan Highways: Implications for Air Quality and Energy Use.* National Research Council, Washington, D.C.

TRB. 1996. *TCRP Report 16: Transit and Urban Form.* Vols. 1 and 2. Transit Cooperative Research Program, National Research Council, Washington, D.C.

United Nations. 1992. *Report of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change.* UN Document A/AC 237/18, Part II. May 15.

Walbridge, E.W. 1995. Real-Time Rideshare Matching with Wireless Access to the Matching Computer. In *Proceedings of the 1995 Annual Meeting of ITS America,* ITS America, Washington, D.C., pp. 463–469.

Waterson, T. 1993. Linked Simulation of Land Use and Transportation Systems: Developments and Experience in the Puget Sound Region. *Transportation Research,* Vol. 27a, No. 3, pp. 193–206.

Williams, R.H. 1994a. Fuel Cell Vehicles: The Clean Machine. *Technology Review,* April, pp. 21–30.

Williams, R.H. 1994b. Roles for Biomass. In *Industrial Ecology and Global Change* (R. Socolow, C. Andrews, F. Berkhout, and V. Thomas, eds.), Cambridge University Press, Cambridge, England, pp. 199–225.

Williams, R.H. 1996. *Fuel Decarbonization for Fuel Cell Applications and Sequestration of the Separated CO_2.* PU/CEES Report 295. Center for Energy and Environmental Studies, Princeton University, Princeton, N.J.

WMO. 1992. *WMO and the Ozone Issue.* Global Atmosphere Watch Programme, Geneva, Switzerland.

WMO. 1995. *Scientific Assessment of Ozone Depletion: 1994.* Report No. 37. Global Ozone Research and Monitoring Project, Geneva, Switzerland, Feb.

Wyman, C.E., R.L. Bain, N.D. Hinman, and D.J. Stevens. 1993. Ethanol and Methanol from Cellulosic Biomass. In *Renewable Energy: Sources for Fuels and Electricity* (T.B. Johnson, H. Kelly, A.K.N. Reddy, and R.H. Williams, eds.), Island Press, Washington, D.C., pp. 865–923.

4

Cumulative Ecological Effects of Vehicle Emissions and Infrastructure

Beyond being sources of greenhouse gases, transportation vehicles and the infrastructure on which they operate are sources of many other environmental disturbances that have collective and potentially permanent ecological consequences. Vehicle emissions, roads, other physical components of the transportation system, and the vehicles, freight, and materials moved over this system are all sources of environmental effects that are beginning to be recognized but that have yet to become explicitly incorporated in transportation regulation, planning, and decision making.

Traditionally, the environmental disturbances from transportation have been catalogued and controlled individually and on a site-specific basis. One reason these disturbances are not always well recognized and treated comprehensively is that transportation systems and their components are usually planned, built, and operated locally and on a project-by-project basis. Moreover, many of the ecological effects of transportation are subtle and gradual, which hinders efforts to understand and control them in a coordinated manner. Individual environmental disturbances and their consequences can appear different when viewed in combination and over longer time horizons and wider geographic areas. From such a vantage point—one that integrates effects over different temporal and spatial scales—it becomes more evident that individual roads and local transport facilities are part of larger infrastructure systems that isolate once-contiguous habitat areas, change the flow of water and nutrients across the land, introduce new species and ecological features, and have numerous other interrelated ecological effects.

From a broader time and space perspective, for instance, it becomes more evident that an individual road can be a source of contaminants and changes in whole watersheds rather than having influences limited to the specific stream it crosses or parallels. Likewise, one can see the thousands of motor vehicles traveling over this road network not only as emitting pollutants that degrade local air quality and threaten public health, but also as being chronic sources of air pollutants that cause ecological consequences occurring hundreds of miles away. Considered together over time, the individual disturbances emerge as sources of larger ecological perturbations that require innovative approaches to understand and control.

An aim of this chapter is to look at these environmental disturbances from such a broad perspective. An important emphasis, therefore, is on identifying general steps that can be taken to improve monitoring and understanding of transportation's ecological repercussions and to begin orienting transportation planning and regulatory processes so they will be better suited to anticipating and taking actions to reduce them. The chapter is organized into two main sections. First, some important ecological effects that have been associated with the chemical pollutants emitted into the atmosphere by motor vehicles are reviewed. These emissions, which disperse widely, have been linked to changes in forest and aquatic ecosystems from mechanisms as varied as exposure to tropospheric ozone and haze to acid deposition and nitrogen enrichment. This review is followed by a discussion of other important disturbances to ecosystems that have been linked to the nearly 4-million-mile (6.25-million-km) road system in the United States. These disturbances range from the acute destruction of habitats caused by road-building activities to the chronic disruption of natural flows and exchanges across the landscape. Because the U.S. transportation system is so pervasive and the ecological systems it traverses are so diverse, it is not feasible in such a short chapter to examine, or even identify, all of these disturbances. Instead, some illuminating examples are given of transportation's primary disturbances to both aquatic and terrestrial systems.

In the second half of the chapter some policy options and opportunities for managing the many cumulative environmental effects of motor vehicle emissions and transportation infrastructure are considered. Some options for reducing vehicle emissions are similar in character to those presented in Chapter 3 and are not repeated here. Other options, however, differ from those presented earlier, reflecting dissimilarities in both the nature of the environmental effects and the scientific information and policy bases available. The climate change risk, transportation's use of energy, and its emission of greenhouse gases have lately been the subject of a significant amount of research and public policy debate. Though some policy options and practices exist for addressing the ecological effects examined in this chapter, too little is understood about the extent to which individual effects, such as injuries to plants and changes in water and soil chemistry, have broader and more lasting effects on whole ecosystems. Most of the ecological concerns discussed in this chapter will require a greater long-term research emphasis to further scientific knowledge and the fieldwork needed to develop more options for mitigation and management.

CUMULATIVE EFFECTS ON ECOSYSTEMS

Effects of Vehicle Emissions

Transportation emissions are a well-known source of urban air pollution detrimental to human health. More recently, however, scientists have begun to understand and seek greater recognition of the ecological harm caused by emissions that alter air, water, and soil chemistry over large expanses (Lovett 1994; Taylor et al. 1994). Whereas air pollutants have long been implicated in the decline of city trees and damage to farm crops on the perimeters of metropolitan areas, many are now known or strongly suspected to be detrimental to forest trees, aquatic habitats, and other natural communities and ecosystems located both near and far from the emission sources.

Certainly, the concern over public health has taken precedence in both research and mitigation. Years of medical and epidemiologic studies indicating adverse health effects from air pollution have spurred public demand for more aggressive and effective pollution abatement. As a result, progress has been made in reducing transportation emissions through a combination of cleaner-burning fuels, more fuel-efficient vehicles, pollution-control equipment on vehicles, and other changes in technology and practice.

Although these public health measures have undoubtedly benefited the environment as a whole, the ecological effects of air pollution are often viewed as side issues, receiving relatively scant research and public policy attention. International concern over acid rain has raised to prominence some of the environmental consequences of air pollution. The full array of environmental effects from emissions, however, remains poorly understood and underemphasized.

Types of Emissions

Transportation vehicles are major emitters of carbon monoxide (CO), particulate matter, oxides of nitrogen (NO_x), and hydrocarbons and other volatile organic compounds (VOCs) (Figure 4-1). All these pollutants have been and continue to be of concern because of their effects on human health. In the case of CO—the main source of which is motor vehicle exhaust—substantial gains have been made in recent years in reducing emissions through fuel reformulation and vehicle control equipment and technologies (EPA 1995a, ES-9). Meanwhile, airborne concentrations of particulate matter, especially the smallest inhalable particles, are becoming a more prominent public health concern.[1] Some of the health issues pertaining to these pollutants are discussed in Box 4-1.

NO_x and VOCs have long been the subject of scientific study and efforts to protect public health. NO_x molecules, encompassing nitrogen oxide (NO) and smaller amounts of nitrogen dioxide (NO_2), are formed in automobile engines during the high-temperature petroleum combustion process and emitted in vehicle exhaust. Natural sources of NO_x are relatively minor; other important human sources are stationary fossil fuel combustion facilities such as electric power plants (National

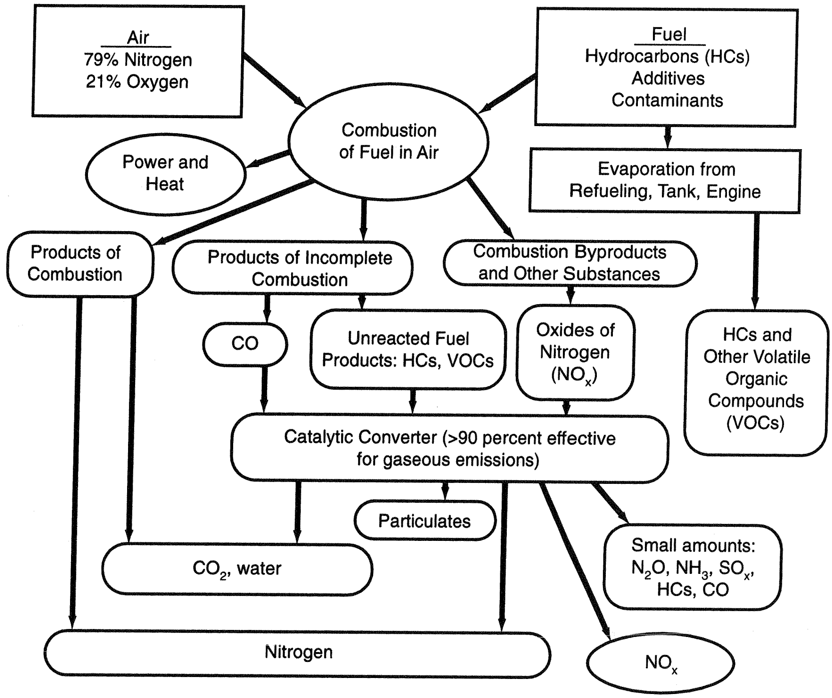


Figure 4-1 Motor vehicle emissions (gasoline-engine) (adapted from Houghton 1994).

Research Council 1991, 1). VOCs are emitted from vehicle exhaust and from fuel vapor (e.g., during vehicle refueling). They are also produced by industrial processes, solvents, and paints and are produced naturally by trees and other plants (National Research Council 1991, 8–9; EPA 1995b, A-10). Natural sources can contribute more than half the VOCs in the atmosphere during the growing season.

There are a number of reasons to be concerned about emissions of these two chemical pollutants. NO_x is a lung irritant when inhaled in high concentrations. The VOCs produced by fuel consist of hundreds of hydrocarbons and aldehydes, some of which are toxic or known carcinogens. The main concern over NO_x and VOCs, however, has been their role in the formation of ozone (O_3) in the lower part of the atmosphere known as the troposphere. This part of the atmosphere contains

Box 4-1

Fine Particulate Matter: A Growing Public Health Concern

Particles in the atmosphere, including dust, solid and liquid aerosol droplets, and finer particles (known as particulate matter), are a growing public health concern. Transportation increases particles in the atmosphere in a number of ways. Particles and aerosol droplets are also formed as by-products of petroleum combustion (see Figure 4-1). They are present in vehicle exhaust as solid particles (e.g., soot) or are formed in the atmosphere from gaseous emissions of hydrocarbons, nitrogen oxides, and sulfur oxides (forming nitrates and sulfates). The combustion process produces a complex mixture of particles consisting of a wide range of organic and inorganic substances, including some known irritants, mutagens, and carcinogens (Health Effects Institute 1995, 5).

Some of these particles are very fine and can be inhaled by humans, irritating membranes of the respiratory system and possibly causing more serious ailments. Particulate matter varies in diameter from more than 10 micrometers (known as PM-10) to less than 1 micrometer. The finest particles, those measuring 2.5 micrometers (PM-2.5) or less, are capable of being absorbed deep into the human respiratory system and are therefore a health concern. Diesel engines, which are used in most medium- and heavy-duty trucks, are an important source of particulate pollution. Particles formed by diesel combustion tend to be very small, most weighing less than 1 microgram and measuring less than 1 micrometer in diameter (Health Effects Institute 1995, 5). Heavy-duty diesel trucks are estimated to account for about three-fourths of highway-related emissions of particulate matter (Sawyer and Johnson 1995, 68).

EPA has set air quality standards for inhalable particulate matter measuring 10 micrometers or less. A number of epidemiology studies have found statistical associations between rates of sickness and mortality from particulate concentration thresholds lower than those prescribed by EPA air quality standards. Episodes of acute particulate pollution have previously been associated with declines in

continued

Box 4-1 *continued*

human lung function and respiratory symptoms (Dockery et al. 1993). More recent epidemiologic studies have correlated higher morbidity and mortality rates with long-term low-level exposures (Pope et al. 1995), suggesting that chronic exposure to particulate matter may be a more serious health concern than previously believed. Further epidemiologic studies are needed along with an improved understanding of the effects of particulate matter on human physiology and health.

the air people breath and surrounds people, plants, and animals. Unlike the beneficial ozone found in the high altitudes of the stratosphere—where ozone shields out excessive ultraviolet light (see Chapter 3)—ozone in this part of the troposphere is undesirable.[2] As a prime constituent of urban smog and haze, tropospheric ozone is one of this country's most pervasive and stubborn environmental problems, a health concern for millions of Americans living in or near the nation's metropolitan centers (Box 4-2).

Only recently has it become apparent that the airborne chemicals that produce ozone in the troposphere are not simply urban- or smog-related problems. There is a growing body of evidence that these chemicals and their products affect people and environments far from where they are produced, altering air, water, and soil chemistry in relatively remote areas of the country once thought to be immune to the influences of human activity. The reason is that NO_x and VOCs are carried for hundreds of kilometers downwind where they react and combine with other natural and human-generated emissions to form ozone, acid rain, and other substances that are dispersed widely. Some of the ecological effects of these emissions are reviewed next.

Ozone, Plant Injury, and Biological Diversity

NO_x and VOCs are often referred to collectively as "precursor" pollutants because they create ozone in the troposphere. Ozone is formed

Box 4-2

▼

Causes of Tropospheric Ozone and Public Health Concerns (EPA 1994, 43)

Ozone (O_3) is a photochemical oxidant and the major component of smog. Whereas O_3 in the stratosphere is beneficial to humans and other life by shielding the earth from harmful ultraviolet radiation from the sun, high concentrations of O_3 in the troposphere are a major health and environmental concern. O_3 is not emitted directly into the air, but is formed through complex chemical reactions between precursor emissions of VOCs and NO_x in the presence of sunlight. These reactions are stimulated by sunlight and temperature so that peak O_3 levels typically occur during the warmer times of the year. Both VOCs and NO_x are emitted by transportation and industrial sources. VOCs are emitted from sources as diverse as motor vehicles, chemical manufacturing and dry cleaning, paint shops, and other sources using solvents.

The reactivity of O_3 can cause human health problems by reducing lung function and sensitizing the lungs to other irritants. Scientific evidence indicates that ambient levels of O_3 affect not only people with impaired respiratory systems, such as asthmatics, but also healthy adults and children. Exposure to O_3 for several hours at relatively low concentrations can result in coughing, eye irritation, nausea, and other acute, short-term symptoms. Such exposure has also been found to reduce lung function and induce respiratory inflammation in normal, healthy people during prolonged periods of moderate or heavy exercise. This decrease in lung function generally is accompanied by symptoms including chest pain, coughing, sneezing, and pulmonary congestion.

EPA monitors and sets air quality standards for ozone. The National Ambient Air Quality Standards pertaining to O_3 are defined in terms of the daily maximum, that is, the highest hourly average for the day, and they specify that the expected number of days per year with values greater than 0.12 parts per million should

continued

Box 4-2 *continued*

not be greater than 1. Both the annual second-highest daily maximum and the number of daily exceedances during certain portions of the year, termed the "O_3 season," are considered by EPA. The strong seasonality of O_3 levels makes it possible for areas to limit their O_3 monitoring to the O_3 season. Peak O_3 concentrations typically occur during hot, dry, stagnant summertime conditions, that is, high temperature and strong insolation. The length of the O_3 season varies from one area of the country to another. May through October is typical, but states in the South and Southwest may monitor the entire year. Northern states have a shorter O_3 season (e.g., May through September for North Dakota).

There are more than 500 monitoring sites in EPA's long-term trends data base, and more than 700 sites that have provided data since 1991. Most of these sites are in or near metropolitan areas.

when NO_x is exposed to sunlight and reacts with oxygen and VOCs in the atmosphere. The reactions that form ozone and the factors that cause ozone to disperse are complex and involve many dynamic variables such as sunlight, temperature, wind, topography, and the presence of other chemicals and materials in the atmosphere (National Research Council 1991, 19). NO_x emissions in particular can move in air masses over long distances, sometimes hundreds of kilometers from their origins to rural areas where their concentrations would otherwise be low. In slow-moving air masses, the transported emissions of NO_x can react with natural VOCs in the atmosphere (emitted by plants), causing ozone to form and concentrate over rural forests and other wilderness areas. The forests of the Appalachian Mountains, for instance, are major recipients of NO_x originating in the cities of the Midwest and Southeast and thus experience chronic exposure, as well as frequent acute episodes, of ozone pollution (National Research Council 1991).

Visible injuries, retarded growth, and declines in the number of certain tree species in the Appalachian Mountains and other high-elevation forested areas subject to ozone exposure have caused researchers to focus greater attention on this atmospheric disturbance as a possible factor. Research on crop responses to ozone exposure is extensive, and studies have begun to uncover possible biologic mechanisms of injury to forest plants. Laboratory studies, for instance, have demonstrated that elevated exposure to ozone can be deleterious to many forest plants, affecting the condition and functioning of their enzymes, substrates, and cell membranes (Cowling et al. 1990; National Research Council 1991, 37–38; Winner 1994). The extent to which recurrent ozone exposure per se affects plant communities and forest ecosystems over many years has proven more difficult to isolate in the field, although ozone clearly puts additional stress on forest ecosystems, making them more susceptible to decline (Cowling et al. 1990).

Strongly suspected long-term effects of ozone exposure include reduced biodiversity and diminished variability of the gene pool of plant communities within forests (Miller 1973; Coyne and Bingham 1981; Fenn and Bytnerowicz 1993; Taylor et al. 1994; Winner 1994). Plants that are known to be tolerant of ozone have been found to persist or even thrive in forests with recurrent ozone exposure, whereas some intolerant species have experienced population declines. Certain genotypes of the eastern white pine, for instance, have declined in many U.S. forests subject to summertime ozone buildup (Taylor et al. 1994; Cowling et al. 1990). Symptoms of ozone stress, however, are often subtle and cumulative, occurring in combination with a background of other human-induced and natural perturbations, and few investigations have been made to disentangle these stresses and their sources. As discussed next, some of these other stresses are also caused by transportation emissions of NO_x and other chemicals.

Acid Deposition and Nutrient Enrichment

During the 1960s and 1970s, the scientific community and the public in general became more aware of the extent to which air pollution from industry and vehicle exhaust was propagating widely and adversely affecting the integrity of remote lakes, forests, and other natural areas. The phenomenon of acid deposition in particular received a great deal of attention in light of reports from around the world of increased acidification of lakes and soils and concurrent declines in fish populations and forest trees (National Research Council 1986, 1).

During the past 20 years, the chemical and physical processes that cause acid deposition, including the role of transportation emissions, have become reasonably well understood and documented. It is now known that emissions of NO_x and oxides of sulfur (SO_x) contribute to the nitric and sulfuric acids that are the prime constituents of acid deposition. These compounds are transported by wind and air currents before falling back to the surface in rain and other precipitation, including snow, cloud water, fog, and dew. In addition, new mechanisms of exposure have been discovered, such as dry deposits of acidic gases and particles (Pitelka 1994).

Much of the regulatory effort to reduce acid deposition in North America has focused on the control of sulfur emissions that form sulfate and sulfuric acid. Sulfuric acid is the common form of acid deposition in the United States, and sulfate particles in the atmosphere are of additional concern because they can reduce visibility and sunlight penetration before falling back to the earth's surface as dry or wet deposits. Most sulfur emissions originate from coal-powered electric power plants and other stationary sources. Whereas transportation accounts for a relatively small percentage of SO_x discharged into the atmosphere,[3] it has a more significant role in the creation of nitrate aerosols, gaseous ammonia and nitric acid, ammonium ions in precipitation, and other nitrogen compounds that form in and fall from the atmosphere. In addition to contributing along with SO_x to the acidification of some soils and surface waters, the deposition of these nitrogen compounds in both dry and wet forms has been linked with changes in soil composition and nutrient availability and flows within ecosystems.

Nitrogen is an essential but limiting nutrient in many ecosystems. Under normal conditions, fixed nitrogen—that is, nitrogen in forms usable by plants and animals—is produced slowly by only a few natural processes, thereby having only limited availability to plants and animals. Mature ecosystems have developed balanced rates of nitrogen availability and loss. The balance is altered by the human production and use of nitrogen-based fertilizer, the planting of soybeans and other leguminous crops (which host bacteria that fix nitrogen), and the combustion of fossil fuels (Ayres et al. 1994; Kinzig and Socolow 1994, 26). These sources increase nitrogen input in ecosystems.

Excess input of nitrogen can affect ecosystem biodiversity and function significantly. Because many terrestrial and aquatic systems are nitrogen limited, the population of native plant species tends to be controlled. Nitrogen input, however, will stimulate plant growth, particularly among species that are capable of using the nitrogen most readily. Differences in the rate of nitrogen assimilation among species will eventually alter the natural mix and abundance of plants in the ecosystem (Kinzig and Socolow 1994, 27). Nitrogen enrichment, for instance, may lead to increased algal growth and dominance. Algal blooms and their subsequent decay can have the important effect of causing the loss of dissolved oxygen necessary to support fish populations and other species (Bakelaar and Odum 1978; Tilman 1982; *Ambio* 1990; Fisher and Oppenheimer 1991). Similar changes in species dominance from nitrogen enrichment may occur in terrestrial ecosystems such as pasturelands and heathlands (Galloway et al. 1995, 247).

Ecological effects of nitrogen enrichment are being observed in some important coastal ecosystems (*Ambio* 1990). For example, studies of precipitation chemistry and nutrient input in the Chesapeake Bay—the largest estuary on the Eastern Seaboard and a principal hatchery for North Atlantic fish populations—have found increasing levels of nitrogen in the usable form of nitrate (NO_3) and ammonia (Fisher and Oppenheimer 1991; Boynton et al. 1995; Jordan et al. 1995). Nutrient enrichment is a suspected cause of the biological changes that have been observed in the Chesapeake Bay estuary (Jordan et al. 1995). In this instance, fertilizer runoff from agricultural and residential lands is the primary nutrient source for much of the nitrogen input in the estuary (Boynton et al. 1995). Atmospheric sources of nitrogen (from both dry and wet deposition), however, are believed to contribute 20 to 30 percent of the nutrient input, derived mostly from nitrate deposits formed in the atmosphere from NO_x created by fossil fuel combustion, motor vehicles being an important source (Fisher and Oppenheimer 1991).

Among other coastal and aquatic systems where atmospheric nitrate is suspected to account for a similarly significant share of nitrogen input are Long Island Sound, the lower Neuse River in North Carolina, and Delaware and Narragansett bays (Fisher and Oppenheimer 1991; National Research Council 1992).

NO_x Emissions and the Global Nitrogen Cycle

Changes in the natural cycling of nitrogen, caused in part by transportation emissions of NO_x, can also be considered from a global vantage point. In addition to altering the character and composition of many ecosystems, another potential by-product of nitrogen input is increased global production of nitrous oxide (N_2O), which is released from nitrogen-enriched soils.[4] Historical records indicate that N_2O concentrations in the atmosphere are increasing (Kinzig and Socolow 1994, 24).

As discussed in Chapter 3, N_2O is an ozone-depleting substance when found in the stratosphere (where ozone concentrations are desirable), as well as a long-lived greenhouse gas. Thus, in addition to having the many ecological consequences already mentioned—ranging from soil and water acidification to aquatic system nutrient enrichment—emissions of NO_x may contribute to changes in the global cycling of nitrogen, having implications for stratospheric ozone depletion, greenhouse warming, and the general movement of this key element through the earth's biological and physical systems (Schlesinger 1994).

The effects of nitrogen emissions are an important area for scientific and public-policy research.

Effects of Transportation Infrastructure

It is important to recognize that if vehicles emitted no air pollution, they would still have important ecological consequences, largely because they are operated over such a vast infrastructure system. The road network in the United States consists of tens of thousands of kilometers of lightly traveled roads (paved and unpaved) cutting through agricultural and wilderness areas, dense networks of residential streets and arteries in urban and exurban areas, and heavily traveled freeways that can extend uninterrupted for hundreds of miles. As might be expected, this extensive system is itself a source of numerous environmental disturbances. Disturbances that have been clearly linked to roads and other transportation infrastructure range from runoff of surface materials and changes in local hydrology to the fragmentation of habitats and the introduction and proliferation of invasive species (Figure 4-2).

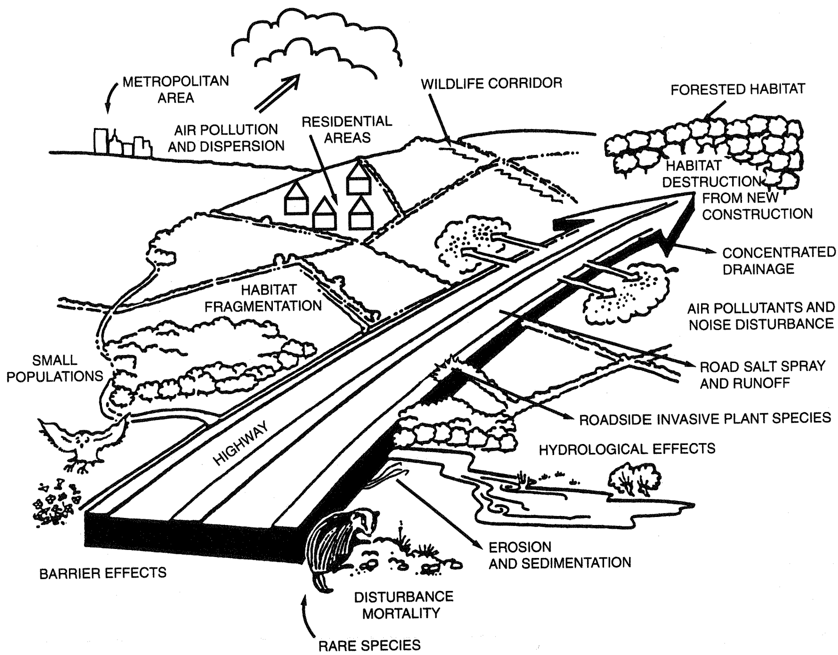


Figure 4-2 Examples of ecological disturbances form a roadway (adapted from Box and Forbes 1992, 19).

A cross section of environmental disturbances from transportation is described here, organized according to whether the disturbance's principal effect is on aquatic or terrestrial ecosystems. The main reason for providing these examples is that transportation systems are the source of ecological disturbances that are occurring concurrently and repeatedly over the landscape and across the country. When these disturbances are considered cumulatively and collectively, the importance of controlling them becomes more evident.

Effects on Water Resources and Aquatic Systems

Transportation systems alter the character of water systems—their quantity, composition, flow, and location—through a number of mechanisms. Primary among these mechanisms are changes in surface water and groundwater composition and modifications in natural drainage patterns, water flows, and quantity. In recent years, much emphasis has been placed on making transportation construction activities more compatible with the need to protect water systems, for instance, by implementing better planning and mitigative measures during construction.

In general, transportation systems and their operations have many enduring effects on water systems that have proved difficult to address. Highway construction can affect local hydrology profoundly. For instance, exposed soils, cut road banks, and uncontained construction debris and building materials are susceptible to mudslides, wind erosion, and movement in surface runoff (Clyde 1978). Many of these materials find their way to local streams, causing sedimentation that can alter the hydrology of an area and reduce water quality, thereby adversely affecting aquatic and terrestrial communities (Goldman and Hoffman 1975; Shaheen 1975; Horner and Mar 1983; Brown 1994). Sedimentation increases water turbidity and siltation of stream beds, reducing the penetration of light needed by aquatic plants and covering fish spawning and feeding areas (Brown 1994). Sediments often contain nutrients, toxic organics, metals, and other contaminants (Lagerwerff and Specht 1970; Hewitt and Rashed 1991; Campbell 1994; Wust et al. 1994). During the past 30 years, various measures have been developed to contain erosion and minimize contaminated runoff and hydrological disturbances from the building of transportation facilities. These measures include temporary fences, sodding, groundcover vegetation and plantings, diversion berms, sediment basins, artificial wetlands, and alternative deicing and maintenance materials (Clyde 1978; TRB 1980; Goldman et al. 1986; AASHTO 1993).

Once built and in operation, highways and other transportation facilities (including structures, terminals, and yards) can have enduring effects on the quality of nearby waters and local hydrology. They remain a chronic source of sediments and contaminants in nearby receiving waters as a result of the runoff of materials deposited on the road surface by traffic and road maintenance crews and by erosion of side slopes and degraded construction materials (Gilson et al. 1994; Price 1994). Storm water runoff from roads and airport surfaces, as well as paved surfaces in ports and other transportation facilities, can include oils and greases and heavy metals such as zinc, lead, copper, and cadmium deposited by tires, vehicle leaks, worn coatings, and metal components of structures (Gilson et al. 1994; Price 1994; Wust et al. 1994). Surface drainage can also carry chemicals and materials used in maintenance operations, including pesticides and herbicides, coatings, sand, and deicing agents (especially chlorides) (Gilson et al. 1994). Likewise, airport runoff (from taxiways, runways, parking lots, and service roads) may contain glycol, acetates, and other chemicals that alter the chemistry and composition of nearby receiving waters (Price 1994).

Runoff infiltrates watersheds through discharge directly into adjacent ponds and other surface waters, through drainage systems, and through infiltration to groundwater. Drainage ditches that concentrate runoff can significantly affect small bodies of receiving waters, especially streams and small wetlands. Where affected groundwater flows into rivers and other surface waters, chronic loadings of contaminants can harm aquatic life; where it is tapped for drinking water, public health effects are of concern. Road salt infiltration into public water supplies and private wells has become a significant problem in several New England and midwestern states (TRB 1991).

The physical imprint of the transportation system also has profound effects on the flow, quantity, and quality of water in hydrological systems. Streams are sometimes rechanneled and wetlands filled, irreparably changing flood regimes, impeding water flows, and shifting the location of stream and drainage networks. Modifications to natural terrain and surface contours from cuts in slopes, changes in gradients, and the construction of ditches and basins can affect overland and groundwater flows. Pipes, culverts, and other drainage structures will alter the rate and location of water flows and flood regimes. Impervious pavement surfaces concentrate water, increasing runoff in some locations and reducing water infiltration to soils. Water runoff from road surfaces increases peak flows, which commonly causes flooding damage and rearranges natural floodplain communities (Jones and Grant 1996).

These effects of the highway sustem are accompanied by those of other components of the transportation system. Waterborne transportation creates several unique disturbances to water systems. Commercial waterways are dredged to widen and deepen channels, upsetting bottom sediments and resuspending and relocating contaminants that had settled to the bottom. By altering channel geometry and hydrology, dredging also alters the sedimentation rate and water salinity and oxygen levels (National Research Council 1992). The locks, gates, channels, levies, and other facilities that accommodate inland water traffic are often associated with losses of floodplain, mudflats, wetlands, and other natural features that support aquatic and riparian habitats (National Research Council 1992). The jettisoning of cargo and wastes from vessels, leaks and spills from water traffic, and contaminants from vessel paints and maintenance chemicals (e.g., antifouling agents) can release contaminants into waterways (National Research Council 1992).

Waterborne transportation, in particular, has proved to be a vexing and costly conduit for exotic species. The invading lamprey eel, which entered the Great Lakes through the St. Lawrence River seaway, and the zebra mussel, carried in ship ballast water, are only two of many examples of exotic species that have permanently altered aquatic ecosystems (many with costly economic consequences) (National Research Council 1992). Increasingly it has become recognized that transportation vehicles and networks serve as conduits for the introduction and dispersal of nonnative species (Saunders and Hobbs 1991; Tyser and Worley 1992; Forman 1995).

Also of significance to water resources and aquatic ecosystems is the role of transportation in moving hazardous materials. These shipments sometimes are released in transport, causing water pollution as well as pollution of land and air. The U.S. Department of Transportation (DOT) estimates that more than 500,000 shipments of hazardous materials are moved each day in the United States (DOT 1995). The majority of these movements consist of small, nonbulk shipments, only a small fraction of which are accidentally spilled or released. Whereas most releases are small and contained, large spills of bulk petroleum and chemical shipments from tanker vessels, barges, pipelines, railroad tank cars, and tank trucks occasionally occur and can have significant and lasting ecological effects.[5]

Effects on Terrestrial Systems

Transportation networks and systems not only cause conspicuous changes to physical landscapes, but also alter the patterns of wildlife and the general function of ecosystems within these landscapes. These

1996). They can become dominated by alien species from other nearby habitats and agricultural fields and are likely to be devoid of many species that previously inhabited the area, especially larger mammals. Rocky Mountain elk, for instance, have been found to be reluctant to range within 100 to 200 meters of roadway openings (Rost and Bailey 1979; Lyon 1983).

By subdividing the landscape into small pieces, roads also fragment habitats and interrupt essential wildlife movements. With an average network density of 1.2 miles of roadway per square mile in the contiguous United States, many landscapes contain fairly dense road networks. The density of a road network can be of particular concern because roads can form barriers that sequester species in much smaller habitats than those to which they are accustomed. If the patches between roads become too small, the habitat may be incapable of providing resources needed to maintain viable and resilient populations. Studies indicate that wolves in the Great Lakes region and mountain lions in the central Rockies do not have viable populations where road density is greater than 1 mile per square mile of area (Mech et al. 1988; Forman et al. 1997). Other wide-ranging species, such as bears, also find it difficult to survive in a road-fragmented landscape.

Landscape and habitat fragmentation can lead to a number of other problems. It can reduce species populations by inhibiting the exchange of breeders, impeding gene flows, and promoting inbreeding among small populations (Soule 1987). Whereas in natural ecosystems a dwindling population can be rejuvenated with the immigration of new individuals, this process becomes inhibited in a fragmented landscape. Again, the Florida panther is often cited as an example. The total panther population in southern Florida is less than 75 individuals. In addition, the animals apparently have low genetic variation because of inbreeding caused by population sequestration and a reduction in range areas resulting from fragmentation by roads and other human development (Evink 1990; Forman and Hersperger 1996).

Roads also act as physical barriers to the horizontal flows and interactions of natural terrestrial systems over broad landscapes (Forman 1995; Harris et al. 1996). Hence, not only do roads isolate and fragment species, but they also impede natural processes and dynamic exchanges that occur between ecosystems and across the landscape. These flows and exchanges are varied; for instance, mammals forage and disperse, birds migrate, floods carry silt and nutrients and deposit them in floodplains, natural fires clear and revitalize vegetation, wind flows across the land carrying seeds, and butterflies traverse the landscape pollinating flowers. A single road, or network of them, can inhibit or modify these processes, having large and lasting repercussions for the many distant but interconnected ecosystems within a wider landscape (Harris et al. 1996).

OPPORTUNITIES FOR UNDERSTANDING AND CONTROL

Vehicle Emissions

For 25 years the Environmental Protection Agency (EPA) has been monitoring air quality and emissions in accordance with the requirements of the Clean Air Act. These efforts have yielded a growing understanding of the major sources of NO_x, VOCs, and other air pollutants and how they interact to affect air quality. Major emission sources have been identified as transportation (primarily motor vehicles), electric utilities, fuel use by industry, chemical processing, and waste disposal, as well as important natural background sources (especially for VOCs and particulate matter). According to EPA data for 1995, transportation vehicles contributed about one-third of total U.S. emissions of NO_x and about 25 percent of VOC emissions (not including natural sources)[7] (EPA 1995a, 2–5). Within the transportation sector,[8] highway vehicles are the predominant source of NO_x, accounting for more than 90 percent (EPA 1996). Highway vehicles also account for most transportation-related emissions of VOCs.

This emission information, along with extensive governmental and industry-sponsored research, has enabled gradual improvement in air pollution standards and abatement practices and technologies over time. Since 1971 EPA has set national standards for acceptable emissions and air concentrations of NO_x, VOCs, ozone, and other pollutants. Individual states and their local jurisdictions are charged with developing strategies and instituting programs to meet many of these standards, whereas automobile suppliers, gasoline stations, and oil companies have effects are caused by transportation networks themselves as well as by the vehicles moved on them.

An obvious alteration is that roads and other facilities occupy land that would otherwise serve as habitat area. It has been estimated that U.S. highways, streets, and adjacent rights-of-way (including paved ways, roadsides, and medians) occupy roughly 20 million acres (about 8 million hectares), averaging about 5 acres per mile (3.2 hectares per km) for the nearly 4 million miles (6.25 million km) of public roads (Cook and Dagget 1995, 15).[6] This estimate—which may be low since it does not include private roads, parking areas, and driveways—represents 1 percent of the total surface area of the contiguous United States, or an area equivalent to the land contained within the state of South Carolina. More than three-fourths of roadway mileage is in rural locations, ranging from forest to agricultural settings (FHWA 1996, Table HM-12). Habitats are lost directly as a result of the physical imprint of a road and the changes to terrain and other natural features that accompany it; for example, a portion of a forest may be removed, a steep slope cut or leveled, and a stream diverted through a culvert. Transportation facilities overlie natural geologic features and also introduce new and artificial physical features, such as detention ponds and drainage ditches, that permanently alter the characteristics of the terrain and can change the mix of biological communities that inhabit the immediate area.

Perhaps the most noticeable and objectionable—from the public's perspective—effect of roads that traverse habitat areas is the dead birds, mammals, and other animals found on roads and along the roadside. Countless birds, reptiles, and small mammals, such as squirrels, raccoons, and skunks, are killed by motor vehicle traffic. Indeed, tens of millions of vertebrates are killed annually. Surveys of state transportation and natural resource agencies indicate that more than 0.5 million deer are killed on roadways each year in the United States (Cook and Dagget 1995). Moose, bear, and other large mammals are also killed. In most cases, these deaths have little effect on animal populations, and the main concern in prevention of roadkills is to ensure public safety. However, the main direct ecological concern of roadkills is their effect on certain rare and endangered species. During the past two decades, the primary cause of death of the Florida panther was vehicle collisions, though recent measures to protect the panther (as noted later and shown in Figure 4-3) have significantly reduced these accidents (Evink 1990; Evink 1996, 54). Other endangered species that are prone to highway accidents include mountain lions in the central Rocky Mountains, the key deer on the Florida Keys, the brown pelican of the Gulf Coast of Texas, and the desert tortoise in southern California (Forman et al. 1997).

Roads and the traffic moving over them are also the source of invasive species that can transform the habitats they enter. Roadside plantings are a source of invasive grasses, shrubs, weeds, and other vegetation that may spread into nearby pasturelands, forests, and nature preserves. The cleared corridors, underpasses, overpasses, and drainage ways of highways, railroads, and other transportation facilities can serve as avenues for the long-distance movement of invading species (Getz et al. 1978). As mentioned earlier, water vessels, as well as aircraft, can be especially problematic, moving exotic species thousands of kilometers. Vehicular traffic on highways and railroads also serves as a transport mechanism for nonnative animals, plants, insects, and seeds. Moreover, roads create opportunities for human access to once-remote areas, leading to further changes in landscape features, overhunting, changes in air and water quality, and the introduction of domestic pet and livestock populations that can adversely affect native communities of plants and animals.

The ecological and habitat disturbances by roads extend far beyond the land they occupy and the habitats they disturb directly. The disturbances created by traffic noise, vibrations, and light, for instance, can extend for some distance, disrupting essential animal behaviors such as feeding and reproduction. Several studies have shown that high traffic activity on roadways is associated with declining bird populations, primarily as a result of vehicle noise (Reijnen and Fopper 1995). Depending on the species and habitat type, the effects may extend for hundreds of meters from the roadway (Reijnen and Fopper 1995).

The physical changes created where roads cut through wilderness areas can also have a broad effect. These openings create edge habitats, ranging from several meters to tens of meters in width, that have significantly different sunlight, wind, temperature, and humidity conditions than interior habitats. These edge areas are usually inhabited by plant and animal communities that differ from those found previously (Saunders and Hobbs 1991; Chen et al. 1993; Forman 1995; Reed et al.

been required to develop and provide pollution abatement technologies such as catalytic converters, fuel vapor recovery systems, and cleaner-burning motor fuel.

As discussed next, these developments have led to measurable progress in pollution control and the promise of further gains in meeting the challenges that lie ahead. One such challenge will be in gaining a better understanding of the effects of emissions on the natural environment and how best to mitigate them.

Progress To Date in Controlling Emissions

Federal regulatory efforts coupled with many innovations by industry have led to reductions in most transportation emissions, including important declines in NO_x and VOCs. According to EPA measurements, national emissions of NO_x from all sources have about held steady since 1980; however, emissions from motor vehicles have declined about 15 percent (EPA 1996). National VOC emissions have also remained fairly stable over the past 15 years; yet transportation emissions are down by about one-third (EPA 1996).

Trends in ozone have proved more difficult to assess. Most regions of the country appear to be experiencing fewer episodes of ozone pollution than they did 10 years ago (EPA 1996). For instance, for the summers of 1989 to 1993, EPA reported about 10 percent fewer high-ozone pollution episodes than occurred during the summers of 1983 to 1987 (excluding the peak ozone summer of 1988) (EPA 1993, 43–45). EPA attributes this improvement in part to reductions in gasoline volatility since 1988, causing lower VOC concentrations (EPA 1993, 43–45). Nevertheless, the occurrence of tropospheric ozone pollution remains a significant and widespread problem that is not well correlated with national reductions in NO_x or VOCs. Among the difficulties of relying on national data and trends to measure progress in ozone abatement is that individual regions of the country differ in their short- and long-term susceptibility to ozone for a variety of reasons, ranging from variability of topography and climate to fluctuations in meteorological conditions and natural concentrations of VOCs in the atmosphere (see Box 4–2). For instance, because ozone is primarily a hot weather problem, periods of marginally hotter or cooler weather, such as an unseasonably warm summer with stagnant weather systems, can have a far greater absolute effect on ozone episodes than marginal changes in NO_x or VOC emissions (National Research Council 1991, 93–108). Annual meteorological fluctuations can therefore mask, at least in the short term, the gains or shortcomings in ozone abatement (National Research Council 1991, 5).

Similarly, the relative importance of NO_x and VOC emissions can differ by area, depending on which pollutant is the limiting factor in ozone formation (i.e., which is more or less abundant and available for reaction). This difference can present a dilemma in devising and choosing effective pollution controls. For instance, in a particular urban area, NO_x emissions may be plentiful, but natural emissions of VOCs may be limited; therefore controlling human-generated emissions of these latter compounds may prove valuable as a means of limiting ozone formation. In a rural area downwind, on the other hand, natural emissions of VOCs may be high, and therefore controlling the availability of NO_x—transported from the upwind urban area—may be far more important.[9]

This variability complicates efforts to develop national abatement strategies. Presenting an exceptional challenge to ozone abatement is the Los Angeles Basin, which has climatic and topographical characteristics that are especially conducive to ozone formation. In confronting this challenge, California has for many years been at the forefront of strategies for ozone control, stimulating new practices and technologies that have had national and international application.[10] Continued efforts to address the vexing ozone problem in the Los Angeles Basin will undoubtedly spur the development of new pollution control technologies and practices.

Opportunities for Further Progress

In many respects, the long-term prospects for control of NO_x and ozone pollution appear favorable because of continued improvement in scientific understanding of emission sources and ozone formation, as well as the public's general concern over air quality. Medical and epidemiologic investigations of the health effects of urban air pollution, including those from particulate emissions, should provide further insight into the most urgent air quality problems and abatement needs.

Continued and determined efforts to achieve progress will indeed be crucial. Many Americans, especially in southern California, are subject to frequent and acute episodes of ozone pollution. Further growth in travel and rising metropolitan populations will make further abatement increasingly demanding but also increasingly important in many locations. Also, because the relationship between ozone formation and its precursor emissions is nonlinear, increasingly disproportionate reductions in these emissions will almost certainly be required to achieve further reductions in ozone pollution.

Among the issues and opportunities that are likely to warrant greater attention in the years ahead are ways to increase the durability and performance of emission control systems, deter use of high-emission vehicles that account for an inordinate share of emissions, minimize emission surges and variations during driving cycles (such as cold-start and acceleration-related emissions), and improve vehicle emission test procedures (Calvert et al. 1993). Opportunities are likely to come from the retirement of older, high-emitter vehicles and a combination of improvements in new-vehicle engines and emission control systems (e.g., exhaust after-treatment, on-board diagnostics), fuels, and more effective vehicle surveillance and inspection and maintenance programs.

Greater targeting of pollution sources and pollution-prone areas will likely become necessary to improve the effectiveness and reduce the incremental cost of further pollution abatement, for instance, by focusing controls on high-emission vehicles. Diesel-powered vehicles have become an increasingly important source of NO_x emissions during the past two decades. About one-third of total motor vehicle emissions of NO_x is from diesel vehicles, even though diesel fuel accounts for less than 15 percent of total motor fuel consumed (EPA 1996; FHWA 1996). Diesel-powered vehicles are heavy emitters of NO_x because no effective catalyst technology has been developed for diesel exhaust. Additional reductions in NO_x emissions from gasoline-powered automobiles and light-duty trucks will further elevate the relative share of emissions from diesel as well as off-road vehicles (e.g., farm and construction equipment). Moreover, diesel fuel has an advantage over gasoline because the internal combustion engine can use it more efficiently. Because of this advantage, diesel cars and trucks may offer a means of reducing total petroleum use and CO_2 emissions (see Chapter 3).[11]

Hence, the development of cost-effective technologies that can help control NO_x and particulate emissions from diesel vehicles—such as catalysts and exhaust traps—would be important if diesel engine use were to expand significantly.

More generally, EPA air quality data and measurement and modeling techniques have been criticized on a number of grounds (National Research Council 1991). Further changes in these methods may be required, particularly to aid state and local governments in developing the most appropriate pollution abatement strategies and monitoring systems for their individual circumstances. Further changes in, and perhaps tightening of, EPA air quality standards may also become warranted as the health effects of ozone and other air pollutants become better understood.

One area in which existing pollution standards certainly warrant reevaluation is their incorporation of environmental effects. To date, consideration of ecological effects of air pollution has had a secondary role in the setting of national air quality standards. If the environmental costs of air pollution had been more fully recognized and accounted for, it is possible that even more aggressive steps to control emissions would have been taken and accepted by the public. Similarly, full consideration of the aesthetic costs of air pollution as a result of diminished atmospheric visibility and damage to buildings, outdoor monuments, and other human infrastructure—effects not considered here—might have led to earlier and more significant actions.

As discussed next, if environmental effects are to figure more prominently in future air quality considerations, a better understanding of them and the mechanisms that cause them will be essential.

Options for Better Understanding of Emissions Effects on Ecosystems

During the past two decades, the National Atmospheric Deposition Program/National Trends Network has monitored and evaluated air composition and precipitation chemistry at more than 100 sites across the United States. Scientists have been using data from this program and other sources to begin more systematic evaluation of the consequences of air pollution for aquatic and terrestrial systems. These efforts, coupled with many investigations in Canada and Europe, have led to advances in the scientific understanding of the effects of air pollution on the natural environment (Pitelka 1994).

Yet the relatively small number of air quality monitoring sites in rural and wilderness locations relative to the number of areas exposed to air pollution has made it difficult for scientists to track and evaluate pollution effects that may be of biological importance (Winner 1994, 653). EPA air quality monitoring stations, for instance, are located in less than one-fourth of the nation's 3,100 counties. Most are in and around metropolitan areas (EPA 1993, 97). Some ecologists have argued for the creation of a pollution monitoring network that would provide a larger spatial and temporal record of ozone and other air pollution (Winner 1994, 660).

National pollution monitoring networks and coordinated research programs have been proposed to facilitate long-term scientific research and understanding of tropospheric ozone and related aspects of air quality (National Research Council 1991). Such networks, perhaps expanded as part of the National Atmospheric Deposition Program/National Trends Network, would offer an opportunity to track and map exposure levels and identify effects on forests and other natural systems. Coupled with more basic research on the capacities of ecosystems to respond to and assimilate these emissions, the information provided would prove valuable in identifying emission control needs and effective remedies.

In general, the establishment of stronger cause-and-effect relationships between transportation emissions and ecological changes will require more systematic and comprehensive investigations of how changes in air, soil, and water chemistry interact with other environmental conditions and disturbances. More specifically, there is a need for more research directly focusing on the effects of ozone, NO_x, particulate matter, and other pollutants from motor vehicles on forest trees, natural plant communities, soil processes, and aquatic systems.

Transportation Infrastructure

As noted at the beginning of this chapter, ecologists increasingly view environmental effects from a broad perspective (in time and space), recognizing that individual ecosystems are seldom independent but almost always interconnected and share many of the same natural resources such as a drainage basin or watershed. Thus disturbances to one ecosystem can have ramifications over the broader landscape. To ecologists, the term "landscape" refers to the diverse mosaic of local ecosystems or land uses covering an extended geographic area and containing a variety of habitats and species (Forman 1995). Inasmuch as landscapes rarely conform to political boundaries or transportation corridors, individual environmental disturbances from transportation systems are seldom viewed in such a comprehensive manner during transportation system and land use planning. Therefore some general approaches for adopting such a broad vantage point to further understand and prevent these cumulative ecological effects are identified in this section.

Today—unlike 30 years ago—most state and local transportation agencies are aware of environmental disturbances caused by highways and the other transportation systems they build, operate, and maintain. The advent of Environmental Impact Statements (EISs), first required by the National Environmental Policy Act of 1969 (for federal-aid projects), undoubtedly had an important role in spurring such awareness. Many states now have their own EIS laws and regulations that apply to most state and local highway projects (Deakin 1993). A wide range of methods and techniques with the express purpose of identifying and reducing adverse environmental effects are now available to highway agencies. Moreover, the notion that highways should be built and maintained to minimize budgetary costs and maximize travel speed, safety, and capacity is no longer the only consideration of highway planners and designers, many of whom are now paying closer attention to the effects of the highways on biodiversity and ecosystems when making decisions. Part of the reason for this shift is that the public has become increasingly interested in environmental quality and is demanding change.

Still, there are many shortcomings in the approaches used, and there is a great deal of variability in the way highway agencies incorporate ecological considerations as part of their policies, practices, and decision-making apparatus. In many instances, ecological effects are still viewed in the context of a short-term and localized project rather than as part of a long-term and broader set of concerns central to the agency's mission. All of the individual design, maintenance, and operations measures that can be taken to reduce the adverse ecological effects of highways are not discussed, but the following are some of the general steps that can be taken to develop a stronger framework for understanding the direct and indirect effects and adopting appropriate preventive and mitigative measures.

Ecological Goals and Condition Indicators

Important in guiding efforts to anticipate and manage the environmental effects of transportation systems is having a general set of goals about environmental expectations for a given area that can serve as guidelines for information gathering and decision making by transportation departments and other public agencies. Some explicit environmental goals, such as no net loss of wetlands, protection of endangered species, and preservation of floodplains, already exist and are prescribed in state and federal regulations (Reid 1995). Other goals, such as maintaining a certain level of biodiversity, minimizing disruption of stream quality and flow, keeping major wildlife corridors intact, and protecting steep slopes, may be developed for specific areas, depending on prevailing conditions and expectations. Such goals would assist in the development of key environmental indicators to inform policy choices and measure the performance of highway systems in minimizing ecological disturbances.

Highway agencies are seldom in a position to set such goals by themselves, especially for habitat protection. Decisions about habitat preservation and whether to build or widen a specific highway in a given area are often made within the broader political framework. Highway agencies, however, can be an important contributor to the process, particularly in recognizing the ecological dangers early and working with other government agencies, elected officials, ecologists, and the public in identifying and selecting highway designs and sitings that minimize those dangers. The state of Florida, for instance, has established a state greenways commission that has an important function in this regard. The commission provides a framework for interagency coordination and public interaction and communication that has led to the establishment of specific ecological goals for particular areas of the state, as well as on a statewide basis (Florida Greenways Commission 1995; Harris 1995).

As noted throughout this report, many ecological issues associated with highway systems—such as biological diversity, cumulative effects of pollutants, and land use patterns—must be addressed over very large spatial scales and long time periods. Thus, early definition of environmental goals and expectations will be essential to enabling the anticipatory actions necessary to monitor and control adverse ecological effects over time. Well-defined goals and early planning activities would also allow ecologists to work with public officials in developing ecological principles that could be used to inform and guide land use planning and regulation and educate the public about the importance of minimizing adverse ecological effects. As an example, the state of California, with federal and local officials, ecologists, and landowners, has initiated an ambitious program to protect endangered species by preserving natural corridors connecting core habitat areas around which development may take place (Steven 1997). Clearly, transportation planners and decision makers must be actively involved in and committed to such a concept for it to work.

Advanced and Integrated Development Planning

Potentially valuable to decisions about where a new road would best be sited to lessen ecological effects or how it should be designed or redesigned to have less effect is the availability of a master plan mapping the environmental conditions of a large area to the existing, planned, and optional road systems and associated developments. The plan should be developed well in advance of individual project planning and updated often.

Unfortunately, EISs seldom serve this purpose or facilitate this process since they are often conducted on a site-specific, project-by-project basis, thereby neglecting areawide and cumulative results of projects over time. Deakin (1993) contends that in many instances, EIS evaluations have become perfunctory exercises that do not have a significant role in shaping decisions about highway projects since they are often not completed until after key decisions have been made. She urges the adoption of transportation system- or corridor-level EISs that consider the broader implications of a long-term highway plan and related projects, permitting anticipation and assessment of cumulative areawide results and with ground rules for professional practices in project development.

Such an overarching plan can provide a framework for considering how the addition or expansion of a highway or network of roads could affect further development and how, in turn, the subsequent development could affect the ecology of the area. As an example, an ecological, or landscape-scale, map would contain detailed information about the major types of flows that traverse the area, such as streams, groundwater, and wildlife corridors. It would also identify other important features within the landscape, such as habitats, wetlands, and erodible slopes (Forman and Hersperger 1996). By superimposing the existing or planned highway network on this map, it would be possible to identify important bottlenecks where natural patterns or processes would be significantly interrupted.

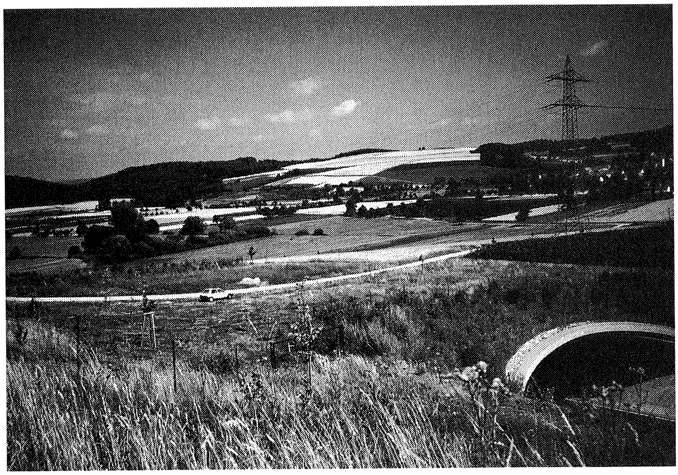
The Netherlands has been active in developing and using systemwide plans of this type and has found that the timely ecological information provided by such early planning increases the options available for avoiding or mitigating environmental problems likely to arise later (Van Bohenan et al. 1994). Newly available technologies such as geographic information systems are making such comprehensive and landscape-level mapping more accurate, easy to update, and affordable.

Research, Experimentation, and Mitigation Opportunities

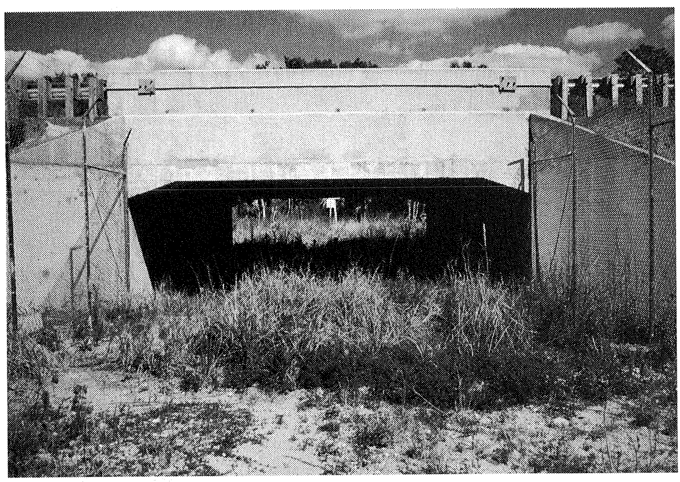
Highway agencies have a number of opportunities to begin taking action to reduce the environmental consequences of the existing road network and to develop the means of making future roads more compatible with the surrounding environment. One such opportunity is the ongoing reconstruction of the highway system. Whereas most roads in the United States were built when ecological effects were not a primary concern, some of these roads will over time undergo major repairs and renovations that will offer the opportunity to explore alternative mitigation measures and begin a systematic process of reducing the ecological effects of the 4-million-mile system. Short-term budget constraints are common to all transportation agencies, affecting the type, scale, and timing of mitigations that can be taken. Nonetheless, over the longer term, budgets and resources are adjusted to reflect gradual changes in societal goals and priorities. Whereas some reconstruction projects may warrant major mitigative measures such as changing an alignment or installing underpasses for large migratory animals, many others may benefit from measures as simple as removing invasive exotic plantings from roadside vegetation or rechanneling drainage systems. For example, a wide range of mitigation structures for facilitating wildlife crossings of roads and highways exists in Europe, as well as some in North America (Figure 4-3) (Forman and Hersperger 1996; Forman et al. 1997).

The vast size of the road system actually provides an opportunity for improving understanding of preventive and mitigative measures. Various steps, ranging from prevention to compensation, have been taken to reduce the ecological effects of highways; some have proved successful, whereas others have not achieved their original expectations. For example, Race and Fonseca (1995) contend that many wetland mitigation programs have not adequately compensated for the gradual loss of wetlands caused by development. Because the road system with its wide variety of designs, traffic conditions, and roadside features traverses thousands of miles of varied ecological conditions, suitable responses differ. The diversity of the system offers a wealth of potential information to assist in decisions about which kinds of species habitats, ecosystems, and landscape features are most susceptible to degradation from roads and how these effects can be best avoided or ameliorated.

More systematic monitoring and evaluation of these efforts and how the road system interacts with ecosystems throughout the country—for instance, through more pilot testing and evaluation of ecologically compatible highway designs and maintenance operations—would offer highway planners, designers, and ecologists a better-informed means of predicting problems and devising preventive or mitigative measures. The number of new road miles is growing at a relatively slow rate, but much of the growth will be in metropolitan fringes, where adverse effects on wildlife can be significant. In addition, many highways are being widened and reconfigured to handle more traffic, thus creating the potential for further habitat fragmentation and loss and disruption of wildlife movement and other flows across landscapes. Ongoing highway expansion and widening projects offer an opportunity to get a better



(a)



(b)

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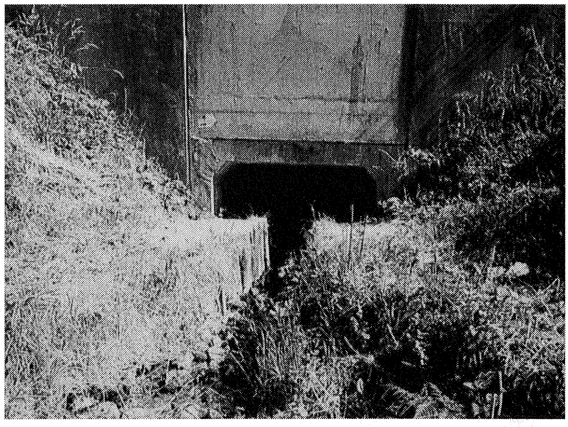
Figure 4-3 Wildlife crossing structures to reduce road barrier effect and enhance faunal movement across roads and highways: (*a*) overpass 80 m wide for faunal movement across Highway B31, Hirschweg, Germany; (*b*) underpass for Florida panther (*Felis concolor*) crossing of Route 29 in South Florida; (*c*) concrete culvert at Snoeyink stream crossing under A1 in Netherlands—dry ledges extend stream bank to other side of highway for animal crossing; (*d*) amphibian tunnel for annual migration of spotted salamander (*Ambystoma maculatum*) across road in Amherst, Massachusetts; (*e*) ecoduct across A50 near Woeste Hoeve, Netherlands. [Photograph credits: (*a*) courtesy Anna Hersperger; (*b*,*d*) courtesy Richard T.T. Forman; (*c*,*e*) RWS 1995.]

(c)



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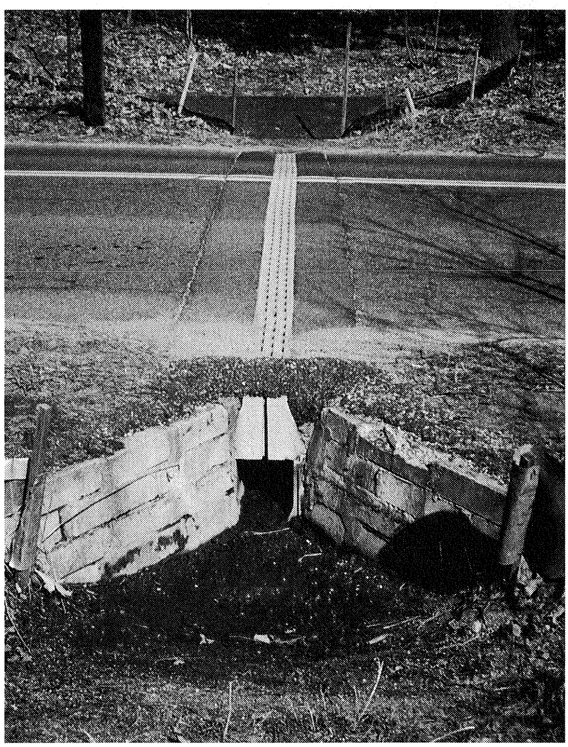
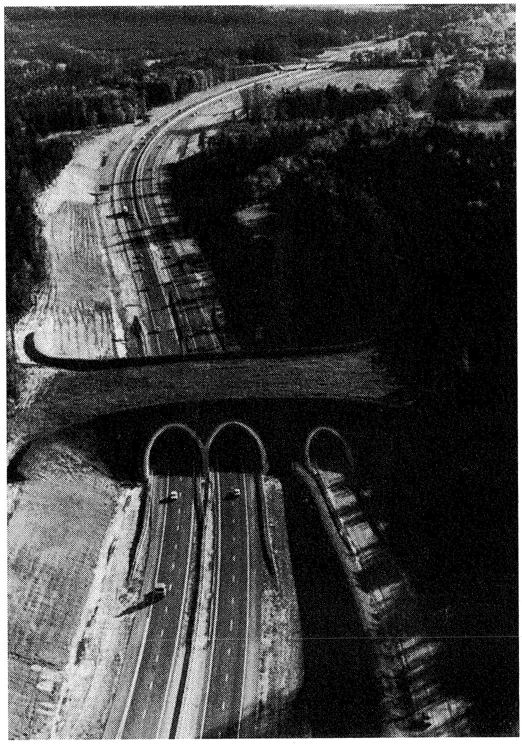


Figure 4-3 (*continued*)



(e)

Figure 4-3 (*continued*)

handle on solutions to these problems and the application of this knowledge to future projects. Experiments might be conducted, for instance, using more animal underpasses and overpasses and design changes that make roadways more permeable to animals and natural flows.

Interdisciplinary Collaboration

None of the foregoing steps can be taken without active collaboration among highway engineers, planners, policy makers, and specialists in ecological sciences. During the past 20 years, many highway agencies have hired ecologists, biologists, hydrologists, and other environmental scientists and planners to assist in minimizing the environmental effects of highway projects; other states have been less active in this regard. Bringing such specialists into the highway planning and design process at the earliest stages and throughout implementation of a project is essential to identifying and minimizing these effects. Early involvement of ecologists in the siting and design of new roads and in the planning of highway expansion has practical advantages in that projects are less likely to be delayed as a result of problems uncovered during EIS evaluations.

Moreover, early and active collaboration is essential to developing and implementing a broader environmental assessment plan as outlined above and in fostering involvement by ecologists at later stages, including highway maintenance. The role of ecologists should become more influential in a highway agency's routine maintenance and operational activities as well as in its major construction and reconstruction projects.

SUMMARY AND ASSESSMENT

During the past two decades, research into and understanding of transportation's varied effects on the natural environment have advanced significantly. Nevertheless, many of these vexing ecological problems remain and new important ones are being recognized. It is now acknowledged that many of these effects cannot be viewed simply as localized phenomena, but must be seen as more pervasive problems that adversely affect natural processes and ecological systems over wide areas and for long time spans. Some of the key problem areas are summarized as follows:

- Air (vehicle emissions of NO_x, VOCs, and particulate matter are the major transportation source)
  - –Ozone formation, damage to trees and other plants, and changes in forest ecosystems, especially in mountain areas;
  - –Nitrogen input and enrichment, stimulating plant growth, changes in species composition, and ecosystem eutrophication;
  - –Acid deposition and changes in soil and water chemistry, causing injury to plants and aquatic communities; and
  - –Changes in global nitrogen cycle over the longer term.

- Water and soil (roadways are the major source)
  - Road network disruption of natural flows across the landscape (e.g., groundwater, surface water, and fire);
  - Higher peak flows of streams and rivers due to concentrated flows from culverts, road drainage systems, and paved-surface runoff, causing flood damage and changes in floodplains;
  - Runoff from roads, accelerating soil erosion and causing mudslides on roadsides and slopes; and
  - Stream sedimentation, resulting in water contamination, turbidity, and fish loss.
- Habitat and species (roads are the main sources; vehicles the secondary source)
  - Road network removal and dissection of natural habitat, sequestering it into smaller habitats capable of supporting fewer species;
  - Road disruption of species movement, especially in wildlife corridors;
  - Traffic noise that impairs the essential behaviors of some species, reducing the biodiversity of habitats, especially for birds;
  - New roads enabling human access and development in previously remote areas, leading to further loss in habitat and changes in species; and
  - Roads and vehicles providing access to invasive species that outcompete and displace native plants and animals.

Although recognition has increased, changes in information bases, regulatory practices, and decision-making processes have often not followed suit. Some options and opportunities for furthering the understanding of these environmental effects and addressing them in a more systematic and anticipatory manner have been identified. These include the following:

- Vehicle emission effects
  - Ways to increase the durability and performance of emission control systems, deter use of high-emission vehicles, minimize emission surges and variations, and improve vehicle emission test procedures;

–Modifications in EPA air quality data and measuring and modeling techniques, and perhaps also in air quality standards, in particular to incorporate environmental effects; and

–Pollution monitoring networks and coordinated research programs to further understanding of the ecological effects of transportation emissions.

- Infrastructure effects

  –Establishment of general and area-specific ecological goals and indicators of environmental conditions;

  –Advanced and integrated development planning, including a master plan mapping areawide environmental conditions and natural flows to existing, planned, and optional road systems and associated developments;

  –Opportunities to reduce environmental effects of the existing road network and make future roads more compatible with the surrounding environment, including the ongoing reconstruction of the highway system and more systematic monitoring and evaluation of how the road system interacts with ecosystems nationwide; and

  –Collaboration among highway engineers, planners, policy makers, and specialists in ecological sciences.

Absent more systematic research, information gathering, and planning of this type, many of the accumulating environmental disturbances from transportation will remain unanticipated and untreated, and the consequences of this neglect will become more pronounced over time. More responsive action today will help prevent more costly consequences in the future.

NOTES

1. As discussed in Chapter 3, an environmental issue having to do with airborne particulate matter is the extent it absorbs and scatters solar and thermal radiation, influencing the earth's radiative balance and climates.
2. Though some of the undesirable ozone created in the troposphere migrates to the stratosphere where it is beneficial, the amount is small relative to the strato-

spheric ozone destroyed by emissions of chlorofluorocarbons and other chemicals (National Research Council 1992, 22).

3. In 1994, all transportation sources contributed less than 3 percent of total SO_x emissions (EPA 1995b). Because federal regulations have lowered the sulfur content of diesel fuel, this share is expected to decline further.
4. N_2O is also emitted in motor vehicle exhaust treated in catalytic converters.
5. For instance, the 1991 release from a railroad tank car of herbicide into the Sacramento River of California is believed responsible for declines in aquatic communities throughout large portions of the river.
6. Right-of-way areas vary greatly by roadway type. For most single- and two-lane local roads and residential streets (which account for about two-thirds of total centerline mileage), 5 acres per mile (3.2 hectares per km), an area averaging 40 feet (12 meters) wide, would be too high a figure. On the other hand, arterial, collector, and freeway corridors occupy much more land per mile, some containing 6 or more 12-foot-wide (3.6 meter) lanes, wide shoulders and medians, interchange areas, and 30-foot (9 meter) tree-clear zones on either side of the pavement.
7. This figure does not include emissions from petroleum production, which accounted for an additional 2 to 3 percent of the national total.
8. The transportation sector, for the purposes of this study, excludes nonroad vehicles such as farm and construction equipment, which are sometimes classified by EPA as transport vehicles.
9. The sources of emissions can also vary by area. Motor vehicles, for instance, may produce a smaller share of total NO_x emissions in regions with significant amounts of heavy industry or a larger share where there is little industrial activity. Likewise, transportation's contribution to VOC concentrations can vary widely by location, depending on the prevalence of natural sources and other human sources such as solvent use, chemical manufacturing, and waste disposal.
10. California began setting automobile emission standards in the 1960s, long before the federal government did.
11. Because diesel vehicles have higher fuel economy than gasoline vehicles, diesel automobiles are common in Europe. Lower diesel fuel taxes and retail prices are another important factor in their popularity.

REFERENCES

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
RWS	Rijkswaterstaat (Public Works and Water Management)
TRB	Transportation Research Board

AASHTO. 1993. *A Guide for Transportation Landscape and Environmental Design.* Washington, D.C.

Ambio. 1990. Marine Eutrophication (entire issue), Vol. 19, pp. 101–176.

Ayres, R., W. Schlesinger, and R. Socolow. 1994. Human Impacts on the Carbon and Nitrogen Cycles. In *Industrial Ecology and Global Change* (R. Socolow, C. Andrews, F. Berkhout, and V. Thomas, eds.), Cambridge University Press, Cambridge, England.

Bakelaar, R.G., and E.P. Odum. 1978. Community and Population Level Responses to Fertilization in an Old-Field Ecosystem. *Ecology,* Vol. 59, pp. 660–665.

Box, J.D., and J.E. Forbes. 1992. Ecological Considerations in the Environmental Assessment of Road Proposals. *Highways and Transportation,* April, pp. 16–22.

Boynton, W.R., J.H. Garber, R. Summers, and W.M. Kemp. 1995. Inputs, Transformations, and Transport of Nitrogen and Phosphorus in Chesapeake Bay and Selected Tributaries. *Estuaries,* Vol. 18, pp. 285–314.

Brown, K.J. 1994. Riverbed Sedimentation Caused by Off-Road Vehicles at River Fords in the Victorian Highlands, Australia. *Water Resources Bulletin,* Vol. 30, pp. 239–250.

Calvert, J.G., J.B. Heywood, R.F. Sawyer, and J.H. Seinfeld. 1993. Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions. *Science,* Vol. 261, July 2, pp. 37–45.

Campbell, K.R. 1994. Concentrations of Heavy Metals Associated with Urban Runoff in Fish Living in Stormwater Treatment Ponds. *Archives of Environmental Contamination and Toxicology,* Vol. 27, No. 3, pp. 352–356.

Chen, J., J.F. Franklin, and T.A. Spies. 1993. Contrasting Microclimates among Clearcut, Edge, and Interior of Old-Growth Douglas Fir Forests. *Agricultural and Forest Meteorology,* Vol. 63, pp. 219–237.

Clyde, C.G. 1978. *Manual of Erosion Control Principles and Practices During Highway Construction.* Hydraulics and Hydrology Series. Utah Water Research Laboratory, College of Engineering, Utah State University, Logan.

Cook, K., and P. Dagget. 1995. *Highway Road Kill, Associated Issues of Safety, and Impacts on Highway Ecotones.* Unreviewed survey report, Task Force on Natural Resources, Transportation Research Board, National Research Council, Washington, D.C.

Cowling, E.B., D.S. Shriner, J.E. Barnard, A.A. Lucier, A.H. Johnson, and A.R. Kiester. 1990. Airborne Chemicals and Forest Health in the United States. *Proceedings of World Congress, International Union of Forestry Research Organizations,* Report B, pp. 25–36.

Coyne, P.I., and G.E. Bingham. 1981. Comparative Ozone Dose Response of Gas Exchange in a Ponderosa Pine Stand Exposed to Long-term Fumigations. *Journal of the Air Pollution Control Association,* Vol. 31, pp. 38–41.

Deakin, E.A. 1993. Policy Responses in the USA. In *Transport, the Environment, and Sustainable Development* (D. Banister and K. Button, eds.), E&Fix Spon, New York.

Dockery, D.W., A. Pope, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris, and F.E. Speizer. 1993. An Association Between Air Pollution and Mortality in Six U.S. Cities. *New England Journal of Medicine*, Vol. 329, pp. 1754–1808.

DOT. 1995. *Transportation Statistics Annual Report 1995*. Bureau of Transportation Statistics.

EPA. 1993. *National Air Quality and Emission Trends Report, 1900–1992*. Report EPA-454/R-93-032. Office of Air and Radiation and Office of Air Quality Planning and Standards, Research Triangle Park, N.C.

EPA. 1994. *National Air Quality and Emission Trends Report, 1993*. Report EPA-45/R-94-026. Office of Air Quality Planning and Standards, Research Triangle Park, N.C.

EPA. 1995a. *National Air Pollutant Emission Trends, 1900–1994*. Report EPA-45/R-95-011. Office of Air Quality Planning and Standards, Research Triangle Park, N.C.

EPA. 1995b. *National Air Quality and Emission Trends Report, 1994*. Report EPA-454/R-95-014. Office of Air Quality Planning and Standards, Research Triangle Park, N.C.

EPA. 1996. *National Air Quality and Emission Trends Report, 1995*. Report EPA-454/R-96-005. Office of Air Quality Planning and Standards, Research Triangle Park, N.C.

Evink, G.L. 1990. Wildlife Crossings of Florida I-75. In *Transportation Research Record 1279*, TRB, National Research Council, Washington, D.C., pp. 54–59.

Evink, G.L. 1996. Florida Department of Transportation Initiatives Related to Wildlife Mortality. In *Trends in Addressing Transportation Related Wildlife Mortality* (G.L. Evink, P. Garret, D. Zeigler, and J. Berry, eds.), Report FL-ER-58–96, Florida Department of Transportation, Tallahassee.

Fenn, M.E., and A. Bytnerowicz. 1993. Dry Deposition of Nitrogen and Sulfur to Ponderosa and Jeffrey Pine in the San Bernardino National Forest in Southern California. *Environmental Pollution*, Vol. 81, pp. 277–285.

FHWA. 1996. *Highway Statistics*. U.S. Department of Transportation.

Fisher, D.C., and M. Oppenheimer. 1991. Atmospheric Nitrogen Deposition and the Chesapeake Bay Estuary. *Ambio*, Vol. 20, pp. 102–108.

Florida Greenways Commission. 1995. *Creating a Statewide Greenways System: Report to the Governor, Summary*. Tallahassee, Fla.

Forman, R.T.T. 1995. *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge, England, 632 pp.

Forman, R.T.T., and A.M. Hersperger. 1996. Road Ecology and Road Density in Different Landscapes, with International Planning and Mitigation Solutions. In *Trends in Addressing Transportation Related Wildlife Mortality* (G.L. Evink, P. Garret, D. Zeigler, and J. Berry, eds.), Report FL-ER-58-96, Florida Department of Transportation, Tallahassee.

Forman, R.T.T., D.S. Friedman, D. Fitzhenry, J.D. Martin, A.S. Chen, and L.E. Alexander. 1997 (in press). Ecological Effects of Roads: Toward Three Summary Indices and an Overview for North America. In *Habitat Fragmentation and Infrastructure*, Proc., International Conference on Habitat Fragmentation and Infrastructure (K. Canter, ed.), Ministry of Transport, Public Works and Water Management, Delft, Netherlands.

Galloway, J.N., W.H. Schlesinger, H. Levy II, A. Michaels, and J.L. Schnoor. 1995. Nitrogen Fixation: Anthropogenic Enhancement—Environmental Response. *Global Biogeochemical Cycles*, Vol. 9, pp. 235–252.

Getz, L.L., F.R. Cole, and D.L. Gates. 1978. Interstate Roads as Dispersal Routes for *Microtus Pennsylvanicus*. *Journal of Mammalogy*, Vol. 59, pp. 208–212.

Gilson, M.P., J.F. Malva, and R.J. Charbeneau. 1994. Highway Runoff Studies. *Water Environment and Technology*, Vol. 6, pp. 37–38.

Goldman, C.R., and R.W. Hoffman. 1975. *A Study of the Influence of Highway Deicing Agents on the Aquatic Environment of the Lake Tahoe Basin and Drainage Along Interstate 80*. Report CA-DOT-TL-7153-75-27-19-4134. California Department of Transportation, Sacramento.

Goldman, S.J., K. Jackson, and T.A. Bursztynsky. 1986. *Erosion and Sediment Control Handbook*. McGraw-Hill Book Co., New York City.

Harris, L.D. 1995. Establishing Wildlife Corridors. In *Local Ordinances: A User's Guide*, Terrene Institute Inc.; Environmental Protection Agency, pp. 29–36.

Harris, L.D., T.S. Proctor, and S.E. Gergel. 1996. Landscape Processes and Their Significance to Biodiversity Conservation. In *Population Dynamics in Ecological Space and Time* (O. Rhodes, Jr., R. Chesser, and M. Smith, eds.), University of Chicago Press, Chicago, Ill., pp. 319–347.

Health Effects Institute. 1995. *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects*. Cambridge, Mass.

Hewitt, C.N., and M.B. Rashed. 1991. The Deposition of Selected Pollutants Adjacent to a Major Rural Highway. *Atmospheric Environment*, Vol. 125A, No. 506, pp. 979–983.

Horner, R.R., and B.W. Mar. 1983. Guide for Assessing Water-Quality Impacts of Highway Operations and Maintenance. In *Transportation Research Record 948*, TRB, National Research Council, Washington, D.C., pp. 31–40.

Houghton, J. 1994. *Transport and the Environment: Eighteenth Report*. Royal Commission on Environmental Pollution, Department of Transport and the Environment, London, England.

Jones, J.A., and G.E. Grant. 1996. Peak Flow Responses to Clear Cutting and Roads in Small and Large Basins, Western Cascades, Oregon. *Water Resources Research*, Vol. 32, pp. 959–974.

Jordan, T.E., D.L. Correl, D.E. Weller, and N.N. Goff. 1995. Temporal Variation in Precipitation Chemistry on the Shore of the Chesapeake Bay. *Water, Air, and Soil Pollution*, Vol. 83, pp. 263–284.

Kinzig, A.P., and R.H. Socolow. 1994. Human Impacts on the Nitrogen Cycle. *Physics Today*, Nov., pp. 24–31.

Lagerwerff, J.V., and A.W. Specht. 1970. Contamination of Roadside Soil and Vegetation with Cadmium, Nickel, Lead and Zinc. *Environmental Science and Technology*, Vol. 4, pp. 583–586.

Lovett, G. 1994. Atmospheric Deposition of Nutrients and Pollutants in North America: An Ecological Perspective. *Ecological Applications*, Vol. 4, pp. 629–650.

Lyon, L.J. 1983. Road Density Models Describing Habitat Effectiveness of Elk. *Journal of Forestry*, Vol. 81, pp. 592–595.

Mech, L.D., S.H. Fritts, G.L. Radde, and W.J. Paule. 1988. Wolf Distribution and Road Density in Minnesota. *Wildlife Society Bulletin 16*, pp. 85–87.

Miller, P.R. 1973. Oxidant-Induced Community Change in a Mixed Conifer Forest. *Advances in Chemistry*, Vol. 122, pp. 101–117.

National Research Council. 1986. *Acid Deposition Long Term Trends*. National Academy Press, Washington, D.C.

National Research Council. 1991. *Rethinking the Ozone Problem in Urban and Regional Air Pollution*. National Academy Press, Washington, D.C.

National Research Council. 1992. *Restoration of Aquatic Ecosystems*. National Academy Press, Washington, D.C.

Pitelka, L.F. 1994. Air Pollution and Terrestrial Systems. *Ecological Applications*, Vol. 4, p. 1.

Pope, C.A, M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.H. Heath. 1995. Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults. *American Journal of Respiratory and Critical Care Medicine*, Vol. 151, pp. 669–674.

Price, M. 1994. Drainage from Roads and Airfield to Soakways—Groundwater Pollutant or Valuable Recharge? *Journal of the Institution of Water and Environmental Management*, Vol. 8, pp. 468–479.

Race, M.S., and M.S. Fonseca. 1995. Fixing Compensatory Mitigation: What Will It Take? *Ecological Applications*, Vol. 6, pp. 94–101.

Reed, R.A., J. Johnson-Barnard, and W.L. Baker. 1996. Contribution of Roads to Forest Fragmentation in Rocky Mountains. *Conservation Biology*, Vol. 10, pp. 1098–1106.

Reid, W.J. 1995. *Status of Ecological Knowledge Related to Policy Decision-making Needs in the Area of Biodiversity and Ecosystems in the United States*. Commissioned paper. World Resources Institute, Washington, D.C.

Reijnen, R., and R. Fopper. 1995. The Effects of Car Traffic on Breeding Populations in Woodland: IV. Influence of Population Size on the Reduction of Density Close to a Highway. *Journal of Applied Ecology*, Vol. 32, pp. 481–491.

Rost, G.R., and J.A. Bailey. 1979. Distribution of Mule Deer and Elk in Relation to Roads. *Journal of Wildlife Management*, Vol. 43, pp. 634–641.

RWS. 1995. *Nature Across Motorways* (*Natuur over wegen*). Road and Hydraulic Engineering Division, Delft, Netherlands.

Saunders, D.A., and R.J. Hobbs (eds). 1991. *Nature Conservation 2: The Role of Corridors*. Surrey Beatty, Chipping Norton, Australia.

Sawyer, R.F., and J.H. Johnson. 1995. Diesel Emissions and Control Technology. In *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects*, Health Effects Institute, Cambridge, Mass., pp. 67–81.

Schlesinger, W.H. 1994. The Vulnerability of Biotic Diversity. In *Industrial Ecology and Global Change* (R. Socolow, C. Andrews, F. Berkhout, and V. Thomas, eds.), Cambridge University Press, Cambridge, England, pp. 245–260.

Shaheen, D.G. 1975. *Contributions of Urban Roadway Usage to Water Pollution.* Report EPA-600/2-75-004. Office of Research and Development, Environmental Protection Agency.

Soule, M.E. (ed.). 1987. *Viable Populations for Conservation.* Cambridge University Press, Cambridge, England.

Steven, W.K. 1997. Disputed Conservation Plan Could Be Model for the Nation. *New York Times,* Sunday, Feb. 16, p. A18.

Taylor, G.E., D. Johnson, and C.P. Anderson. 1994. Air Pollution and Forest Ecosystems: A Regional to Global Perspective. *Ecological Applications,* Vol. 4, No. 4, pp. 662–689.

Tilman, D. 1982. *Resource Competition and Community Structure.* Princeton University Press, Princeton, N.J.

TRB. 1980. *NCHRP Report 221: Erosion Control During Highway Construction—Manual on Principles and Practices.* National Research Council, Washington, D.C.

TRB. 1991. *Special Report 235: Highway Deicing: Comparing Salt and Calcium Magnesium Acetate.* National Research Council, Washington, D.C.

Tyser, R.W., and C.A. Worley. 1992. Alien Flora in Grasslands Adjacent to Road and Trail Corridors in Glacier National Park, Montana. *Conservation Biology,* Vol. 6, pp. 253–262.

Van Bohenan, H., C. Padmos, and H. de Vries. 1994. Versnippering-Outsnippering: Beleid en Onderzoek bij Verkeer en Waterstaat. *Landschap,* Vol. 3, pp. 15–25.

Winner, W.E. 1994. Mechanistic Analysis of Plant Responses to Air Pollution. *Ecological Applications,* Vol. 4, pp. 651–661.

Wust, W., U. Kern, and R. Herrmann. 1994. Street Wash-Off Behavior of Heavy Metals, Polyaromatic Hydrocarbons and Nitrophenols. *Science of the Total Environment,* Vol. 147, pp. 457–463.

5

Summary Assessment and Implications for Research and Policy Making

The key findings and points from the preceding chapters are summarized in this chapter. It is anticipated that this information will help stimulate and inform public debate about transportation's contribution to several emerging environmental concerns. Although they are not the primary purpose of this study, some general implications for research and policy making emerge from the discussion and are noted here. Clearly, much remains to be learned about the environmental issues discussed in this report, including transportation's role and the opportunities for reducing it. Observations about the nature of the challenges that lie ahead are made at the end of the chapter.

KEY STUDY FINDINGS AND POINTS

Concern about Sustainable Development and the Role of Transportation (Chapter 1)

• *A basic aim of sustainable development is to ensure that current generations do not deprive future generations of essential environmental resources.*

Whereas future generations are likely to develop alternatives to current sources of energy and materials as finite supplies dwindle, they may find it far more difficult to adapt to changes in certain other critical natural resources and processes such as the earth's climate and biological diversity. If irreplaceable resources such as these are permanently altered or degraded, the consequences for future generations may be serious.

• *Transportation is a source of several environmental disturbances that present complex challenges for research and policy making.* Many of these disturbances, ranging from the emission of air pollutants and noise by motor vehicles to the destruction of habitats by road building, are being managed to varying degrees. Some—such as urban air pollution—are well recognized by the public and are the subject of regulatory programs and other mitigations. Others are more prone to neglect or mismanagement. In the former case, the biggest challenge is often to devise more cost-effective and acceptable mitigation measures. In the latter instance, often the greatest challenge is to build a stronger understanding of the problems and generate public support for addressing them. Greenhouse gas buildup, caused in part by the emission of carbon dioxide (CO_2) from the burning of gasoline and other motor fuels, is an example of such a disturbance, having consequences that may not become evident for decades. Other examples include gradual ecological losses caused by emissions that change air, water, and soil chemistry and by transportation infrastructure systems that fragment habitats and disrupt natural processes across the landscape.

• *As the dominant mode of transportation, motor vehicles pose the greatest challenge and offer the most opportunity for controlling the environmental effects of transportation.* Motor vehicles produce most of the CO_2 emitted by the transportation sector, as well as most of the other transportation emissions of environmental concern. The road system over which motor vehicles operate is by far the most extensive component of the nation's transportation infrastructure and is a source of varied environmental disturbances. As motor vehicle travel continues to grow, controlling the environmental effects of motor vehicles and the road system on which they operate will become increasingly important and challenging. The United States is a leader in motor vehicle technology and a bellwether of trends in motor vehicle use worldwide. How this environmental challenge is confronted in the United States will have implications elsewhere.

Trends and Outlook in Motor Vehicle Transportation (Chapter 2)

• *Motor vehicles have become integral to the U.S. economy and daily lives of most Americans.* Transportation has played a central role in shaping the United States throughout its history, influencing the nature and location of economic activity, the size and form of cities, and the daily activities and habits of Americans. In this century, the motor vehicle has become the principal means of both personal travel and goods movement, accounting for the largest share of transportation energy use, infrastructure investment, and activity. On average, Americans travel in their motor vehicles one hour each day, and most of the goods they purchase have been shipped by truck for part of their journey. As motor vehicles have grown in use, so has their influence on the national economy and people's decisions about where to live, work, and socialize. Policies to influence motor vehicle transportation are therefore controversial and have important ramifications.

• *The past half century has witnessed sharp growth in motor vehicle travel, which was influenced by a complex assortment of economic, demographic, social, and technological forces, such as increasing affluence, a growing economy, and the influx of women and maturing baby boomers into the driving pool.* Public policy has both responded to and contributed to this trend. The advent of a national freeway system and the continued migration of people and businesses from center cities to suburbs have influenced—and been influenced by—the rise in motor vehicle use for personal travel and freight movement. The oil supply shocks of the 1970s and early 1980s caused a brief downturn in motor vehicle travel and a number of public policies and programs to encourage fuel conservation. Some of these programs continue to exert influence on fuel use, although growth in motor vehicle travel has reverted to its upward course. Since World War II, the U.S. population has grown by three quarters, motor vehicle travel has increased by nearly fivefold, and motor fuel use has more than tripled.

• *An understanding of how trends in motor vehicle use are likely to unfold over the next several decades will be valuable to managing future environmental effects.* During the next half century different demographic, technological, and economic forces are likely to emerge as important influences on motor vehicle travel. Technological change—some only vaguely foreseeable, such as the advent of automated and "intelligent" transportation systems—could have revolutionary effects on travel. Certain demographic trends appear more predictable; for instance, the U.S. population is aging and a surge in new drivers similar to that occurring 20 to 30 years ago does not appear imminent. How an aging population will use their motor vehicles for work, family, and leisure travel will have a significant effect on the amount of motor vehicle travel in the future. Nevertheless, a continually growing population, as projected, should generate more motor vehicle travel in the aggregate. Should motor vehicle travel simply grow as fast as the population (projected at 0.75 percent per year), Americans will be driving nearly 50 percent more by the middle of the next century, which will intensify already important environmental challenges.

• *The rest of the world appears to be following the lead of the United States in motor vehicle use and technologies.* It appears certain that the pace of growth in motor vehicle use will accelerate throughout most of the world over the next several decades. Many industrializing nations are on a motorization path similar to that of the United States earlier in the century. The United States, Europe, and Japan, however, design and supply most of the world's transportation equipment and technologies, exerting an influence on the characteristics of motor vehicles and fuels used worldwide. Steps taken in the United States and other industrialized nations to influence emissions of greenhouse gases and other environmental effects from motor vehicles will likely have far-reaching consequences.

CO_2 Buildup, Role of U.S. Transportation, and Policy Options (Chapter 3)

• *Transportation is an important source of greenhouse gases.* Transportation vehicles are major emitters of CO_2, a long-lived greenhouse gas whose concentrations in the atmosphere are growing. Transportation is an especially important source of CO_2, accounting for about 20 percent of worldwide emissions from human activities each year. Motor vehicles in the United States account for 20 to 25 percent of worldwide transportation emissions (i.e., approximately 5 percent of the world's anthropogenic CO_2), almost all produced as a result of the combustion of gasoline and diesel fuels.

• *Whereas the long-term environmental consequences of greenhouse gas buildup remain uncertain and efforts continue to reduce these uncertainties, scientific consensus is emerging that human energy use is changing the earth's climate.* Scientists know that a number of gases and substances in the atmosphere have properties that alter the radiative balance of the earth. Some of these gases, such as CO_2, are measurably accumulating in the atmosphere as a result of human-generated emissions. These findings, which are generally not considered controversial, are the basis for scientific concern over climate change. The extent to which climate change poses a serious risk to future generations is far more controversial for several reasons. One is that it is not known with certainty how fast- and profoundly rising concentrations of greenhouse gases will alter climates and cause ancillary changes in other natural systems and processes. A related uncertainty is that scientists cannot be sure how fast concentrations of greenhouse gases will continue to grow in the atmosphere, although current predictions indicate steadily rising levels in the absence of major changes in energy use. The extent to which future generations will be able to accommodate changes in climate and other environmental systems is also uncertain. Given what is known and still unknown about greenhouse gas buildup, the international community is increasingly concerned about this issue and is struggling to find the most prudent combination of research and policy measures.

• *As a major emitter of CO_2, transportation is, and will likely continue to be, the subject of research and policies to reduce long-term risks from greenhouse gas buildup.* Because no single nation or economic sector accounts for a predominant share of total emissions, there is little direct incentive for any one sector to reduce emissions. Moreover, because many of the consequences of CO_2 buildup, such as climate change, are not likely to occur for many years, there is even less incentive for current emitters to take steps to control emissions in the near or medium term. Nevertheless, the transportation sector is likely to become the subject of increasing attention as policies to influence CO_2 emissions are considered and assessed by the international community. Given its research and technical capabilities, as well as its size and influence, the U.S. transportation sector is positioned to take a lead role in developing and evaluating alternative policies and technologies to control greenhouse gas buildup and its consequences.

• *Several policy and technology options are available for influencing CO_2 emissions from transportation, though most require further development and evaluation and will not have a significant effect for many years.* Various policy and technology options for controlling transportation's emissions of CO_2 are available or emerging. Most are intended to influence one of two variables: the amount of motor vehicle travel or the type and amount of motor fuel used per mile traveled. Policy measures that are intended to influence the first include those seeking to increase ride-sharing, transit use, and the cost of owning and operating motor vehicles, for instance through road tolls, vehicle taxes, and parking fees. Those seeking to influence the second include programs to raise vehicle fuel economy or develop and introduce vehicles that run on alternative, low-emission fuels. Policies that raise the price of motor fuel, such as a fuel tax or a tax on fuel carbon content, could influence both variables.

• *The likelihood that motor vehicle travel will continue to increase, combined with the uncertain and potentially slow influence of many policies and technologies on emission trends, makes early efforts to develop these options important.* Time may be the most valuable resource available for addressing the climate change threat; however, the initial assessment of options in this study indicates the importance of using this time effectively through more varied and sustained research on alternative technology and policy options.

Cumulative Ecological Effects of Vehicle Emissions and Infrastructure (Chapter 4)

• *Transportation vehicles and the infrastructure over which they operate are the source of a number of apparently site-specific environmental disturbances that have larger ecological consequences.* A local environmental disturbance, repeated often and in many areas, is more aptly described as a regional or national disturbance. Because environmental effects are frequently recognized and treated on a project-by-project basis, other environmental effects occurring over large spatial and time horizons are often neglected. For instance, emissions from motor vehicles disperse widely and the roads over which these vehicles operate have become indelible features of the landscape, altering natural flows and processes. Occurring gradually and subtly, these disturbances may nevertheless result in permanent ecological changes and losses. Transportation is not the sole cause of such effects, but its contribution is important and might be reduced if better understood and explicitly recognized.

• *The pollutants emitted by motor vehicles disperse widely and have ecological effects that can be long-lasting.* Motor vehicles emit a number of gases and other substances that are the subject of government air pollution standards and regulations aimed mainly at protecting public health in urban areas where emissions are highest. Substances emitted and subject to regulatory controls include carbon monoxide, particulate matter, volatile organic compounds, and oxides of nitrogen. The latter gases are implicated in the production of ground-level ozone, a major constituent of urban smog. Over the past three decades, required changes in vehicle technology, fuel composition, vehicle maintenance and inspection programs, and other products and practices have led to progress in controlling these pollutants and their adverse effects on the nation's urban populations. The influence of these emissions on the natural environment outside urban areas, however, has received relatively scant attention in terms of research and regulatory provisions. The repeated occurrence of many disturbances in combination—from ozone that concentrates in mountain forests to the nitrogen compounds that settle on and change the chemical balance of many aquatic and terrestrial ecosystems—suggests the need for more systematic and precise monitoring and assessment. Until they are addressed more purposefully, starting with more extensive monitoring and evaluation, the long-term effects of these disturbances will remain poorly understood and incidentally treated. Effects that are not adequately addressed may become more severe.

• *The road infrastructure has many ecological effects—on species, habitats, terrestrial and aquatic ecosystems, and natural processes—that are long-lasting, broadly dispersed, and often cumulative. Understanding and treating them from a broader landscape or regional perspective presents a major challenge for research, public education, and mitigation.* The most obvious environmental effect of roads and other transportation infrastructure is changes in the natural environment nearby. They can also fragment the land and alter natural flows and processes. For instance, roads can fragment habitats, isolating animals and altering feeding, reproduction, and migration patterns. Likewise, water flow and wildlife movement can be interrupted by a single road or network of roads, having repercussions on multiple ecosystems that are connected and share affected ecological resources such as a drainage basin or aquifer. When viewed from the perspective of an individual road project or point in time, the cumulative and collective effects of these disturbances may appear small, and therefore they may be overlooked. The ecological changes and losses are likely to build gradually and become much more evident. Transportation agencies differ in their consideration and treatment of these effects. In some instances, mitigations are available but are not routinely considered. Acknowledgment of such effects is necessary to generate support for the kind of data collection and research efforts that will enable well-conceived mitigations.

IMPLICATIONS FOR RESEARCH AND TECHNOLOGY DEVELOPMENT

The environmental disturbances that are the focus of this report are complex and controversial, as are most environmental issues. An unusual and complicating factor, however, is that many of their adverse consequences may not become manifest for decades, so that little public and political support for research to better understand the disturbances and inform public policy is engendered. Furthermore, such broad, long-term issues often do not fit well within the defined missions of governmental agencies, whose research activities are often compelled by political imperatives, resource constraints, and regulatory needs to focus on subjects within narrow areas of interest with the potential for early and implementable results. A number of prospective, longer-range research topics were identified in the preceding two chapters. Many of these topics will require years of sustained research support to achieve significant progress.

Opportunities for undertaking such research may be available through existing transportation and environmental research and development (R&D) activities in the public and private sectors. Appendix B provides an overview of federal R&D expenditures on surface transportation vehicles and fuels, indicating the magnitude of federal R&D activity and the extent to which resources in this one area alone are dispersed widely among agencies. Efforts are under way at the federal level to address institutional impediments to coordinating and integrating research across a broader range of interrelated subject matters. For instance, the White House Office of Science and Technology Policy has been charged with reviewing and rationalizing R&D activities and funding across the federal government. Within the transport field, the National Science and Technology Council's Transportation R&D Committee has been assessing ongoing research activities and long-term needs. Such periodic assessments provide an opportunity to identify gaps in research and find ways to bring a longer and broader perspective to federal research activities. The following examples illustrate how some ongoing research and programmatic activities might be better coordinated or reoriented to fill important gaps.

Support of More Varied and Long-Range R&D for Alternative Transportation Technologies

Through several agencies and programs, the federal government supports research to develop vehicle and fuel technologies that will reduce emissions of CO_2, oxides of nitrogen, and other pollutants. The largest and most prominent is the Partnership for a New Generation of Vehicles (PNGV). A main goal of the program, as discussed in Chapter 3, is to develop technologies for a new class of vehicles that can achieve fuel economies up to three times those of contemporary family sedans. By reducing motor fuel use, it is expected that such a vehicle will substantially reduce emissions of CO_2 and other gases, creating lasting environmental benefits.

Although many of the potential benefits of this research have a long-term horizon, the near-term objectives of the program—developing a production prototype by 2004—have compelled program managers to concentrate on candidate technologies with the best chance for commercialization within a decade. Less emphasis has been placed on still-emerging and therefore risky technologies and fuels—such as fuel cells, biomass, and hydrogen—that may not offer the prospect of early commercialization but that may have the technical potential for more substantial reductions in greenhouse gas emissions over longer time frames.

Another National Research Council committee charged with reviewing the PNGV program has noted the importance of maintaining a compatible long-term technology program that avoids the singling out of one or two technologies for concentration of public resources (National Research Council 1997, 5–6). That committee has urged the continued development of nonconventional technologies under a long-range sustained R&D program. This recommendation is further supported by the findings of this study, which suggest that the introduction of new vehicle and fuel technologies may require significant infrastructure changes and take many years to develop and introduce in quantities that will significantly influence trends in greenhouse gas emissions. Thus, early and persistent efforts to explore a varied array of options may help ensure that significant lead time is not lost by pursuing a small number of technologies that may encounter unforeseen technical and economic barriers or not meet future emission reduction needs.

It is important to recognize that government spending on research may not be adequate by itself and that a mix of policies to encourage private-sector R&D on advanced technologies will likely be essential to achieving progress. Finding the right mix of inducements will require experimentation and study. Private-sector R&D is many times larger than public-sector research activity, and the private sector has repeatedly demonstrated its capacity to innovate when properly motivated to address environmental problems. The automobile and oil industries, for example, have spent hundreds of millions of dollars over the past three decades in developing and introducing catalysts, reformulated fuels, and other products and technologies to achieve pollution abatement goals. Further inducements for the private sector to take a long-term perspective in advancing alternative transportation fuels and technologies may yield similarly beneficial returns over the next several decades.

Coordination and Expansion of Ecological Research in Transportation

Millions of dollars in federal funds are spent each year by states and other government agencies on projects to mitigate the ecological effects of highways and other transportation facilities. In many instances, the mitigations—which range from major wetland restoration to changes in roadside maintenance activities—represent opportunities for ecological field evaluations. However, the mitigations and their environmental consequences are seldom carefully evaluated and documented, particularly from the perspective of their long-term, combined ecological effects. For instance, little is known about the collective ecological effects of projects to preserve or restore wetlands, facilitate animal movements, or control erosion and stream sedimentation.

In many cases, federal agencies contribute funds and offer guidance on such mitigation projects. An opportunity exists therefore for the federal, state, and local governments to take a more systematic approach to monitoring and assessing the ecological value of these field experiments, examining their long-term benefits in concert and over entire regions. Rather than planning, designing, and implementing environmental mitigations on a case-by-case basis, transportation agencies, working with ecologists, may seek opportunities to integrate their efforts in ways that recognize the importance of minimizing the collective environmental effects of the vast system of transportation infrastructure. A number of ways to begin forging such links are discussed in Chapter 4, from the establishment of common ecological goals and condition indicators to more collaborations among transportation planners, engineers, and specialists in ecological sciences.

Collaboration should extend beyond the transportation sector. A substantial amount of ecological research and data collection is funded by the federal government, acting through many agencies. Much of this work is in basic fields of scientific inquiry, such as the effects of emissions on atmospheric chemistry and the ability of soils, receiving waters, and plant and animal communities to assimilate emissions. Results from this research will be important to furthering recognition, understanding, and treatment of transportation's multidimensional ecological effects.

Prediction of Travel Trends and the Influence of Policies To Alter Them

In general, information that can be used to better predict travel trends and activities is important to transportation planning and policy making, particularly when considering policies to control environmental disturbances from transportation. In recent years, a combination of demographic, social, technological, and economic forces has had a large influence on travel trends and patterns. These forces will undoubtedly exert further influence, though in ways that are difficult to predict.

Certain influences are especially difficult to forecast, such as technological change, which could transform transportation products, behavior, and services. More predictable, perhaps, are the demographic factors that will help shape transportation patterns and trends over the next several decades. Many demographic patterns are evolving gradually, enabling some rough estimates of how travel trends might unfold early in the next century. The U.S. population, for instance, is aging and the adult population is expected to grow at a slower rate over the next few decades. These trends will undoubtedly influence growth in motor vehicle travel, just as demographic shifts have influenced past travel trends.

Given the availability of good demographic projections, a sophisticated, ongoing evaluation of future demographic changes that are likely to influence future travel trends appears both possible and important to transportation planning. The U.S. Department of Energy and the U.S. Department of Transportation independently project travel trends and patterns to forecast energy demand and infrastructure needs. The Census Bureau makes detailed demographic projections of the U.S. population. The integration of data and projections developed by each of these agencies would undoubtedly provide a more accurate picture of the factors likely to influence travel in the United States over the next half century.

Such information will also be of value in assessing alternative policies to reduce transportation's environmental effects over time. It will need to be complemented, however, by a better understanding of the factors influencing travel demand and how travel behavior changes with income, lifestyle, life stages, and settlement patterns. For instance, the influence of several policy options reviewed in this report on travel hinges on assumptions and findings about travel behavior changes in response to changes in prices, land use, transportation options, and other factors. Currently, the Department of Transportation's research budget provides little support for research on travel behavior, though such information is essential to developing policies that might eventually be needed to alter travel behavior and trends in ways that are least disruptive.

The initial review of policy options in this study only touched on the many environmental, economic, technical, social, and other factors that must be considered when assessing policy options. Research and data collection to improve policy assessment capabilities will be important in developing and prioritizing policy options and strategies to control the long-term environmental effects of transportation.

GENERAL OBSERVATIONS AND OUTLOOK

Greenhouse gas buildup and the other environmental disturbances discussed in this report occur gradually without much public notice and with consequences that remain poorly understood. A manifestation of this situation is that other near-term concerns often take precedence in research, making it difficult to resolve some of the uncertainties and gaps in information. This is a cause for concern.

Recent history in the transportation sector offers insights into the importance of supporting and encouraging research to improve scientific understanding of an environmental problem, both to inform the public and to strengthen public policy. For instance, only 50 years ago scientists first began to suspect that motor vehicle emissions were an important factor in the creation of urban smog and other forms of air pollution. Less than 20 years later, California adopted emission control standards that prompted scientists and engineers in the public and private sectors to find ways to reduce emissions. National emission standards soon followed as public recognition of the problem grew. By the early 1980s, major advances had been made in pollution control technologies, causing emissions of many pollutants to decline even as motor vehicle travel increased. Over the same period, significant changes were made in the way highways and other transportation facilities were planned and constructed to reduce egregious environmental problems such as erosion and stream sedimentation. In neither instance were the environmental problems resolved, but the transformations that occurred in perceptions and practices are remarkable given the short time frame.

Such a progression in understanding and practice may take many more years for the longer-range environmental issues that are the subject of this report. The scientific uncertainties remain daunting in some instances. Furthering scientific understanding will reduce the likelihood of neglectful or poorly conceived public policies. At the same time, research on technological and policy options to address these long-range environmental threats should be accelerated even as efforts to better understand them continue.

REFERENCE

National Research Council. 1997. *Review of the Research Program of the Partnership for a New Generation of Vehicles: Third Report.* Board on Energy and Environmental Systems. National Academy Press, Washington, D.C.

Appendix A

Assumptions, Calculations, and Data Sources for Baseline and Hypothetical Scenarios

Chapter 2 contains a baseline scenario giving plausible trends in motor vehicle miles traveled (VMT) in the United States and resultant petroleum fuel use for the four-decade time frame encompassing the years 2000 to 2040. The baseline trend is shown in Figure 2-11.

In Chapter 3, this baseline was used to develop a plausible scenario for future trends in carbon dioxide (CO_2) emissions from motor vehicles. Four hypothetical scenarios were also developed in Chapter 3 to illustrate the effects on emission trends of the following options for reducing transportation emissions:

1. Reductions in motor vehicle travel demand,
2. Increase in conventional vehicle fuel economy,
3. Higher petroleum fuel prices, and
4. Development of vehicles emitting low amounts of CO_2 and other greenhouse gases.

The purpose of these scenarios is not to judge the probability that specific policies (e.g., a carbon tax, land use controls, inducements for technological change) will be adopted and spawn changes in vehicle fuel economy, travel demand, and low-carbon vehicles. Nor is their purpose to portray all of the costs and benefits of specific policies or outcomes.[1] Rather, their intent is to provide a general sense of the magnitude and timing of changes in motor vehicle travel, fuel economy, fuel prices, and vehicle technologies that may be warranted to influence long-run trends in CO_2 emissions. Although in practice one would not expect many of the outcomes of the scenarios to occur singularly, that is, without many other ramifications,[2] the committee nevertheless believes that the simple scenarios are sufficiently plausible to serve the largely illustrative purposes for which they are intended.

Results from the hypothetical scenarios are presented in Figures 3-2, 3-3, 3-5, and 3-6. The assumptions and data used in developing the baseline and four alternative scenarios (Scenarios 1, 2, 3, and 4 as listed above) are described in this appendix and tables showing the results are given.

BASELINE SCENARIO

The baseline scenario is intended to illustrate a plausible, long-range "business-as-usual" situation in which minimal action is taken to control emissions of CO_2 from U.S. motor vehicles. It is anticipated that motor vehicle travel, petroleum use, and resulting CO_2 emissions will grow at a constant rate of 1.5 percent per year over the 40-year period. Growth in petroleum use and CO_2 emissions is presumed to be driven primarily by demographic and economic forces spurring increased motor vehicle travel. Whereas such an even rate of growth is unlikely, this supposition nevertheless enables straightforward calculations that are sufficiently plausible for demonstrating the general magnitude and timing of the effects. Additional assumptions and calculations were made in developing the baseline trends.

Key Assumptions, Calculations, and Data Sources

Although the scenario time line begins in the year 2000, some simple extrapolations from 1995 data were required to arrive at likely levels of

VMT, petroleum fuel use, and CO_2 emissions for this initial year. In 1995 the U.S. motor vehicle fleet (all vehicle types—cars, trucks, and buses) traveled 2,420 billion miles and consumed 143 billion gallons of gasoline and diesel fuel, thus averaging about 16.9 miles per gallon of fuel consumed (VMT divided by gallons of petroleum consumed).[3] These data can be found in Table VM-1 of *Highway Statistics 1995*, published by the Federal Highway Administration (FHWA) of the U.S. Department of Transportation (FHWA 1996). FHWA's *Highway Statistics* series, which has been issued annually for more than 40 years, provides fairly consistent historical data on motor vehicle travel trends and fuel use. These data cover all on-road vehicles, including passenger cars, motorcycles, buses, light trucks (two-axle, four-tire vehicles, including vans, pickup trucks, and sport-utility vehicles), single-unit medium- and heavy-duty trucks (vehicles with two axles and six or more tires), and combination vehicles (e.g., tractor-trailers). Data for off-road vehicles such as farm and construction equipment are not included. FHWA obtains its motor fuel use and travel data from state records of fuel tax receipts and traffic counts, supplemented by periodic travel surveys.

On the basis of the 1995 data, VMT is anticipated to reach 2,610 billion in the initial year, 2000. It is assumed that VMT will grow about 1.5 percent per year for the rest of the 1990s, which is the same as the baseline rate of growth. A 1.5 percent annual rate of growth is fairly consistent with the latest travel data by FHWA, which show that national VMT grew 1.7 percent during 1995 (FHWA 1996, Table VM-1). It is further assumed that fleetwide fuel economy (i.e., total VMT divided by total fuel consumed) will remain stable at 16.9 miles per gallon, and thus petroleum consumption will track growth in VMT, totaling about 154 billion gallons in 2000. The rationale for holding fuel economy constant is provided in Chapter 2. Also, as discussed in Chapter 2, U.S. population is forecast to be on the order of 275 million in 2000, resulting in per-capita VMT of about 9,490 (compared with 9,132 in 1995).

On the basis of calculations described below and in Chapter 3, each gallon of petroleum (gasoline and diesel fuel) is assumed to produce an average of 19.5 pounds of CO_2. Thus, the 143 billion gallons of motor fuel consumed in 1995 produced 2,789 billion pounds of CO_2, equivalent to 1,260 million metric tons. Assuming the same per-gallon rate of CO_2 emissions, the baseline projection of 154 billion gallons of petroleum consumed in 2000 would generate 3,003 billion pounds of CO_2 (154 billion gallons multiplied by 19.5 pounds per gallon), equivalent to 1,360 million metric tons. Not considered—for reasons given in Chapter 3—are "upstream" emissions of CO_2 from fuel extraction, production, and distribution. [As noted in Chapter 3 (footnote 4), DeLuchi (1991) has estimated that the latter emission sources might result in 25 percent more CO_2 emissions per mile traveled.]

The CO_2 emission rate per gallon was derived as follows. Gasoline and diesel fuel account for about 85 and 15 percent of motor vehicle petroleum use, respectively (FHWA 1996, Table MF-21). According to calculations by Delucchi (1991) and the U.S. Department of Energy (DOE) (1995, 77), a 6.1-pound gallon of gasoline contains about 5.2 pounds of carbon since about 85 percent of its weight is carbon.[4] Light-distillate diesel fuel (as commonly used in commercial trucks) is denser than gasoline and therefore contains more carbon per unit of volume: each 6.9-pound gallon of diesel fuel, which is about 87 percent carbon by weight, contains about 5.9 pounds of carbon. Thus, the average gallon of motor fuel consumed contains approximately 5.3 pounds of carbon when weighted according to the respective shares of gasoline and diesel fuel (85/15) consumed by the fleet. The long-run fate of most of the carbon contained in this fuel will be to combine with oxygen to form CO_2. Each pound of carbon will produce 3.67 pounds of CO_2; therefore, each gallon of petroleum fuel will generate about 19.5 pounds of CO_2 [5.3 pounds carbon $\times$ 3.67 (conversion factor)]. As discussed in Chapter 3, these calculations are consistent with estimates of annual CO_2 emissions by DOE (1995, 12, 92) (see Table 3-2 and the accompanying discussion).

Thus, the baseline scenario starts in 2000 with the following assumptions: (*a*) VMT = 2,610 billion miles, (*b*) motor vehicle petroleum fuel use = 154 billion gallons, (*c*) fleet average miles per gallon (*a*/*b*) = 16.9, (*d*) each gallon of petroleum fuel emits 19.5 pounds of CO_2, (*e*) an average of 1.15 pounds of CO_2 is emitted per mile traveled (*d*/*c*), (*f*) CO_2 emissions from fuel use = 1,360 million metric tons, and (*g*) U.S. population = 275 million, thus (*h*) VMT per capita = 9,490 (*a*/*g*).

Starting with these base year values, VMT is assumed to grow an average of 1.5 percent per year from 2000 to 2040. This trendline, shown in Figure 2-11, is consistent with the most recent 20-year forecast by DOE covering the period 1995 to 2015 (DOE 1996, 24; see Chapter 2). VMT growth in the United States during the past 40 years has been significantly higher than 1.5 percent per year; however, many of the demographic, economic, and social forces that spurred rapid growth in motor vehicle travel have subsided, as detailed in Chapter 2. The Census Bureau predicts that U.S. population will grow an average of 0.75 percent per year from 2000 to 2040, which is significantly lower than the rate of population growth during the second half of this century (Bureau of the Census 1995, Table 3). The assumed 1.5 percent rate of growth in VMT is therefore twice the forecast rate of growth in population, implying that annual VMT per capita will increase 0.75 percent per year.[5]

During the same 40-year period, it is assumed that petroleum consumption by the fleet will rise an average of 1.5 percent per year, mirroring growth in motor vehicle travel. This trendline, also shown in Figure 2-11, presumes no changes in fleet average fuel economy (stable at 16.9 miles per gallon) or in the mix of vehicles or fuels in use. These assumptions are varied in the four scenarios described later.

Baseline emissions of CO_2 are assumed to grow an average of 1.5 percent per year in accordance with growth in petroleum fuel use. It is assumed that the proportion of gasoline to diesel fuel used will remain stable (at 85/15) and that no other changes in fuel composition or formulation will have a meaningful effect on the rate of CO_2 emitted per mile of motor vehicle travel.

Thus, the following values are projected for the baseline scenario covering 2000 to 2040: (*a*) VMT grows 1.5 percent per year, (*b*) petroleum fuel use grows 1.5 percent per year, (*c*) CO_2 emissions grow 1.5 percent per year, (*d*) fleet fuel economy (miles per gallon) remains constant, (*e*) petroleum prices do not fluctuate so as to significantly affect petroleum demand, (*f*) use of nonpetroleum fuels remains negligible, and (*g*) U.S. population grows 0.75 percent per year; thus annual VMT per capita grows 0.75 percent per year.

Results

Figures 3-1, 3-2, 3-3, and 3-5 show the baseline trends in CO_2 emissions developed from the VMT and fuel usage assumptions and values given above. The baseline data in 5-year increments are provided in Table A-1. VMT, petroleum use, and CO_2 emissions are projected to be about 35 percent higher in 2020 than in 2000, and about 80 percent higher in 2040. Compared with 1995 CO_2 emission levels (about 1,260 million metric tons as calculated above), the baseline scenario projects a near-doubling of CO_2 emissions by 2040. Annual VMT per capita would be about 35 percent higher in 2040 than in 2000, rising from 9,490 to about 12,750.

Table A-1 Summary of Baseline Scenario

Year	VMT (billions) (1)[a]	Petroleum Fuel Consumed (billion gallons) (2)[b]	Carbon Dioxide Emitted (million metric tons) (3)[c]	Fleet Miles per Gallon (4)[d]	U.S. Population (millions) (5)[e]	VMT/ Capita (6) = (1)/(5)
1995	2,420	143	1,260	16.9	265	9,132
2000	2,610	154	1,360	16.9	275	9,490
2005	2,810	166	1,470	16.9	286	9,825
2010	3,030	179	1,580	16.9	296	10,135
2015	3,260	193	1,700	16.9	308	10,580
2020	3,510	207	1,830	16.9	319	11,000
2025	3,780	224	1,980	16.9	332	11,385
2030	4,070	241	2,130	16.9	344	11,831
2035	4,390	259	2,290	16.9	357	12,297
2040	4,730	279	2,470	16.9	371	12,749

[a]VMT grows 1.5 percent per year.

[b]Petroleum consumed increases 1.5 percent per year.

[c]Gallons of petroleum consumed (2) multipled by 19.5 pounds. Product divided by 2,205 to convert to metric tons.

[d]VMT divided by petroleum consumed (1)/(2). Value remains constant throughout baseline scenario.

[e]U.S. population grows 0.75 percent per year.

SCENARIO 1: REDUCTION IN MOTOR VEHICLE TRAVEL DEMAND

Scenario 1 supposes that some combination of travel demand management measures (such as parking restrictions, ridesharing, and vehicle fees), land use controls, and transit investments is successful in slowing growth in motor vehicle travel. Again, the purpose of the scenario is not to judge whether such measures could or should be taken or whether they would be effective in slowing growth in motor vehicle travel but to illustrate how changes in travel growth within a plausible range and time frame could affect CO_2 emission trends, both in timing and in magnitude.

Key Assumptions, Calculations, and Data Sources

Widespread adoption of travel control measures in major metropolitan areas is assumed to reduce the rate of growth in national VMT by 10 percent. Thus, VMT grows at an annual rate of 1.35 percent rather than 1.5 percent as is assumed in the baseline case (0.90 × 1.5 percent = 1.35 percent).[6] This 10 percent reduction is derived from an analysis by the U.S. Department of Transportation (DOT) of long-range travel forecasts of metropolitan planning organizations (MPOs) of the nation's largest urban areas. State and local governments in many of these areas are compelled by requirements of the federal Clean Air Act to take action to curb growth in motor vehicle travel as a means of controlling local air pollution (e.g., particulates, NO_x). Many MPOs are therefore developing plans to deter motor vehicle travel, for instance, through measures such as ridesharing, parking restrictions, and transit investments. In analyzing the motor vehicle travel forecasts of these large metropolitan areas, DOT found that they collectively yielded rates of growth in travel that are significantly lower than conventional DOT forecasts. To be consistent with the MPO forecasts, DOT estimates that it would have to lower by nearly 10 percent its projected national annual rate of growth in travel for the period 1994 to 2013 (from 2.37 percent per year to 2.15 percent) (DOT 1995, 162–168).[7] Accordingly the study committee reduced the 1.5 percent baseline growth rate by 10 percent to 1.35 percent per year.

Since most of these metropolitan travel management plans do not include controls on land use and development to curtail travel, additional assumptions were made about the adoption of such measures over time. A key assumption is that all new residential and commercial developments are oriented in favor of non-motor-vehicle modes of travel, such as transit, biking, and walking, and that this new orientation will lead to sizable reductions in motor vehicle travel for those living and working in these newly developed areas. Studies of such unconventional developments have shown or predicted reductions in travel on the order of 5 to 15 percent, as discussed in Chapter 3. Given that the potential for these developments has not been explored or tested on a widespread basis, a more optimistic assumption is that they will, if instituted widely, reduce per-capita motor vehicle travel by 20 percent among those living and working there (relative to the per-capita travel of those in established areas that are oriented toward motor vehicle travel).

However, in recognition that land use patterns are by and large established and enduring in most areas of the country, it is assumed that these new developments will be phased in gradually, only affecting new development that accommodates net population growth. The Census Bureau projects 0.75 percent annual population growth during the first four decades of the next century (Bureau of the Census 1995, Table 3). Hence, it is assumed that each year a growing share of the U.S. population will work and reside in new developments and that these residents will travel 20 percent fewer miles per capita. Thus about one-eighth of the population will be accommodated by these new developments in 2020 and about one-fourth will be two decades later.

The combined effect of all these assumptions is to reduce the rate of growth in motor vehicle travel to an average of 1.1 percent per year during the 40-year time horizon of the scenario, which is about 25 percent lower than the baseline 1.5 percent annual rate of growth. This scenario growth rate, however, will not be constant (as supposed in the baseline scenario) but will be declining gradually over time as a larger share of the population is accommodated by the new, less-travel-intensive developments.

As in the baseline case, it is assumed that trends in travel (VMT) will be mirrored by trends in petroleum use and CO_2. All else (such as petroleum prices, use of alternative vehicles and fuels, and fleet fuel economy) is presumed constant. In addition, not factored into the results are the emissions that will be expected from the increased transit use that will likely result from reductions in motor vehicle travel. Presumably, increased ridership on mass transit (including buses) will produce some additional CO_2, offsetting some portion of the emission savings achieved by slowing growth in motor vehicle travel.

Results

The results from this scenario are given graphically in Figure 3-1. Data for 5-year increments are provided in Table A-2. Under this alternative scenario, CO_2 emissions would be about 6 percent lower than baseline emissions by 2020 and nearly 15 percent lower by 2040. Changes relative to 1995 levels are also shown in Table A-2.

SCENARIO 2: INCREASE IN MOTOR VEHICLE FUEL ECONOMY

Scenario 2 supposes that some combination of policies that spur the development and introduction of fuel-saving technologies is successful in continually raising the fuel economy of new vehicles (again, all vehicle types) entering the fleet. For simplicity, it is assumed that new vehicles have performance characteristics and purchase prices similar to those of existing vehicles, so that they enter and remain in the fleet at about the same rates as in the baseline scenario.[8] As the fleet turns over, one would expect this increase in new-vehicle fuel economy to cause an increase in average miles per gallon of the overall fleet, thus causing petroleum use to decline relative to the baseline. These gains in vehicle fuel economy would lead to some additional driving as the cost per mile of motor vehicle travel falls (this presumes stable fuel prices, an assumption that is varied in the next scenario). Overall, however, aggregate fuel consumption is expected to fall relative to the baseline trend.

Key Assumptions, Calculations, and Data Sources

Average miles per gallon of new vehicles entering the fleet is assumed to rise 1.5 percent per year. This growth rate is comparable with the

Table A-2 Summary of Scenario 1: Reduction in Motor Vehicle Travel Demand

Year	U.S. Population (millions) (1)[a]	Population in Established Developments (millions) (2)[b]	VMT/Capita of Population in Established Developments (3)[c]	VMT of Population in Established Developments (billions) (4) = (2) × (3)	Population in New Developments (millions) (5)[d]	VMT/Capita of Population of New Developments (6)[e]	VMT of Population in New Developments (billions) (7) = (5) × (6)	Total VMT (billions) (8) = (4) + (7)	Total Petroleum Used (billion gallons) (9)[f]	Total CO_2 Emissions (million metric tons) (10)[g]
1995	265	265	9,132	2,420	0	0	0	2,420	143	1,260
2000	275	275	9,490	2,610	0	0	0	2,610	154	1,360
2005	286	275	9,778	2,688	11	7,822	86	2,774	164	1,450
2010	296	275	10,074	2,770	21	8,059	169	2,939	174	1,540
2015	308	275	10,380	2,854	33	8,304	274	3,128	185	1,630
2020	319	275	10,695	2,941	44	8,556	376	3,317	196	1,730
2025	332	275	11,020	3,030	57	8,816	502	3,532	209	1,850
2030	344	275	11,354	3,120	69	9,083	627	3,747	222	1,960
2035	357	275	11,699	3,217	82	9,359	767	3,984	236	2,010
2040	371	275	12,315	3,386	96	9,852	945	4,331	256	2,260

[a] U.S. population grows 0.75 percent annually after 2000.
[b] Established developments (oriented toward motor vehicle travel) are enduring and continue to acommodate 275 million people.
[c] VMT pet capita grows 0.6 percent per year, which is lower than in baseline scenario (0.75 percent per year) because of the implementation of effective travel demand management measures.
[d] All net population growth is accommodated by new developments that are oriented toward less motor vehicle travel.
[e] VMT/capita is 20 percent lower than VMT/capita of population in established developments. VMT/capita for population in new developments does not change over time.
[f] Total VMT (8) divided by 16.9 miles per gallon.
[g] Gallons of petroleum fuel consumed (9) multiplied by 19.5 pounds. Product divided by 2,205 to convert to metric tons.

annual rate of growth in new-vehicle (in this case, passenger car) fuel economy deemed feasible by a 1992 National Research Council study (National Research Council 1992), which calculated that an average increase in fuel economy of roughly 2 percent per year is technically achievable for new passenger cars over the course of a dozen years (though still resulting in somewhat higher vehicle purchase prices) (see Chapter 3). This 1.5 percent per year rate of growth is also about the average rate of growth in miles per gallon (VMT divided by total petroleum use) for the entire vehicle fleet since 1975 (see Figure 2-7). Thus, according to this assumption, new vehicles entering the fleet in the first year of the scenario would have an average fuel economy of 17.15 miles per gallon rather than the baseline average of 16.9. The latter value would remain the average for the remainder of the fleet. The following year, however, new vehicles entering the fleet would average 17.4 miles per gallon, and so on.[9]

As time passes, the new, more fuel-efficient vehicles—which would remain in the fleet for many years—would continue to boost the average miles per gallon of the overall fleet. As successive generations of vehicles entered the fleet—each new one averaging 1.5 percent more miles per gallon than the last one—the annual rate of growth in miles per gallon of the entire fleet would continue to grow, approaching 1.5 percent per year over time. How quickly fleetwide average fuel economy rises will depend on the rate of vehicle turnover and usage by age. Data from DOT's Nationwide Personal Transportation Survey (DOT 1995, 30) show that vehicles 5 years of age and under account for more than half of all miles traveled.[10] The data suggest (holding all else equal) that by about 2010 in this scenario, nearly 80 percent of VMT would be from the more fuel-efficient vehicles (i.e., those averaging more than 16.9 miles per gallon) that began entering the fleet at the start of the decade. At some point during the decade between 2010 and 2020, the older vehicles that were in the fleet at the beginning of the century would account for a negligible share of overall VMT.

It is assumed (on the basis of the data presented in endnote 10) that beginning in 2001, vehicles under 2 years of age will account for 12 percent of total fleet VMT, gradually declining to 5 percent for 9-year-old vehicles. Vehicles 10 years of age or older would account for only 22 percent of VMT. Thus, in 2001, first-year vehicles that average 17.15

miles per gallon would account for about 310 billion miles, which is 12 percent of the anticipated total VMT for the nation (about 2.6 trillion). The rest of the fleet, averaging 16.9 miles per gallon, would account for the remainder of VMT; hence, total fleet miles per gallon (i.e., fleet VMT divided by petroleum use) would rise only slightly during the first few years as the more fuel-efficient vehicles are phased in.

An important consideration that needs to be factored into the scenario is that vehicles offering higher fuel economy will be less costly to drive on a per-mile basis than are the vehicles they replace (again, holding constant fuel prices and other vehicle- and driving-related costs). For example, when the price of a gallon of motor fuel is \$1.35, the fuel cost per mile of driving a vehicle offering 16.9 miles per gallon will be \$0.0798 (\$1.35/16.9 miles per gallon). On the other hand, the cost per mile of driving a vehicle offering 17.15 miles per gallon will be \$0.787 (\$1.35/17.15 miles per gallon). This reduction in per-mile fuel costs is equivalent to a drop of \$0.02 per gallon in the real price of motor fuel, a 1.5 percent decline (\$0.02/\$1.35), which is commensurate with the rate of increase in vehicle fuel economy. Hence, as the real cost of driving declines, one would expect motorists to drive more. This stimulative effect, often referred to as a "rebound" effect, is discussed in Chapter 3.

The size of the so-called rebound effect is controversial but important when estimating the effect of fuel-economy gains in reducing total fuel use since the additional "rebound" driving will offset some of the fuel saved by the higher fuel economy. No good estimates of the rebound effect exist that would apply neatly to the long-range scenario described here. Nevertheless, estimates of this effect, even over shorter time horizons than in Scenario 2, can provide a general basis for these calculations. The literature cited in Chapter 3 gives a wide range of values for measuring this effect. Some studies suggest that for every 1 percent increase in vehicle fuel economy (that is, a 1 percent reduction in the fuel cost per mile of driving, or a 1 percent reduction in the price of a gallon of motor fuel), motorists will drive 0.5 percent more than they would otherwise have driven. Others suggest that the effect of such a fuel-economy gain would be significantly less, perhaps less than 0.01 percent for every 1 percent increase in miles per gallon. Given this fairly wide range of values, a mid-range estimate was chosen that assumes every 1 percent increase in vehicle fuel economy will result in 0.2 percent more miles driven. Since VMT is already expected to rise in Scenario 2, a further increase in annual VMT growth is implied.

Even in the absence of fuel economy gains, VMT in the baseline scenario is assumed to grow 1.5 percent per year, suggesting that each successive cohort of new vehicles is driven 1.5 percent more miles than the previous cohort of new vehicles. Likewise, the next group of 2-year-old vehicles would be driven 1.5 percent more miles than 2-year-old vehicles during the previous year, and so on. Because it is assumed that each successive cohort of vehicles is more fuel efficient than their immediate predecessors—averaging 1.5 percent more miles per gallon—these newer vehicles will be driven somewhat more, namely, an extra 0.3 percent because of the assumed rebound effect described above (0.2 × 1.5 percent). Therefore, the new vehicles entering the fleet in 2001, which average 17.15 miles per gallon, would not only be driven 1.5 percent more than the previous cohort of new vehicles, they would also be driven an additional 0.3 percent, boosting the annual rate of growth in VMT to 1.8 percent.[11] It is important to remember that this effect will continue as each successive cohort offers 1.5 percent more fuel economy than the last one; hence, at some point around 2020—when the number of older vehicles (those averaging 16.9 miles per gallon) is no longer meaningful—total fleet VMT will rise an average of 1.8 percent per year.

On the positive side, because the more fuel-efficient, newer vehicles are driven more, they would be expected to account for a larger share of total fleet VMT, thereby giving an additional boost to the average miles per gallon of the entire fleet (again, calculated by dividing total fleet VMT by total fleet fuel consumption). On the negative side, the 0.3 percent additional miles traveled will generate some additional petroleum demand, offsetting a portion of the fuel savings promised by increasing vehicle fuel economy.

Whether a 1.5 percent annual increase in new-vehicle miles per gallon is indeed achievable and sustainable over such a prolonged period and for all vehicle types (e.g., new passenger cars as well as new trucks) was not considered in the scenario. Nor were the policies that might be employed to achieve such a result or the range of responses by motorists (including the plausibility, over long time horizons, of the "rebound" effect assumed). Certainly one could argue that a constant rate of improvement in new-vehicle fuel economy is unrealistic; however, for the purposes of illustration, this simple premise is acceptable since the outcome is not likely to differ significantly from what would occur if fuel economy rose *an average* of 1.5 percent over the period but with modest annual fluctuations in growth. More debatable is whether it is indeed plausible to presume an average rate of increase in new-vehicle fuel efficiency of 1.5 percent sustained over several decades absent significant changes in vehicle prices and performance or fuel prices that stimulate consumer demand for fuel economy. The assumed 1.5 percent fuel-economy growth rate is also comparable with the average rate of increase in fleet fuel economy that occurred from 1975 to 1995 (1.7 percent per year) (see Figure 2-7). It is important to recognize, however, that the growth in fleet fuel economy during the past 20 years was in large part spurred by the rising fuel prices that occurred during the 1970s and 1980s; fuel prices are assumed stable in this scenario. Also, if one were to attempt to achieve these annual increases in vehicle fuel economy by focusing on any one portion of the motor vehicle market (e.g., passenger cars, which are the focus of federal fuel-economy standards, as discussed in Chapter 3), the challenge and time frame required for fleetwide influences would be even greater.

Results

Some of the results from this scenario were shown in Figure 3-2. The data in 5-year increments are shown in Table A-3. Under this alternative scenario, CO_2 emissions would be 15 to 20 percent lower than baseline emissions by 2020 and about 35 percent lower by 2040. Changes relative to 1995 levels are also shown in Table A-3.

SCENARIO 3: HIGHER MOTOR FUEL PRICES

Scenario 3 considers the effect on CO_2 emissions of continually rising petroleum prices, presuming that higher fuel prices will slow growth in motor vehicle travel and encourage demand for fuel-saving vehicles and technologies. Though fuel taxes (including carbon taxes) are one means of achieving higher fuel prices, natural market forces (e.g., rising world

Table A-3 Summary of Scenario 2: Increase in Motor Vehicle Fuel Economy

Year	Average Miles per Gallon for New Vehicles Entering Fleet (1)[a]	VMT by Entire Fleet (billions) (2)[b]	Average Miles per Gallon of Entire Fleet (3)[c]	Total Petroleum Consumed by Fleet (billion gallons) (4) = (2)/(3)	Total CO_2 Emitted by Fleet (million metric tons) (5)[d]
1995	16.9	2,420	16.9	143	1,260
2000	16.9	2,610	16.9	154	1,360
2005	18.2	2,810	17.3	161	1,420
2010	19.6	3,030	18.3	166	1,470
2015	21.1	3,310	19.5	169	1,500
2020	22.8	3,620	21.0	172	1,520
2025	24.5	3,950	22.6	175	1,540
2030	26.4	4,320	24.4	177	1,570
2035	28.5	4,720	26.3	180	1,590
2040	30.7	5,170	28.3	183	1,620

[a]It is assumed that initially (in 2000) new-vehicle fuel economy (all types of new vehicles) is the same as that of the entire fleet (e.g., 16.9 mpg) and that new-vehicle fuel economy grows 1.5 percent per year after 2000.

[b]VMT increases 1.5 percent per year, with an additional increase in VMT of 0.3 percent for those vehicles having 1.5 percent higher fuel economy (because of rebound effect).

[c]Rising fleet average miles per gallon is a function of increasing share of VMT by newer vehicles having higher fuel economy and declining share by older vehicles with lower fuel economy.

[d]Gallons of petroleum consumed (4) multiplied by 19.5 pounds. Product divided by 2,205 to convert to metric tons.

demand for petroleum fuel accompanied by dwindling petroleum supplies) could also prompt increases in petroleum prices over time. Some of the economic and political issues associated with the fuel- and carbon-tax options are discussed in Chapter 3. The purpose of Scenario 3 is not to examine the costs and benefits of a fuel tax per se but to illustrate how rising fuel prices in general could affect trends in motor vehicle travel, vehicle fuel efficiency, petroleum consumption, and resulting emissions of CO_2.

Key Assumptions, Calculations, and Data Sources

Petroleum prices are assumed to rise an average of 3 percent per year for the four-decade period encompassing 2000 to 2040. If gasoline and diesel prices average $1.35 per gallon in 2000 (similar to mid-1990s prices), this rate of growth will lead to per-gallon prices that are about $1.00 higher in 2020 and $3.00 higher in 2040. An implied assumption is that these fuel prices are also rising 3 percent faster than inflation and growth in real income; hence, motor fuel is becoming less affordable over time.[12]

Since higher petroleum prices will increase the cost per mile of driving, two responses are assumed to occur: motorists will drive less, and they will demand less-fuel-intensive vehicles. That such responses will occur is not an especially controversial assumption. What is more debatable, however, is the timing and size of the responses. As cited in Chapter 3, numerous studies have attempted to gauge consumer responses to higher fuel prices and the resulting effects on petroleum demand. These studies, based mainly on observations in the passenger car market, have found a wide range of price-elasticity values, measuring how a percentage increase (or decrease) in petroleum prices will lead to a percentage decrease (or increase) in petroleum consumption. Some long-run elasticity values found in the literature approach or exceed −1, suggesting that a 10 percent increase in petroleum prices will have a one-to-one relationship with petroleum demand, reducing it by about 10 percent. Other studies have found more modest price elasticities on the order of −0.2, implying that a 10 percent increase in fuel prices will produce only a 2 percent decline in petroleum usage.

Because none of the price-elasticity estimates in the literature cover price changes and responses occurring over periods as long as a decade —much less several decades—they provide very rough benchmarks for price elasticities relevant to long-range situations. In recognition of these limitations, a mid-range price-elasticity value of −0.4 was chosen for this scenario. This value implies that a 10 percent increase in petroleum prices would yield a 4 percent reduction in petroleum use over time, a response that is of sufficient size to demonstrate how apparently modest and gradual changes in fuel prices can have a large influence on total fuel consumption over the course of decades.

It is assumed that half the reduction in petroleum consumption caused by rising fuel prices is the result of a reduction in VMT by motorists, whereas the other half is caused by an increase in the fuel economy of the vehicles they operate. In other words, a 10 percent increase in petroleum prices—equivalent to a 10 percent increase in the per-mile fuel cost of driving (all else being unchanged)—causes miles traveled to go down by 2 percent (which is comparable with the rebound effect described above). At the same time, it is assumed that average miles per gallon of the fleet will increase by 2 percent, resulting in a 4 percent reduction in total petroleum consumption.[13] Faced with higher vehicle fuel costs, motorists would presumably curtail their discretionary travel first. Over time, however, motorists could make other changes that affect travel behavior, for instance, relocating and reducing the distance between home and work. For simplicity, the elasticity value is assumed to remain stable over time, although one might expect it to gradually increase as motorists' response options expand. The increases in fuel economy are also assumed to reflect an average gain for the entire fleet. Scenario 2 assumed increases in new-vehicle fuel economy that would gradually have a meaningful effect on the average fuel economy of the fleet. Rising fuel prices, however, would have a broader influence, not only spurring motorists to purchase new, fuel-efficient vehicles but also causing them to reduce their use of older, more fuel-intensive vehicles and to drive in a manner that saved fuel (e.g, more slowly). This multipronged response will cause miles per gallon to increase among vehicle age categories (though to varying degrees). Hence, the focus in this scenario is on changes in fleetwide fuel economy, and no specific estimates are made of the effects on new-vehicle fuel economy per se.[14]

These elasticity assumptions suggest that a 3 percent annual increase in petroleum prices, as assumed, would yield a 0.6 percent decline in travel (3 percent × 0.2), reducing the baseline rate of growth in VMT (1.5 percent annual) to 0.9 percent per year (1.5 − 0.6). Meanwhile, fleetwide fuel economy would grow 0.6 percent (3 percent × 0.2) per year from its baseline value of 16.9 miles per gallon.

For a number of reasons, this is a highly simplified illustration of how rising fuel prices affect motor fuel consumption. Not portrayed, for instance, is how higher fuel prices would affect increasing transit ridership or other transportation activities that are also a source of greenhouse gas emissions, albeit less so than private motor vehicles. It is also assumed, for the narrower purposes of this scenario, that alternative fuels do not become price-competitive with petroleum fuels. Thus, motorists are presumed to respond to higher fuel prices by reducing motor vehicle travel or increasing vehicle fuel economy, or both; other likely responses (such as switching to another fuel) are not considered.

Results

The results of this scenario are shown in Figure 3-5. The data in 5-year increments are shown in Table A-4. Under this scenario, CO_2 emissions would be about 20 percent lower than baseline emissions by 2020 and 35 to 40 percent lower by 2040. These changes are comparable with those in Scenario 2. Note, however, that fleetwide fuel economy under this scenario does not rise nearly as much during the 40-year period, whereas VMT is significantly lower. Fleet fuel economy increases by more than 25 percent relative to the stable baseline trend. Meanwhile, VMT is more than 20 percent lower than in the baseline scenario.

SCENARIO 4: DEVELOPMENT OF VEHICLES EMITTING LOW CO_2 AND OTHER GREENHOUSE GASES

Scenario 4 considers the effect on CO_2 emissions of the development and gradual introduction of vehicles that emit low amounts of carbon (CO_2) (and presumably other substances that form greenhouse gases) relative to the fleet of vehicles in the baseline scenario. As in the other scenarios presented in this report, not considered are the various technical, political, and economic issues associated with such an outcome and the policy measures that might be required or best suited to achieving it (e.g., a carbon tax on energy, more public support for technology research and development, and inducements for vehicle makers). Some of these issues are examined in Chapter 3. Instead, the scenario supposes that some combination of policies and developments has the

Table A-4 Summary of Scenario 3: Higher Motor Fuel Prices

Year	Price per Gallon of Petroleum Fuel ($) (1)[a]	VMT by Entire Fleet (billions) (2)[b]	Average Miles per Gallon of Entire Fleet (3)[c]	Total Petroleum Consumed by Fleet (billion gallons) (4) = (2)/(3)	Total CO_2 Emitted by Fleet (million metric tons) (5)[d]
1995	1.35	2,420	16.9	143	1,260
2000	1.35	2,610	16.9	154	1,360
2005	1.57	2,730	17.4	157	1,380
2010	1.81	2,850	17.9	159	1,410
2015	2.10	2,980	18.5	161	1,430
2020	2.44	3,120	19.1	164	1,450
2025	2.83	3,260	19.6	166	1,470
2030	3.28	3,410	20.2	169	1,490
2035	3.80	3,570	20.8	171	1,510
2040	4.40	3,730	21.5	174	1,540

[a] Price per gallon of petroleum fuel increases 3 percent per year.

[b] VMT increases 0.9 percent per year. This is 0.6 percent lower than baseline rate of growth, reflecting reduced travel by 0.2 percent for every 1 percent increase in fuel prices (3 percent × 0.2 = 0.6 percent).

[c] Average miles per gallon of fleet grows 0.6 percent per year as higher fuel prices spur motorist demand for fuel economy. Every 1 percent increase in fuel prices causes a 0.2 percent increase in fleet fuel economy (3 percent × 0.2 = 0.6 percent).

[d] Gallons of petroleum consumed (4) multiplied by 19.5 pounds. Product divided by 2,205 to convert to metric tons.

effect of spurring research, development, and the gradual introduction of low-carbon vehicles that prove acceptable to large numbers of consumers.

Key Assumptions, Calculations, and Data Sources

During the first decade of this scenario, a new vehicle type that emits very little CO_2 (and other greenhouse gases) is developed and readied for introduction into the mass market starting in 2010. This new vehicle is expected to emit only about one-third as much CO_2 per mile as the conventional vehicles in the baseline scenario. Otherwise, the new vehicle will differ very little from conventional motor vehicles; hence, its introduction will not alter trends in motor vehicle travel but will mainly influence growth in petroleum use and CO_2 emissions. This outcome (e.g., a large reduction in CO_2 emissions per mile with minimal effect on travel behavior) is essentially the goal of the PNGV research program (as discussed in Chapter 3), which aims to increase vehicle miles per gallon by up to threefold while holding constant vehicle cost and performance attributes.[15] PNGV is focusing much of its effort on hybrid systems;[16] presumably, however, other kinds of technologies and systems—such as hydrogen, biofuel, and fuel-cell electric systems—could also produce an outcome similar to the one in this scenario (the probabilities that individual kinds of new technologies will produce such an outcome are not considered here).

It is further assumed that these new low-carbon-emitting vehicles are gradually introduced into the fleet during the three decades between 2010 and 2040. The conversion period is intended to reflect a rate of transition that is sufficiently conservative given the time required for fleet turnover and for new technologies to mature and consumers to accept them. By 2020, these new vehicles will account for 5 percent of fleet VMT, up from zero at the beginning of 2010 and increasing steadily during the decade. Their share grows to 20 percent by 2030 and 45 percent by 2040. The higher rate of introduction would be expected as technologies mature and consumer acceptance grows.

Depending on the characteristics of the new low-emission vehicles, including ownership and operating costs, one would expect changes in vehicle use patterns (such as the rebound effect discussed in the preceding two scenarios). For illustrative purposes, however, it is assumed that these vehicles so closely match conventional vehicles in terms of costs and benefit (including per-mile operating costs) that vehicle usage and travel trends are not affected.

Results

The results of this scenario are shown graphically in Figure 3-6. The data in 5-year increments are shown in Table A-5. Under this alterna-

Table A-5 Summary of Scenario 4: Development of Vehicles Emitting Low CO_2

Year	Vehicle Miles Traveled by Total Fleet (billions) (1)[a]	Vehicle Miles Traveled by Low-Emission Vehicles (billions) (2)[b]	CO_2 Emitted by New Low-Emission Vehicles (million metric tons) (3)[c]	Vehicle Miles Traveled by Conventional Vehicles (billions) (4) = (1) − (2)	CO_2 Emitted by Conventional Vehicles (million metric tons) (5)[d]	Total Fleet Emissions of CO_2 (million metric tons) (6) = (3) + (5)
1995	2,420	0	0	2,420	1,260	1,250
2000	2,610	0	0	2,610	1,360	1,360
2005	2,810	0	0	2,810	1,470	1,470
2010	3,030	<20	<10	3,015	1,540	1,555
2015	3,070	50	10	3,020	1,650	1,660
2020	3,510	170	30	3,340	1,720	1,750
2025	3,780	380	70	3,400	1,750	1,820
2030	4,070	820	140	3,250	1,670	1,810
2035	4,390	1,320	230	3,070	1,570	1,800
2040	4,730	2,140	370	2,590	1,310	1,680

[a] Total VMT of fleet grows 1.5 percent per year as in baseline scenario.

[b] VMT by new low-emission vehicles grows from 0.5 percent of total VMT in 2010 to 5 percent by 2020 to 20 percent by 2030 to 45 percent by 2040.

[c] New low-emission vehicles emit 0.38 pounds of CO_2 per mile, or one-third as much as conventional vehicles (see note *d* below). Emissions are derived by multiplying total VMT of new low-emission vehicles by 0.38 pounds CO_2 per mile. The product is divided by 2,205 to convert to metric tons.

[d] Average fuel economy for conventional vehicle fleet remains constant at 16.9 miles per gallon as in baseline, thus averaging 1.15 pounds of CO_2 per mile traveled. Total emissions derived by multiplying VMT of conventional vehicles by 1.15. The product is divided by 2,205 to convert to metric tons.

tive scenario, CO_2 emissions would be virtually the same as baseline emissions in 2020 but nearly one-third lower by 2040 (this is because CO_2 emissions would be reduced by 0.67×45 percent share of fleet VMT accounted for by these new low-emission vehicles in 2040).

NOTES

1. Determining whether specific policies aimed at reducing CO_2 emissions could indeed be implemented, and at what cost and benefit, requires consideration of a host of technical, economic, political, and institutional issues and uncertainties, many of which are identified in Chapter 3.
2. For example, one would expect rising petroleum prices to stimulate motorist interest in alternative fuels. Likewise, one might also expect that policies aimed at reducing motor vehicle travel (such as land use controls) or increasing vehicle fuel economy (for instance, through higher fuel-economy standards) would reduce demand for petroleum but would, as a result, produce lower fuel prices and stimulate some additional petroleum demand.
3. The figure 16.9 miles per gallon is an average for the entire fleet (all vehicle types), including older vehicles with lower fuel economy. Average fuel economies for new vehicles (cars, trucks, and buses) may be higher.
4. The density of motor gasoline and diesel fuel varies according to octane grade, additives (such as oxygenates), and other factors. On the basis of DOE calculations (DOE 1995), gasoline and diesel fuel are assumed to have API-scale densities of 55 to 65 degrees and 35 to 40 degrees, respectively. This is equivalent to specific gravities of 0.74 for gasoline and 0.83 for light-distillate diesel fuel. Using these measures, one gallon of gasoline weighs about 6.1 pounds and one gallon of diesel fuel weighs about 6.9 pounds.
5. Thus, even if annual VMT per capita were to remain stable, total VMT would be expected to grow 0.75 percent per year simply because of population growth.
6. Given projected population increases of 0.75 percent per year, the assumption of 1.35 percent growth in VMT implies a 0.6 percent annual rate of growth in VMT per capita (1.35 − 0.75).
7. As explained in Chapter 2, DOT has projected a rate of growth in motor vehicle travel for the next 15 years (2.37 percent per year) that is higher than the more conservative baseline rate of growth (1.5 percent per year) given here.
8. This assumption is simplistic since one would expect—if indeed motor vehicle fuel saving could be achieved without cost—that motorists would increase their demand for these new vehicles, thereby accelerating fleet turnover.
9. For simplicity, it is assumed that new-vehicle fuel economy in 2000 is the same as the average fuel economy of the fleet (e.g., 16.9). This is an oversimplification since new-vehicle fuel economy is likely to be higher, the actual value depending in part on the mix of vehicles (e.g., cars, trucks, and buses) entering the fleet in any given year relative to the mix on the road.

10. The data show that in 1990 vehicles aged 2 years and under accounted for 22 percent of total VMT, vehicles 3 to 5 years old accounted for 30 percent, vehicles aged 6 to 9 accounted for 25 percent, and vehicles 10 years old or older accounted for 22 percent.
11. In other words, suppose that the newest vehicles in 2001 traveled 300 billion miles that year. Absent fuel economy gains, one might expect VMT for the follow-on group of new vehicles in 2002 to be 1.5 percent higher than the VMT of their predecessors, growing by 4.5 billion to 304.5 billion (consistent with the baseline rate of growth in VMT). A 1.5 percent increase in fuel economy for this new group of vehicles, however, would generate additional driving totaling 0.9 billion miles (0.003×304.5). Thus total VMT for new vehicles would increase by 1.8 percent [$(4.5 + 0.9)/300$].
12. In other words, it is assumed that the demand-dampening effect of higher fuel prices is not offset by the demand-stimulating effect of higher real incomes and that rising fuel prices are not simply a manifestation of inflation.
13. For example, if motor fuel prices rise from $1.00 to $1.10 per gallon (a 10 percent increase), those motorists who previously drove an average of 10,000 miles per year in vehicles averaging 20 miles per gallon will drive an average of 9,800 miles (−2 percent) in vehicles averaging 2 percent more miles per gallon (20.4 miles per gallon). This scenario will reduce annual petroleum consumption by 4 percent, from 500 gallons (10,000 miles divided by 20 miles per gallon) to about 480 gallons (9,800 miles divided by 20.4 miles per gallon).
14. Also, it should be noted that the rebound effect from higher fuel economy—as discussed in the previous scenario—does not apply to situations where vehicle fuel economy is the result of consumer demand for this attribute when prompted by higher fuel prices.
15. It is assumed in this scenario—absent more detailed assumptions about the kind of low-emission technologies developed and introduced—that the fuel cost per mile of driving is unchanged for the new low-emission vehicles relative to conventional vehicles. A rebound effect (as in Scenario 2) is therefore not assumed.
16. A focus of PNGV is on diesel-electric hybrid technologies, consisting of a direct-injected diesel engine combined with a small, battery-powered electric drive line.

REFERENCES

ABBREVIATIONS

DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration

Bureau of the Census. 1995. *Statistical Abstract of the United States.* U.S. Economics and Statistics Administration, U.S. Department of Commerce.

DeLuchi, M. 1991. *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity.* Report ANL/ESD/TM-22. Center for Transportation Research, Argonne National Laboratory, Argonne, Ill.

DOE. 1995. *Emissions of Greenhouse Gases in the United States, 1987 to 1994.* Report DOE/EIA-0573(87-94). Washington, D.C.

DOE. 1996. *Annual Energy Outlook 1996: With Projections to 2015.* Report DOE/EIA-0383(96). Energy Information Administration.

DOT. 1995. *1995 Status of the Nation's Surface Transportation System: Condition and Performance.* Report to Congress.

FHWA. 1996. *Highway Statistics 1996.* U.S. Department of Transportation.

National Research Council. 1992. *Automotive Fuel Economy: How Far Should We Go?* Commission on Engineering and Technical Systems. National Academy Press, Washington, D.C.

Appendix B

Federal Research on Alternative Transportation Fuels and Vehicles

As background for the discussion in Chapter 3, estimates are given of federal research and development (R&D) expenditures related to alternative transportation vehicles and fuels.

Federal funding for transportation vehicles and fuels is dominated by the aeronautical research of the National Aeronautics and Space Administration (NASA) and the Department of Defense (ICC 1994). Although some of the research conducted by these two agencies is important to surface transportation and is discussed briefly, the main focus of this appendix is on the civilian sectors, encompassing research in the Department of Energy (DOE), the Department of Transportation (DOT), and several other federal agencies.

DEPARTMENT OF ENERGY

Most federally supported R&D for surface transportation vehicles and fuels in the civilian sector is funded through DOE. Overall funding for transportation fuel and vehicle R&D for 1996 was about $207 million. This funding was down about 9 percent from 1995 as DOE's energy efficiency and renewable energy programs were reduced significantly. Historically, DOE's budget has been subject to swings as a result of changes in the priorities of presidential administrations and Congress. For example, the Department's electric and hybrid vehicle program was pared back from about $38 million in 1979 to about $8 million by 1985; by 1994 it had risen to about $72 million (OTA 1995). Such fluctuations may continue as efforts are made to reduce the federal deficit.

DOE FY 1996 R&D funding in transportation fuels and vehicles is allocated as follows:

Program	*Millions of Dollars*
Alternative fuel vehicle (mainly natural gas) R&D	18.0
Alternative fuel vehicle deployment	11.0
Biofuels	30.2
Electric (battery) vehicles	18.5
Hybrid vehicles	53.3
Fuel cells	21.5
Propulsion system materials	20.1
Lightweight vehicle materials	13.3
Light-duty engine technology	5.5
Heavy-duty vehicle R&D	5.4
Management/other	9.4

Much of DOE support for alternative fuel vehicles is directed to advances in natural gas vehicles. Cleaner burning natural gas emits fewer air pollutants and generates less carbon dioxide than gasoline. Prototype vehicles powered by natural gas have exhibited increased range but these vehicles remain uncompetitive in cost and performance compared with gasoline- and diesel-fueled vehicles. FY 1996 funding for alternative-fuel vehicle R&D (mostly natural gas) was $18 million. Another $11 million was spent in grants to support development of refueling stations and to subsidize use of natural gas vehicles in private and government (transit, school bus, heavy-duty municipal vehicle) fleets.

DOE also has a substantial biofuels program (about $80 million in FY 1996), of which the transportation component is about $30 million.

The program funds research on biomass feedstocks, development of alcohol fuels from unconventional sources such as cellulosic biomass, and development of biodiesel (biomass additives to diesel), among other activities. From the standpoint of the full production cycle, some biomass-derived alcohol fuels (such as those derived from certain grasses, woody plants, and other cellulosic sources) have the potential to reduce the carbon content of transportation fuels. An R&D goal of DOE is to make the most promising alcohol fuels (in terms of carbon emissions) more price-competitive with gasoline and diesel fuel.

DOE's longer-range research efforts are in alternative propulsion systems, such as pure electric-drive vehicles and "hybrid" vehicles powered by electricity and an internal combustion engine. The electric vehicle R&D program focuses on advances in batteries. Much of the program is conducted under a cooperative agreement between DOE and the Advanced Battery Consortium (ABC), formed in 1991 by Chrysler Corporation, Ford Motor Company, and General Motors. Because electric vehicles could help reduce mobile source air pollution while allowing electric utilities to utilize excess capacity during off-peak hours, the electric power industry has joined in this effort. DOE joined the consortium in 1991 following a legislative mandate to pursue the benefits of electric vehicles, and the Department now has an active role in managing the collaborative research program. The long-term goal of ABC is to develop a battery that will enable electric vehicles to compete with petroleum-powered vehicles in terms of performance and cost. Efforts so far have been focused on the development of a battery that would allow a vehicle to travel at least 100 miles under routine driving conditions.

Another long-range research area is the development of hydrogen as a fuel for use in internal combustion engines and fuel cells. DOE's hydrogen research budget was about $14 million in 1996. Through this research program, the Department works with industry and a scientific advisory panel to develop safe, practical, and competitive hydrogen technologies to meet energy needs. Research issues include how to safely transmit and store hydrogen for energy applications in transportation and other sectors. Through other budget categories DOE is also investigating fuel sources other than hydrogen for fuel cells, such as methanol.

PARTNERSHIP FOR A NEW GENERATION OF VEHICLES

The Partnership for a New Generation of Vehicles (PNGV) research program, initiated in late 1993, is a cooperative research program between the U.S. government and the U.S. Council for Automotive Research, a research consortium formed by Chrysler, Ford, and General Motors. One of the goals of PNGV is to develop a vehicle that will achieve up to three times the fuel economy of today's family-oriented vehicles while maintaining or improving current levels of performance, size, utility, and total cost of ownership and meeting or exceeding federal safety and emissions requirements. Advanced R&D on such technologies as compression ignition direct injection engines, gas turbines, fuel cells, batteries, flywheels, ultracapacitors, composite materials, and manufacturing is being conducted and coordinated under the program in an effort to meet these goals (National Research Council 1996).

Federal government expenditures on the PNGV research program are not organized as a line item in the federal budget; rather, they come from a variety of programs across agencies. For example, a substantial part of DOE's advanced automotive technology program, which funds research on advanced engines, materials, and storage devices, is counted as PNGV research expenditure. Total federal expenditures on PNGV research for FY 1995 and FY 1996 are estimated at about $270 and $293 million, respectively (see Table B-1) (OTA 1995; R. Chapman, Program Manager, PNGV, Testimony before House Subcommittee on Energy and Environment, July 30, 1996). Among the federal agencies contributing to PNGV are the U.S. Department of Commerce (which manages the federal role), DOE, DoD, Department of the Interior (DOI), Environmental Protection Agency (EPA), NASA, and National Science Foundation (NSF).

Related and complementary research is being conducted in industry, with its share of PNGV research being contributed in kind at a level equivalent to what is being spent by government. Of course, automotive manufacturers, parts suppliers, and energy companies conduct proprietary research on alternative vehicles and fuels that is difficult to quantify.

Table B-1 PNGV-Related FY 1995 Appropriations by Technical Area and Agency (OTA 1995)

Technical Area	Allocation by Agency ($ millions)								
	DOC[a]	DOD[b]	DOE	DOI	DOT	EPA[c]	NASA	NSF	Total
Lightweight materials	6.83	7.03	47.42	0.50				19.24	81.02
Energy conversion			70.47			2.75		0.84	74.06
Energy storage	0.04		0.47			2.00		2.69	5.20
Efficient electrical systems		1.20					1.00	15.41	17.61
Exhaust energy recovery			1.04				0.20		1.24
Analysis and design methods	1.50	1.98	3.71				2.20	1.85	11.24
Reduction of mechanical losses	0.25							1.25	1.50
Aerodynamic and rolling improvements			0.78						0.78
Advanced manufacturing	10.46	2.75	23.64					4.61	41.46
Improved internal combustion	0.58	11.02	7.04			2.90	0.25	3.02	24.81
Emissions control			3.78				1.35	2.07	7.20
Fuel preparation, delivery, storage								0.15	0.15
Efficient heating, cooling, etc.			0.50					2.81	3.31
Crashworthiness								0.14	0.14
Total	19.66	23.98	158.85	0.50	0.00	7.65	5.00	54.08	269.72

NOTE: Allocations are specific to PNGV and identified as such. In FY96, $1 million of the $20 million will be targeted specifically for PNGV. DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; DOI = Department of the Interior; DOT = Department of Transportation; EPA = Environmental Protection Agency; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; PNGV = Partnership for a New Generation of Vehicles; R&D = research and development.

[a] In addition to the base of $19.7 million, DOC through the National Institute of Standards and Technology's Advanced Technology Program has selected relevant projects with requested funding of $30.1 million.

[b] DOD allocations are based on information from program personnel and were tentative at the time this table was prepared.

[c] EPA allocations were still in discussion at the time this table was prepared.

SOURCE: PNGV Secretariat.

DEPARTMENT OF TRANSPORTATION

DOT vehicle and fuel R&D is more modest and limited in scope compared with the DOE programs. A new effort is under way in the Federal Railroad Administration (FRA) on high-speed rail and a small program is ongoing in the Federal Transit Administration (FTA).

Roughly $25 million was authorized in 1996 for FRA's R&D program on high-speed rail. This program is focused on incremental changes in speed (up to 125 mph). Expenditures are focused on safety issues (train signaling and control technologies to allow mixing of freight and passenger trains and to address grade-crossing hazards). A small share of funds (less than $5 million annually) is being spent on upgraded diesel propulsion systems and experimental flywheels to improve acceleration. Funding for magnetically levitated (mag lev) trains has largely been eliminated because of technical, cost, and market challenges.

FTA has managed and funded the development of buses powered by fuel cells. Expenditures in 1996 are roughly $10 million (with $3 million transferred from DOE). Prototype vehicles have been produced, which are now in a pilot testing and demonstration phase. The agency is also participating in a smaller-scale R&D effort on advanced lead-acid batteries for transit vehicle applications. FTA also provides funds to assist local transit agencies in purchasing compressed natural gas buses.

DEPARTMENT OF DEFENSE

Though focused on military applications, DoD R&D programs have traditionally had broader influence. Perhaps the most closely tied to the commercial transportation sector is the research conducted by the Defense Advanced Research Programs Agency (DARPA), which had a $14.7 million program in electric vehicles in FY 1996. Through this program, the Department funds seven national consortia that are integrating and promoting hybrid electric vehicles for military and commercial applications. The consortia include other public and private funds not included in the figure above. Though many DARPA initiatives are specifically designed for military application, such as developing prototype hybrid electric drive "Humvee" vehicles, the technology may generate commercial interest. DARPA initiatives that are more closely related to commercial applications: small electric (commuter-style) passenger vehicles, hybrid electric buses, electric pickup trucks, and neighborhood electric vehicles are being pursued. Some component technologies being investigated would clearly have dual applications (recharging stations, improved drive trains and electric motor designs, and advanced battery technologies). DoD R&D that is related to the PNGV program is estimated by PNGV program staff as approximately $25 million in FY 1996.

OTHER

EPA funds a substantial laboratory to test new vehicle and fuel concepts and technologies, funding for which totaled $68 million in 1996. This work is mostly related to Clean Air Act mandates, including analysis of catalysts for reducing emissions that cause air pollution and to prompt industry to develop new technologies to achieve mission reductions. Undoubtedly most of the vehicle R&D to meet Clean Air Act mandates occurs in industry and far exceeds the scale of federal funding. NSF estimates that approximately $54 million of NSF support in FY 1995 was for projects with the potential to improve the design, production, use, disposal, and recycling of automobiles and their accessories or components (J. Bordogna, Assistant Director for Engineering, NSF, Statement before House Subcommittee on Energy and Environment, July 30, 1996). Most of these projects are integrated research and education awards involving individual university researchers or small groups of faculty with graduate and undergraduate students. NSF funds are also counted as part of the PNGV effort.

REFERENCES

ABBREVIATIONS

ICC Interagency Coordinating Committee on Transportation Research and Development

OTA Office of Technology Assessment

ICC. 1994. *Strategic Budget Guidance—Full Report of the Interagency Coordinating Committee on Transportation Research and Development*. National Science and Technology Council. Unpublished manuscript, 24 pp.

National Research Council. 1996. *Review of the Research Program for the Partnership for a New Generation of Vehicles*. Commission on Engineering and Technical Systems. National Academy Press, Washington, D.C.

OTA. 1995. *Advanced Automotive Technology: Visions of a Super-Efficient Family Car*. U.S. Congress, Washington, D.C.

Appendix C

Statement of David G. Burwell

This report fills a long-neglected gap in the field of transportation research: the nature of long-term threats to the environment due to transportation infrastructure development and operation in the United States. Necessarily, the report has narrowed its scope to threats presented by surface transportation (thus excluding long-term environmental threats presented by aircraft operations and marine transport). Within surface transportion, it has focused on threats presented by the construction and operation of highways, thus excluding effects of rail, transit, pipeline, and nonmotorized infrastructure and operations. It has also defined its geographic scope as national, not international, thus excluding threats from activities outside the United States however strongly influenced by U.S. transportation policy. Finally, it has focused on long-term threats, thus excluding noise, accessibility, and short-term pollution effects that do not, in and of themselves, threaten the ability of future generations to meet their own needs.

These scoping decisions were made to allow the committee, and the readers of the report, to focus on transportation-related environmental threats of intergenerational concern. Such boundary-setting, as long as it is fully disclosed and considered in crafting the committee's conclusion, is entirely appropriate.

This concurring statement is submitted to clarify any confusion arising from the fact that this report, despite its boundary-setting, professes to address the interrelationship between transportation and efforts to promote sustainable development or principles of sustainability. Even if the term "sustainability" can be parsed to isolate its environmental components from its other two commonly understood components (equity and economic development), this report still does not address the full set of issues encompassed by the phrase "transportation for a sustainable environment." Instead, it is precisely, and only, an analysis of threats presented by "those [transportation-related environmental disturbances] that are especially prone to being neglected and have consequences that, accumulated over time, threaten serious and irreparable harm to the environment (see Chapter 1).

Why is it important to distinguish between (*a*) a report that identifies long-term threats to our environment from transportation and (*b*) a report that addresses issues relating to transportation and a sustainable environment? There are two reasons.

First, because sustainability is not about threat analysis; sustainability is about systems analysis. Specifically, it is about how environmental, economic, and social systems interact to their mutual advantage or disadvantage at various space-based scales of operation (local, landscape, regional, national, international, etc.). A line of research, or a program of action, designed exclusively to identify and address environmental threats (whether long-term or short-term) within a specific geographic context (here, the national scale) from a specific source (here, surface transportation infrastructure and operation) is not a study about sustainability because it attempts to control for everything except the environmental threat. Sustainability assumes no such controls; indeed, its very purpose is to study the interrelationships between environmental threats and the social and economic contexts within which they arise.

Second, because sustainability is about more of good things and less of bad things. A threat analysis is simply about avoiding bad things over a chosen time period and scale of operations. Although the terms "good" and "bad" are value-laden, sustainability is about a process to agree on these terms within a specific context (here, long-term, national), setting performance standards to measure "good" and "bad" outcomes, and then applying policy tools or other inputs to watch how the system operates.[1] A study about transportation and sustainable environment, therefore, would outline a research agenda designed to identify which measures of transportation performance must grow to promote environmental goals and which must not. It would also study the interaction between such measures and economic and social measures of performance.

Again, this report is an excellent analysis of the long-term threats to our environment presented by the growth and operation of our national surface transportation system. The amelioration of these threats, in my view, can be most directly pursued through a vigorous line of research to establish and measure the environmental performance of our surface transportation system on a continuous basis.

NOTE

1. This is explicitly recognized in the "We Believe" statement of the President's Council on Sustainable Development (1996), which lists as its first principle the following: "We believe, to achieve our vision of sustainable development, some things must grow—jobs, productivity, wages, capital and savings, profits, information, knowledge, and education—and others—pollution, waste, and poverty—must not."

REFERENCE

President's Council on Sustainable Development. 1996. *Sustainable America: A New Consensus for Prosperity, Opportunity, and a Healthy Environment for the Future.* Washington, D.C.

Study Committee Biographical Information

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David G. Burwell is President and cofounder of Rails-to-Trails Conservancy. He is also an Executive Committee member and co-founder of the Surface Transportation Policy Project. From 1977 to 1987, he was an attorney with the National Wildlife Federation. His areas of specialty are environmental law, transportation law, and land use. Mr. Burwell is a member of TRB's Executive Committee and has served on several other TRB committees, including the Research and Technology Coordinating Committee. He is active in other regional and national environmental advocacy organizations.

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ISBN 0-309-05969-0