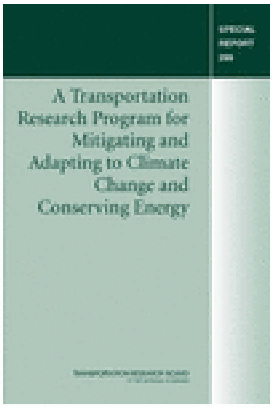

A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy Special Report 299

Committee for Study on Transportation Research Programs to Address Energy and Climate Change, Transportation Research Board 2009 Executive Committee

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SPECIAL REPORT 299

A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy

Committee for Study on Transportation Research Programs
to Address Energy and Climate Change

TRANSPORTATION RESEARCH BOARD
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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 competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the 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.

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Preface

In mid-2008, the Transportation Research Board (TRB) Executive Committee recognized that major legislation might be enacted in 2009 that could have profound effects on future surface transportation policies at all levels of government. The congressional reauthorization of surface transportation legislation, then due by October 1, 2009, was being considered, and the United States Senate was debating proposals to address climate change through a system that would regulate the total amount of greenhouse gases (GHGs) that could be emitted annually. As the sector with the fastest-growing share of carbon dioxide emissions (the main transportation GHG), transportation was sure to be affected by such legislation.

The Executive Committee recognized that new research and policy analysis would be needed to inform decisions at all levels of government in responding to the challenges of reducing transportation energy consumption and GHG emissions. In reviewing proposals for transportation research programs as part of reauthorizing the federal surface transportation program, the Executive Committee also recognized a gap: no proposals explicitly addressed research to mitigate GHG emissions and energy consumption attributable to passenger and freight travel or to adapt to climate change. Also of concern was the lack of discussion and analysis concerning how proposals to change travel demand might interact with the system in place to raise revenues for surface transportation. Currently, about two-thirds of the revenues raised from users to help pay for the construction, maintenance, and operation of highway and transit systems—more than \$100 billion annually—comes from motor fuel taxes on highway users.[1] In response to its concerns about gaps in proposed research programs, the Executive Committee recommended a study to suggest research programs to fill those gaps. This report is the product of that study.

STATEMENT OF TASK

The Executive Committee and the National Research Council (NRC) approved the following statement of task:

> This project will develop research program proposals that would address major questions and technical issues regarding transportation strategies to mitigate energy consumption and GHG emissions, replace or supplement fuel taxes with an alternative user fee system, and adapt to expected climate changes. Given the relatively short time frame available for the project, the research program proposals will be conceptual in nature. Nonetheless, they will have enough detail to provide policy makers with information about the nature of the research programs that are needed, the approximate cost of these programs, and how they could be most effectively organized to deliver implementable results in a timely manner.

The Executive Committee's intent was to identify research needs with regard to policies and strategies relating to the use of the transportation system and to assist infrastructure owners in adapting to climate change. Policies and governmental research programs concerning motor vehicle fuels and propulsion systems have been and are being addressed by other recent and ongoing NRC activities;[2] thus, this report does not recommend research on motor vehicles or fuels. The report focuses on surface

[1] For additional background on these issues, see *Special Report 285: The Fuel Tax and Alternatives for Transportation Funding*, Transportation Research Board of the National Academies, Washington, D.C., 2006.

[2] In particular, see the reports released while this study was under way: *America's Energy Future: Technology and Transformation: Summary Edition*, National Academies Press, Washington, D.C., 2009 (http://www.nap.edu/catalog.php?record_id=12710) and *Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts*, National Academies Press, Washington, D.C., 2009 (http://www.nap.edu/catalog.php?record_id=12620). Some recent examples of NRC studies evaluating federal research programs addressing transportation vehicles are cited in Chapter 2.

transportation infrastructure and operations, specifically on research programs that could provide guidance to officials at all levels responsible for policies that affect the use of such infrastructure and its operation, maintenance, and construction. The report also aims to help officials begin to adapt the infrastructure to climate changes that are already occurring or that are expected to occur in the next several decades.

Even this narrowing of the scope of the charge leaves the committee open to take stock of a vast literature in transportation economics, planning, land use policy, design, construction, maintenance, and operations and to consider insights that might be drawn from this material to develop transportation mitigation and adaptation strategies. Given the constraints of time and funding, the committee has addressed this task by applying its judgment to gaps in the literature and by recommending deeper inquiries into the existing knowledge base to inform public policy as an essential element of the research program it identifies.

STUDY PROCESS

NRC appointed a committee of experts to conduct this study under the chairmanship of Michael D. Meyer of the Georgia Institute of Technology. The members have expertise in transportation and environmental policy, administration of transportation programs, and research. The background and affiliations of the members are described at the end of this document. To carry out the study, the committee organized its work into three areas, two of which built on the prior work of NRC-appointed committees:

- To inform its thinking about needed research on mitigation policies, the committee commissioned a paper by Cynthia Burbank of PB, Inc.
- In the area of adaptation, the committee commissioned a paper by Sue McNeil of the University of Delaware to develop and expand on the research recommendations in TRB's *Special Report 290: Potential Impacts of Climate Change on U.S. Transportation*, which was published in 2008.
- With regard to alternatives to the motor fuel tax for transportation finance and linkages to environmental policies, the committee com-

missioned a paper by James Whitty and John Svadlenak of the Oregon Department of Transportation, both of whom had been centrally involved in Oregon's multiyear demonstration program of mileage charging concepts. These authors were asked to build on the recommendations made in *Special Report 285: The Fuel Tax and Alternatives for Transportation Funding.*

Initial drafts of these papers were presented and discussed at special sessions held during the 2009 TRB Annual Meeting [in a session of the TRB Executive Committee, in a joint meeting with a World Road Association (Permanent International Association of Road Congresses) committee on the environment and the TRB Special Task Force on Climate Change and Energy, and in a working meeting of the Special Task Force]. The authors responded to comments. The committee has drawn on the commissioned papers in the development of its report. Copies of the finished papers are available on the TRB website.

Since the initiation of this study, other major reports have recommended research and demonstration programs to test the concept of mileage taxes as a replacement or supplement to the motor fuel tax, which, along with other considerations, led the committee to give this topic less emphasis in its report. The recommendations of these other reports and the linkage of mileage tax proposals to potential transportation mitigation policies are referred to in Chapter 3 and summarized in more detail in Appendix A of this report.

ACKNOWLEDGMENTS

The committee received briefings at its meetings from Jack Wells of the U.S. Department of Transportation; Ken Adler, Megan Susman, and John Thomas of the U.S. Environmental Protection Agency; Charles Kooshian of the Center for Clean Air Policy; John Heywood of the Massachusetts Institute of Technology; Steven Plotkin of Argonne National Laboratory; and Joanne Potter of Cambridge Systematics. The committee thanks these individuals for their contributions. The committee also expresses its appreciation to Cynthia Burbank, Sue McNeil, James Whitty, and John Svadlenak, whose contributions and efforts in preparing their commissioned papers far exceed the compensation the committee was able to provide to them.

The report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that assist the authors and NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The committee thanks the following individuals for their participation in the review of this report: A. Ray Chamberlain, Fort Collins, Colorado; Randall D. Crane, University of California, Los Angeles; David L. Greene, Oak Ridge National Laboratory, Knoxville, Tennessee; Maxine L. Savitz, Los Angeles, California; Henry G. (Gerry) Schwartz, Jr., St. Louis, Missouri; Martin Wachs, RAND Corporation, Santa Monica, California; and Richard N. Wright, Montgomery Village, Maryland.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the committee's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Susan Hanson, Clark University, Worcester, Massachusetts, and C. Michael Walton, University of Texas at Austin. Appointed by NRC, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Stephen R. Godwin, TRB's Director of Studies and Special Programs, managed the study and drafted the final report under the guidance of the committee. Suzanne Schneider, Associate Executive Director of TRB, managed the report review process. Special appreciation is expressed to Norman Solomon, who edited the report; Jennifer J. Weeks, who prepared and formatted the report for web posting; and Juanita Green, who managed the book design and production, all under the supervision of Javy Awan, Director of Publications. Amelia Mathis assisted with meeting arrangements and communications with committee members.

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACCRI	Aviation Climate Change Research Initiative
BAA	Broad Agency Announcement
BTS	Bureau of Transportation Statistics
Btu	British thermal unit
CAFE	Corporate Average Fuel Economy
CBO	Congressional Budget Office
CCAP	Center for Clean Air Policy
CFS	Commodity Flow Survey
DOE	U.S. Department of Energy
EERE	Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GCRP	Global Change Research Program
GDP	gross domestic product
GHG	greenhouse gas
GPS	Global Positioning System
HFCV	hydrogen fuel cell vehicle
ICT	information and communication technology
ITS	intelligent transportation systems
LDV	light-duty vehicle
LED	light-emitting diode
MPO	metropolitan planning organization

NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NGO	nongovernmental organization
NHTS	National Household Travel Survey
NOAA	National Oceanographic and Atmospheric Administration
NOx	nitrogen oxides
NRC	National Research Council
NSF	National Science Foundation
O-D	origin–destination
PTC	positive train control
RITA	Research and Innovative Technology Administration
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
STEP	Surface Transportation Environment and Planning
SUV	sport-utility vehicle
TCRP	Transit Cooperative Research Program
TMIP	Travel Model Improvement Program
TOD	transit-oriented development
TRB	Transportation Research Board
USDOT	U.S. Department of Transportation
UTC	University Transportation Centers
VMT	vehicle miles traveled

Contents

Executive Summary

The risks posed by climate change and the dependence on imported petroleum are among the most challenging problems facing the United States. Many state and national policy makers are embracing proposals to reduce total greenhouse gas (GHG) emissions by 50 to 80 percent below current levels by 2050 and to reduce energy consumption by the transportation sector.

Transportation, which depends on petroleum for 97 percent of its fuel, is a major contributor to both climate change and energy dependence. It accounts for 28 percent of U.S. GHG emissions and consumes twice as much petroleum as the United States produces annually. Passenger and freight vehicles using surface transportation modes account for about 88 percent of transportation carbon dioxide emissions and for a comparable share of energy consumption.

Projections of the impact of policies already in place to improve fuel economy and introduce alternative fuels suggest that total transportation GHG emissions by 2030 would be about the same as currently. The substantial improvements in vehicle fuel economy that will occur and other improvements will roughly offset the effects of expected population and economic growth on demand. As a result, additional reductions from the transportation sector are being sought in proposed legislation through policies that would reduce demand for the most fuel-intensive modes.

Transportation contributes significantly to total GHGs and energy dependence, but it also contributes to economic and social well-being. Careful selection of policies to reduce or shift demand will help to avoid or minimize losses to the economy and society. Unfortunately, the effectiveness, costs, feasibility, and acceptability of various policies to **mitigate** transportation's GHG emissions and energy consumption are not well understood.

Also not well understood are the policies and practices that should be considered for **adapting** the transportation system to changes in precipitation, flooding, storm surges, and wind loadings that are likely to occur in the future as climate changes. The cost of **adapting** infrastructure is high, as is the uncertainty about the timing, magnitude, and location of the risks.

Federal, state, and local policy makers need informed guidance about the effectiveness costs, feasibility, and acceptability of transportation mitigation and adaptation strategies. The committee that prepared this report recommends making a modest investment of $40 million to $45 million annually that would be used to develop the best available guidance quickly on the basis of existing information and then to improve that guidance over time as new research is completed (Table ES-1). Such an investment represents about 9 percent of current U.S. Department of Transportation research spending on surface modes. Because of the importance of making policy choices that produce the most benefit for the least harm, such investments could pay substantial long-term dividends. The committee's research cost estimate is an approximation meant to give Congress a sense of the level of investment needed.

TABLE ES-1 Estimated Cost of Mitigation and Adaptation Research Programs ($ millions)

Program	6-Year Total	Annual Average
Mitigation[a]		
Guidance and outreach	60.0	10
Fundamental research	130.0	21.7
Subtotal	190.0	31.7
Adaptation		
Research	60.0	10
Total	250.0	41.7

[a]The mitigation research cost estimate does not include the cost of collecting travel data for research and improved modeling practice purposes (Appendix B) or the cost of a mileage charging demonstration program (Appendix A).

The topics suggested for research in the report are preliminary and should be refined by convening expert and practitioner stakeholders early in the program to develop more detailed plans and more refined estimates of investment needs over the longer term.

For such research to be most effective, it should be guided by the following principles: the topics investigated should be directly relevant to the needs of federal, state, and local transportation policy makers; funding should be awarded on the basis of open competition and merit review of proposals by peers; and results should be evaluated by expert and practitioner stakeholders. Program managers should have the flexibility to shift areas of investment as knowledge is developed. Such a program should also be evaluated on an ongoing basis by an independent group that would report directly to Congress.

One of the most effective mitigation strategies would be to tax or charge for use of the system in ways that more fully reflect the economic, social, and environmental costs of its use. Charging for mileage traveled on all roads could make this possible in the future and could supplement or replace taxes on fuels that currently generate revenues for highway and transit infrastructure. Fuel taxes have become unreliable revenue generators, and their unreliability will grow as fuel economy improves. Mileage charging shows promise but is controversial because of concerns about privacy, equity, and administrative costs. The committee joins other groups—including two congressional commissions—that have called for investing in an aggressive demonstration program to test alternative concepts and address these concerns. The total cost would probably be in the $70 million to $100 million range over a multiyear period (see Appendix A).

Research into and analysis of cost-effective GHG emission-reduction strategies will depend on quality data. The passenger and freight travel data available for national-level estimates are useful, but they are too crude to guide the detailed analysis and planning required to inform decisions about the best strategies at the state and local levels. Much of the needed data could be used for statewide and metropolitan area planning, could improve compliance with other environmental policy goals, and would be essential if performance standards are included in surface transportation reauthorization. The committee recommends that Congress authorize funding for the collection of data adequate to meet the needs of federal, state, and local governments as they analyze options and plan for mitigation strategies.

Climate change and energy dependence will continue to be significant problems for decades to come. Transportation's contributions to these problems must be addressed, but choosing the wrong policies could impose significant costs without ensuring the intended effects. The research programs identified in this report represent the topics that will be of greatest importance for informing the best choices in coming years.

1

Introduction

BACKGROUND

The burning of fossil fuels to power transportation is one of the main sources of growth in greenhouse gas (GHG) concentrations in the atmosphere. Petroleum-based fuels used by almost all cars, trucks, ships, and aircraft account for 97 percent of energy use in the transportation sector (Davis et al. 2009, Table 2-5). Collectively, the U.S. transportation modes produce about 28 percent of the GHGs emitted from the country each year (Davis et al. 2009, Table 11-4). Moreover, transportation carbon dioxide emissions (the main GHG emissions from transportation) are growing faster than is the U.S. economy as a whole (Davis et al. 2009, Table 11-5).

In addition, the transportation sector's dependence on oil contributes to U.S. reliance on petroleum from exporting regions of the world. Transportation in the United States alone consumes more than twice the petroleum that is produced domestically (Davis et al. 2009, Tables 1-11 and 1-16). U.S. reliance on foreign sources of petroleum contributes significantly to the U.S. balance of payments deficit and raises security challenges.

In 2009, prospects were heightened for significant federal action to reduce energy imports and respond to climate change when a new Congress and a new administration arrived in Washington. At the time of this writing, October 2009, legislation had already passed the U.S. House of Representatives that would limit carbon emissions through a carbon cap-and-trade proposal and impose additional constraints on transportation to reduce its large and growing share of national GHG emissions.[1] A bill

[1] Clean Energy and Security Act of 2009, H.R. 2454. Passed the House of Representatives on June 26, 2009.

with similar provisions was unveiled by the chairman of the Senate Environment and Public Works Committee, Barbara Boxer, and Senator John Kerry in October 2009. Earlier, in May 2009, the Obama administration brokered a compromise between the automobile industry and California over proposed state regulation of motor vehicle fuel economy standards by agreeing to accelerate achievement of increased fuel economy standards enacted by Congress as recently as 2007 from 2020 to 2016. Yet to come is the reauthorization of surface transportation programs, which affects infrastructure investment policies as well as policies affecting the use of the infrastructure. In June 2009, Chairman Oberstar and the leadership of the Transportation and Infrastructure Committee, U.S. House of Representatives, unveiled a sweeping proposal for reauthorizing transportation legislation, which included significant linkages to the climate change legislation already passed in the House.

The House climate bill, the proposed climate bill of Chairman Boxer and Senator Kerry, and the proposed surface transportation reauthorization legislation of Chairman Oberstar would require extensive new planning processes under which officials at the federal, state, and local levels would set targets for transportation GHG reduction and then develop plans and programs to achieve them. The achievement of these goals would be enforced through provisions in the Clean Air Act that allow withholding of federal aid for noncompliance (Holt 2009, 56) and possibly through citizen lawsuits.[2]

States have also been active in responding to climate change. About three dozen states have created climate action plans, of which about half have set specific GHG reduction targets, typically 75 to 85 percent below current levels by 2050. Few states have transportation-specific targets; rather, the statewide targets are meant to inform the planning of state and metropolitan planning agencies. California, however, has been at the forefront of state action. The state has set aggressive GHG emission stan-

[2] The transportation planning and GHG target-setting provisions are in a title of the Waxman–Markey climate bill that amends the Clean Air Act. Metropolitan planning organizations and others have raised concerns about whether these new provisions would be subject to citizen lawsuits. [See letter to Chairman Waxman from the Association of Metropolitan Planning Organizations and others dated June 1, 2009 (http://www.ampo.org/assets/library/209_amponadoaashtoclimatelett.pdf, accessed Aug. 7, 2009).]

dards for light-duty vehicles and has required the California Air Resources Board to establish transportation GHG reduction targets for each of the state's 18 metropolitan planning organizations. In September 2008 California adopted the first state law to include land use policies designed to curb sprawl and reduce automobile travel as part of a strategy to reduce state GHG emissions.

Most current federal transportation policies and programs that attempt to reduce emissions focus on vehicles and fuels, which, as explained in the Preface, are not within the committee's charge and for which research recommendations are not made in this report. New policies being contemplated, referred to as mitigation policies, influence the use of vehicles through strategies that raise the cost of using, or regulate more heavily the use of, higher energy-consuming and GHG-emitting types (automobiles, trucks, and aircraft) and encourage shifts to more energy-efficient modes (transit, rail, and water). State climate action plans having a transportation component drive state mitigation policies in the same direction. The Obama administration's strong commitment to investment in high-speed passenger rail is also considered a mitigation policy.

Although mitigation policies are most prominent, it is also important to adapt to climate change. Adaptation refers to actions taken to alleviate, reduce, or eliminate the impacts of changes in climate. A recent National Research Council report (TRB 2008) made a compelling case for the need to consider adaptation of transportation infrastructure and operations in response to changing climate and weather conditions.

Both mitigation and adaptation policies will be set at all levels of government. Transportation infrastructure, particularly highways, transit, ports, and many short line railroads, are owned and operated by governments. Roads and highways are owned and operated by the 50 states and tens of thousands of counties and cities. Transit systems are owned and operated by hundreds of cities, counties, and special authorities. Many states own short line railroads. Although some port terminals are private, most port properties are owned and managed in the public sector. Whereas the federal government typically regulates vehicles and fuels at the national level, governments at all levels set policies affecting the use of infrastructure. Moreover, the land use decisions that determine the spatial arrangement of the built environment, which, in turn, establishes the distances between origins and destinations and the amount of travel, are set by tens of thousands of local governments.

Mitigation and adaptation policies cover a broad range. This report discusses policies with regard to charging for the use of infrastructure, setting tax rates to reflect the full societal cost of infrastructure use, setting regulations that directly and indirectly affect the choices of modes, investing in new infrastructure, regulating land use, and others. Also covered briefly are strategies to reduce energy consumption and GHG emissions through more efficient management of surface transportation infrastructure and through less energy-intensive construction and maintenance practices. Adaptation strategies include investment in protection (berms and levees); the replacement, movement, and upgrading of infrastructure; revision of standards and operating practices; and improvement in the monitoring of infrastructure performance under climate change–induced stresses.

It is not always clear which choices will result in desired effects, what the costs and benefits might be, what the implications are for equity, or which choices will provide the most benefit for the least cost. Policies affecting transportation have both economic and social consequences. Travel is an integral part of the economy and lifestyles of the nation's citizens. Informing the choices facing federal, state, and local policy makers is the role of transportation research and policy analysis; this report addresses the research needed to make these choices as well informed as possible.

REPORT ORGANIZATION

Chapter 2 provides an overview of existing federal transportation and transportation-related research programs addressing climate change and energy. It provides a description of the scale and scope of these programs. Chapter 3 addresses gaps in knowledge about transportation mitigation strategies and identifies areas for research. Chapter 4 addresses surface transportation adaptation knowledge gaps and areas for research. Chapter 5 summarizes the main research initiatives identified in Chapters 3 and 4 and the level of investment needed, describes criteria for how the research programs should be managed to be most effective, and provides a summary of the report. Research and demonstration strategies to address mileage charging fees or taxes as a supplement to the motor fuel tax are reviewed in Appendix A. Critical travel data gaps and the potential cost of providing the needed data are described in Appendix B.

REFERENCES

Abbreviation

TRB   Transportation Research Board

Davis, S. C., S. W. Diegel, and R. G. Boundy. 2009. *Transportation Energy Data Book*, 28th ed. ORNL-6984. Prepared by Oak Ridge National Laboratory for the U.S. Department of Energy, Washington, D.C. http://www-cta.ornl.gov/data/Index.shtml. Accessed Sept. 28, 2009.

Holt, M. 2009. *Greenhouse Gas Legislation: Summary and Analysis of H.R. 2454 as Passed by the House of Representatives.* R40643. Congressional Research Service, Washington, D.C.

TRB. 2008. *Special Report 290: Potential Impacts of Climate Change on U.S. Transportation.* National Academies, Washington, D.C.

2

Existing Transportation Research Programs Addressing Climate Change and Energy Conservation

Described in this chapter are the existing transportation and related research programs of the federal government that address transportation greenhouse gas (GHG) emissions and energy consumption. The chapter begins with an overview of the U.S. Department of Transportation (USDOT) programs, and then describes the programs of the Department of Energy (DOE) and the Environmental Protection Agency (EPA). A brief summary of transportation research programs that are managed by the Transportation Research Board (TRB) is provided. The chapter is intended to give the reader an overview of the various federal programs that invest in transportation research, a sense of the scale of the investment, and an appreciation of the kinds of research that DOE, EPA, and USDOT support. The main point is that the research areas that are recommended in the chapters that follow are not addressed systematically by existing programs.

U.S. DEPARTMENT OF TRANSPORTATION

Most of the R&D activities within USDOT are funded and organized by mode; thus, this section reviews the modal administration programs addressing climate change and energy conservation separately. The exception to USDOT's modal orientation is the Climate Change and Environmental Forecasting Center, which has had a few projects on climate change, energy conservation, and transportation. After an overview of the center's activities is provided, the climate change and energy conservation research activities of the modal administrations are summarized.[1]

Climate Change and Environmental Forecasting Center

The center sets departmental priorities for multimodal climate change policy analysis and research, and funds from various modal administrations have been pooled there. The center's funding in FY 2007 was $400,000, and its activities were not budgeted for in subsequent years by the previous administration.[2] In 2009 the center began providing a clearinghouse of information and links about climate change and transportation's role in it, tools and models for practitioners, and reports.[3]

The center's most significant activity has been the "Gulf Coast" study, which is part of the governmentwide Global Change Research Program (Savonis et al. 2008). In that study, USDOT partnered with the U.S. Geological Survey to estimate the highway infrastructure along the Gulf Coast that will become more prone to flooding in the future because of land subsidence and higher storm surges. Phase 2, to begin in late 2009, will examine infrastructure impacts at selected locations in greater detail and begin developing information and tools for planners and engineers. The study will also develop risk-assessment tools to assist metropolitan planning organizations and other infrastructure investment decision makers in prioritizing resources and facilities that need protection, accommodation, or relocation.[4] Examples of recent, ongoing, and planned research of the center include development of models to allow comparison of modal emissions; partial support for the National Research Council (NRC) study that resulted in the report on adapting transportation to climate change (TRB 2008); and comparisons of emis-

[1] Much of the overview of the department's climate and energy research is drawn from the March 31, 2009, testimony of David Matsuda, Acting Assistant Secretary for Transportation Policy, USDOT, before the Subcommittee on Technology and Innovation, Committee on Science and Technology, U.S. House of Representatives (http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Tech/31mar/Matsuda_Testimony.pdf, accessed March 31, 2009).

[2] *The U.S. Climate Change Science Program for FY 2009*, p. 232. See http://www.faa.gov/about/office_org/headquarters_offices/aep/research/, accessed March 31, 2009.

[3] http://climate.dot.gov/, accessed April 1, 2009.

[4] http://environment.fhwa.dot.gov/strmlng/newsletters/feb09nl.asp, accessed March 30, 2009.

sions by various modes of transport, including the proposed short sea shipping.[5]

Federal Aviation Administration

Aviation represents a substantial share of transportation energy consumption, roughly 9 percent and growing, and aircraft contrails are implicated as contributing to climate change. The Federal Aviation Administration's (FAA's) Office of Energy and Environment Research and Development funds research on emissions characterization and impact, climate change impacts, emissions impact mitigation, aircraft technology, alternative fuels, operations, and environmental policy measures.[6] Activities funded as part of the executive branch Global Change Research Program ranged between $1 million and $2 million in FY 2008 and 2009.[7] FAA and the National Aeronautics and Space Administration also support research to improve engine efficiency and aircraft routing, to improve assessment of the impacts of contrails, and to develop tools and models for assessing climate impacts.[8]

The FY 2009 Omnibus budget legislation, finalized in early 2009, also provides funding for FAA to improve the scientific understanding of the impacts of aviation emissions on climate. Other federal agencies—the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and EPA—have joined FAA in an Aviation Climate Change Research Initiative (ACCRI) (Brasseur 2008).

The proposed ACCRI seeks an improved understanding of the chemistry and radiative effects of contrails and of the impact of aircraft emissions of nitrogen oxides in the upper troposphere and lower stratosphere. FAA also has research under way to inform administration policy choices with regard to mitigating the impact of aviation emissions on climate through possible carbon emissions standards, carbon emission cap-and-trade strategies, and carbon taxes.

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[5] *The U.S. Climate Change Science Program for FY 2009,* p. 202. See http://www.faa.gov/about/office_org/headquarters_offices/aep/research/, accessed March 31, 2009.

[6] http://www.faa.gov/about/office_org/headquarters_offices/aep/research/, accessed March 31, 2009.

[7] *The U.S. Climate Change Science Program for FY 2009,* p. 232. See http://www.faa.gov/about/office_org/headquarters_offices/aep/research/, accessed March 31, 2009.

[8] http://web.mit.edu/aeroastro/partner/index.html, accessed March 31, 2009.

Federal Highway Administration

As described in the following paragraphs, the Federal Highway Administration (FHWA) has a variety of relatively small-scale R&D activities under way on such topics as (*a*) models of land use and infrastructure interactions to analyze how different policies in these areas affect behavior, (*b*) GHG emissions and strategies for adaptation, and (*c*) highway pavement designs and materials with lower GHG emissions.

Research

The Office of Planning, Environment, and Realty has invested about $700,000 annually over the FY 1999–2006 time period on planning and environmental research directly related to climate change (personal communication). FHWA programmed $300,000 for outreach and communication on air quality, climate change, and other environmental impacts as part of the FY 2009 Surface Transportation Environment and Planning (STEP) Cooperative Research Program.[9] Also allocated in STEP's FY 2009 research budget is $500,000 for activities that include developing and testing strategies to reduce GHG emissions, analysis of how national GHG emission reduction strategies would affect transportation, possible GHG emission reductions through reduced vehicle miles traveled (VMT), and funding for USDOT's Climate Change and Environmental Forecasting Center. This office also funds a related activity—the Travel Model Improvement Program (TMIP). TMIP funds technology transfer and professional development in the application of models, the use of which may become important in assessing the benefits of regional and state policies to change travel behavior.[10] The current annual climate change mitigation R&D expenditures in the Office of Planning, Environment, and Realty appear to be on the order of $1 million annually.

[9] FY 2009 STEP Research Plan. See http://www.fhwa.dot.gov/hep/step/fy09rp.htm, accessed March 30, 2009.

[10] A 2007 TRB report pointed out that current models in use in most metropolitan areas are not designed to be sensitive to policies that would affect travel behavior. The report lays out a research and technology transfer program to improve models and modeling practice. See *Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction,* Transportation Research Board of the National Academies, Washington, D.C. http://www.trb.org/news/blurb_detail.asp?id=7821, accessed March 31, 2009.

FHWA has a few other research projects on GHG-related subjects, such as probabilistic models of bridge scour from flooding, potential use of vegetation in highway rights-of-way to capture carbon, reductions in GHG emissions through increased use of warm-mix asphalt, increased use of recycled materials in pavements, and expanded use of fly ash in concrete. In addition, some of FHWA's programs have activities that will contribute to informing policy decisions about climate change, as described next.

Illustrative Operational Programs

Some of the operating programs in FHWA, as distinct from R&D programs, address goals related to climate change and energy consumption. Those designed to reduce congestion, for example, also affect vehicle fuel economy and GHG and other emissions. Stop-and-go traffic causes vehicles to operate inefficiently and to have excess emissions. In addition, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) gives states more flexibility in the use of pricing to manage congestion. Several provisions of SAFETEA-LU pertain to congestion pricing, including the Value Pricing Pilot Program, funded at $59 million for 2005–2009, to support the costs of implementing up to 15 variable pricing pilot programs nationwide. Also, the Express Lanes Demonstration Program allows a total of 15 pricing demonstration projects through 2009. The Office of Operations has other initiatives aimed at reducing congestion, such as its effort to reduce delays associated with incident management.

Federal Railroad Administration

Almost all of the R&D supported by the Federal Railroad Administration (FRA) has been focused on safety, which is FRA's primary mission. During the Clinton administration, however, FRA was authorized by the Swift Act to support R&D on intercity passenger rail. The Swift Act envisioned an incremental strategy for passenger rail that would mix passenger and freight trains on the same lines and envisioned passenger rail service that would not exceed 150 mph. FRA's research under this authorization included work on high-speed diesel locomotives, the safety of grade crossings, and positive train control (PTC). PTC is a technology for controlling trains on the same line to avoid collisions and would be required for lines with mixed passenger and freight service because the trains would be traveling at much different speeds. Major rail legislation passed in late 2008 and early 2009 has revived prospects for high-speed and intercity passenger rail and has required implementation of PTC by 2015 on lines with mixed freight and passenger service, including commuter trains. The legislation gives FRA discretion to use some of the new funding for R&D, and at the time of this writing, FRA is proposing to do so, particularly for R&D with regard to the complexities of implementing PTC nationwide (TRB 2009).

Federal Transit Administration

The Federal Transit Administration's (FTA's) R&D program is based on three goals: leadership in transit research, increasing transit's market share, and improving the performance of transit operations and systems.[11] The latter two goals include research objectives related to climate change and energy conservation.

The work on increasing market share is focused on R&D to improve transit capacity and performance as well as transit riders' experience. Although this research is certainly related to climate change mitigation and energy conservation, it is not directly focused on these areas. Not included in FTA's R&D portfolio, for example, is research directly targeted at encouraging mode shift through measures that directly or indirectly increase the cost of driving.

Under the goal of improving the performance of transit operations and systems, FTA has R&D under way on technologies to improve the energy efficiency of buses through the use of fuel cell and hybrid bus propulsion systems. These activities include many earmarked fuel cell and hybrid bus demonstrations funded through the capital rather than the research titles of SAFETEA-LU for FY 2006–2009. Thus, much of the $65 million cost of this multiyear activity is for purchase of fuel cell and hybrid buses.[12] About $2.5 million annually of FTA's R&D budget appears to be related

[11] *FTA Multi-Year Research Program Plan (FY 2009–2013)*. See http://www.fta.dot.gov/documents/FTA_TRI_Final_MYPP_FY09-13.pdf, accessed March 31, 2009.

[12] See Table 4-9 of *FTA's Multi-Year Research Program Plan (FY 2009–20013)*. http://www.fta.dot.gov/documents/FTA_TRI_Final_MYPP_FY09-13.pdf, accessed March 31, 2009.

to bus and rail energy conservation. In 2008 FTA unveiled a more deliberate multiyear research program plan for improving electric-drive technologies, for which budget estimates have not yet been developed.

Increasing the energy efficiency of bus and rail operations is a valuable goal. However, bus and rail commuter transit only accounts for about 1 percent of total U.S. transportation energy consumption.[13] Thus, improving the energy efficiency of transit technology alone would not result in a significant improvement in U.S. transportation energy efficiency, even if transit's total energy consumption could be reduced by half. Shifting highway use to transit could have a much more substantial energy conservation benefit, given that passenger vehicles account for 61 percent of U.S. transportation energy consumption. This potential energy benefit argues for mitigation R&D to encourage mode shift (as described in Chapter 3).

FTA has little R&D focused on mode shift. It does have a $1 million earmark for R&D in transit-oriented development (TOD), and FTA's budget funds the Transit Cooperative Research Program (TCRP), which is managed by TRB. TCRP has funded a few projects over the years on policy strategies to encourage mode shift and TOD. Most notably, it has funded the development of *TCRP Report 95: Traveler Response to Transportation System Changes,* a multivolume guidebook for practitioners (each chapter is published as a separate volume). *TCRP Report 95* provides estimates of how various kinds of transit investments and services, as well as strategies to affect mode choice, such as road and parking pricing and TOD, could affect transit ridership.[14] Although the volume is useful and valuable, *TCRP Report 95* is only as good as the research and data on which it is developed, and in mitigation-related areas the research base is weak. For example, lack of good information about how TOD changes travel behavior was noted in the relevant *TCRP Report 95* chapter.[15] Similarly, the chapter on parking management and supply notes, "Available sources notwithstanding, there is relatively little satisfactory information

[13] See Table 2.6 of S. C. Davis, S. W. Diegel, and R. G. Boundy, *Transportation Energy Data Book,* 27th ed., 2008. http://cta.ornl.gov/data/index.shtml, accessed March 31, 2009.

[14] http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=1034, accessed March 31, 2009.

[15] *TCRP Report 95: Traveler Response to Transportation System Changes: Chapter 17—Transit Oriented Development,* p. 17-4. http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_rpt_95c17.pdf, accessed March 31, 2009.

on the effects of parking supply—and changes thereof—on travel behavior."[16]

Research and Innovative Technology Administration

The Research and Innovative Technology Administration (RITA) serves a research coordination function within USDOT, which includes coordination of the department's work in alternative technologies. It also manages a small hydrogen research program (about $550,000 annually) authorized by SAFETEA-LU, the focus of which is to develop safety systems and standards for hydrogen infrastructure.[17]

RITA is responsible for the intelligent transportation systems (ITS) research program, which, although it is not directly related to climate change, does focus on congestion relief as one of its two goals. Reducing congestion can save energy and reduce GHG emissions. The program funds research on topics such as traveler information systems, corridor traffic management approaches, and operational tests of technologies and systems to reduce congestion.[18]

RITA also manages the University Transportation Centers Program, which funds transportation educational and research programs at about 60 University Transportation Centers (UTCs). Some of this research addresses mitigation and adaptation. A search of the UTC records with regard to research on climate change in TRB's Research in Progress database indicated 15 projects under way in March 2009. A few records did not show the project cost, but the highest-cost project was $200,000, and most were $50,000 or less. Thus, the total research under way probably costs about $1 million.

Summary

USDOT funds a small number of R&D projects directly addressing climate change and energy conservation. FTA's annual $2.5 million in

[16] *TCRP Report 95: Traveler Response to Transportation System Changes: Chapter 18—Parking Management and Supply,* p. 18-4. http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_rpt_95c18.pdf, accessed March 31, 2009.

[17] See *Research, Development, Demonstration and Deployment Roadmap for Hydrogen Vehicles and Infrastructure to Support a Transition to a Hydrogen Economy,* RITA, USDOT. http://hydrogen.dot.gov/publications/hydrogen_roadmap/, accessed March 31, 2009.

[18] *Intelligent Transportation Systems,* RITA. http://www.its.dot.gov/index.htm, accessed March 31, 2009.

R&D expenditures on energy-conserving technologies for transit and TOD appears to be the largest USDOT research and technology budget for energy- and climate-related research. FAA's program in 2009 totals about $2 million, as does FHWA's. On the basis of its hydrogen safety and UTC projects under way, RITA's climate change R&D expenditures appear to be about $1.5 million annually. These USDOT-wide activities sum to roughly $8 million annually, which represents only 0.9 percent of USDOT's approximately $900 million annual R&D expenditures. Admittedly, some USDOT programs address strategies that could affect transportation GHG emissions. For example, RITA's ITS program and FHWA's traffic operations initiatives may smooth traffic flows and reduce wasted energy in stop-and-go traffic. FHWA's value pricing program, not an R&D effort per se, is yielding insights into travelers' responses to road pricing strategies. On the whole, however, the level of USDOT's R&D investment in climate change and energy conservation is simply not of the magnitude of the problems related to transportation energy consumption and GHG emissions that the nation faces.

DEPARTMENT OF ENERGY

By far the largest federal investments in R&D to reduce transportation energy consumption and GHG emissions are those of DOE. Because the committee's focus in this report is on R&D most likely to be funded through USDOT, it has examined the DOE programs in less detail. The department's energy R&D budget is extensive—about $4.8 billion in 2009—and includes many programs. Some may deal with aspects of transportation energy consumption, but those aspects were not discussed in the budget documents reviewed for this chapter. This overview of DOE's programs is intended to provide a sense of scale and perspective on the overall federal R&D investment in transportation, but the estimates of budgetary resources provided in the transportation area are not to be considered precise.

Transportation Technologies and Fuels

DOE has a broad-based transportation R&D program as part of its Office of Energy Efficiency and Renewable Energy (EERE). The EERE Vehicle

Technologies appropriation for FY 2009 totaled $273 million.[19] (The automotive and heavy-truck vehicle initiatives described below draw on other DOE resources; thus, the total programs described are larger than EERE's Vehicle Technologies budget.)

EERE's Vehicle Technologies Program "is developing more energy efficient and environmentally friendly highway transportation technologies that will enable America to use less petroleum. The long-term aim is to develop 'leap frog' technologies that will provide Americans with greater freedom of mobility and energy security, while lowering costs and reducing impacts on the environment."[20] R&D covers hybrid and vehicle systems (including plug-in hybrids and battery electric vehicles), energy storage, power electronics, advanced combustion engines, fuels and lubricants, materials technologies, and analysis and tools. The Vehicle Technologies Program has two major partnerships with industry to provide precompetitive research:

- *FreedomCAR and Fuel Partnership:* "The FreedomCAR and Fuel Partnership examines the pre-competitive, high-risk research needed to develop the component and infrastructure technologies necessary to enable a full range of affordable cars and light trucks, and the fueling infrastructure for them that will reduce the dependence of the nation's personal transportation system on imported oil and minimize harmful vehicle emissions, without sacrificing freedom of mobility and freedom of vehicle choice."[21] R&D includes integrated systems analysis, fuel cell power systems, hydrogen storage, technologies for production and distribution, technical bases for codes and standards, power electronics and electric motors, lightweight materials, energy storage systems, and advanced emission control systems. The FY 2009 EERE Vehicle Technologies appropriation for the FreedomCar totaled $190 million, but this is apparently not the full expenditure on this program. For example, the FY 2008 budget for this partnership exceeded $400 million, including activities funded by other DOE programs (NRC 2008b, 2).

[19] http://www1.eere.energy.gov/vehiclesandfuels/about/fcvt_budget.html, accessed Sept. 11, 2009.
[20] http://www1.eere.energy.gov/vehiclesandfuels/index.html, accessed Feb. 17, 2009.
[21] http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/index.html, accessed Feb. 17, 2009.

- *21st Century Truck Partnership:* "The vision of the 21st Century Truck Partnership is that our nation's trucks and buses will safely and cost-effectively move larger volumes of freight and greater numbers of passengers while emitting little or no pollution and dramatically reducing the dependency on foreign oil."[22] Partnerships with industry address research on engines, fuels, exhaust after-treatment, advanced materials, hybrid technologies, safety, idle reduction, and other topics. The program spans multiple federal agencies (DOE, USDOT, EPA, Department of Defense) and funding sources. DOE's share of the partnership funding is about $28 million in the most recent year; the funding provided by other federal agencies and private industry partners is not documented (NRC 2008a, 18).

Both of these programs have been reviewed by NRC committees. The FreedomCar and Fuel Partnership has been reviewed twice (NRC 2005; NRC 2008b). The committee responsible for the second review concluded that there are many technical barriers to be overcome before hydrogen fuel cell vehicles are competitive with internal combustion engine vehicles on the basis of cost and service. The committee concluded, however, that the partnership is "well planned, organized, and managed" and that the "expense of this research, if it overcomes these barriers, is justified by its potentially enormous benefits to the nation relative to its use of petroleum" (NRC 2008b, 4). Another NRC committee evaluated the vehicle, fuel, and fuel distribution systems that would be needed to transition to a hydrogen fuel cell vehicle fleet by 2050 (NRC 2008c). That committee indicated that public-sector R&D in these areas would need to increase to $300 million annually to provide for such a transition.

The truck partnership research program was also reviewed in 2008 (NRC 2008a). The committee concluded that the partnership had many successful programs and that it should be continued. The committee noted that some technical goals of the program have not been met and commented that some of these goals were not plausible. It offered several recommendations to strengthen the program.

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[22] http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/index.html, accessed Feb. 17, 2009.

In addition to the Vehicle Technologies Program, EERE has hydrogen and fuel cell initiatives that were appropriated about $200 million in FY 2009.[23] These initiatives include such topics as hydrogen production and delivery, storage, fuel cell stack technologies, safety, and codes and standards. Although these initiatives are not limited to transportation vehicles, they are all central to hydrogen fuel cell vehicles becoming cost-competitive with other transportation technologies. (Presumably a considerable portion of the hydrogen and fuel cell program expenditures are included in the FreedomCar and Fuel Partnership expenditures of $400 million cited above.)

In May 2009 the Obama administration proposed shifting away from hydrogen fuel cells for transportation vehicles and emphasizing plug-in hybrids instead. At the time of this writing, the administration has requested $68 million for hydrogen and fuel cells rather than $200 million for FY 2010,[24] but House and Senate appropriation committees have proposed restoring much of the vehicle fuel cell funding.

DOE's Office of Science also has an initiative that closely relates to transportation within its Basic Energy Sciences Program.[25] Approximately $50 million of this budget in 2009 was allocated for development of energy storage/advanced batteries.

A sense of the scale of the DOE R&D investment in transportation can be provided by combining the appropriations for DOE's Vehicle Technologies Program, Hydrogen and Fuel Cell Program, and the Office of Science allocation for batteries. In total, these investments exceeded $0.5 billion in FY 2009.

Alternative Fuels

DOE also has energy R&D programs that are not focused explicitly on transportation but that could have significant impact on this sector. One involves alternative fuels that could be used for transportation, including biomass, among other energy sources.[26]

[23] http://www1.eere.energy.gov/hydrogenandfuelcells/budget.html, accessed Sept. 11, 2009.
[24] http://www1.eere.energy.gov/hydrogenandfuelcells/budget.html, accessed Sept. 11, 2009.
[25] http://www.science.doe.gov/obp/FY_09_Budget/Overview.pdf, accessed Sept. 11, 2009.
[26] http://www1.eere.energy.gov/biomass/about.html and http://www1.eere.energy.gov/hydrogenandfuelcells/, accessed Feb. 17, 2009.

An increase in the amount of energy that the transportation sector draws from the electrical distribution system—for example, through rapid growth of plug-in hybrids—would increase the importance of DOE R&D on topics related to energy sources for electric power (solar, wind, nuclear, hydropower, and fossil fuels and carbon sequestration from coal burning).[27] DOE's energy programs for electricity delivery and reliability, fossil energy, and nuclear energy total approximately $2 billion in FY 2009.[28]

Summary

DOE research related to transportation exceeds $500 million annually, and investments in sources of electric energy total roughly $2 billion. The committee cannot judge whether the roughly $0.5 billion invested in vehicle energy and propulsion systems R&D at DOE is the right amount, but DOE investments in transportation dwarf those of USDOT. It is likely that the new administration, given the high priority it has placed on addressing energy independence and climate change, will continue to invest in transportation R&D at DOE.

ENVIRONMENTAL PROTECTION AGENCY

EPA's R&D program is organized by media (air, land, atmosphere, water). It has no transportation-specific categories, which makes it difficult to find transportation-related R&D topics under way at EPA. Extensive searching of the EPA website for reports on transportation research turned up few references, most of which relate to EPA's regulation of air and water quality and to the health effects of motor vehicle emissions. EPA staff briefed the committee at its March 2, 2009, meeting and provided more detail about EPA's research.

EPA's Office of Transportation and Air Quality has research activities related to transportation and climate change: development of models of emissions from road and nonroad vehicles, the testing and measurement

[27] For program descriptions, see http://www.energy.gov/energysources/index.htm. Accessed Feb. 18, 2009.

[28] http://www.cfo.doe.gov/budget/10budget/Content/OrgSum.pdf, accessed Sept. 11, 2009.

of emissions, clean automotive technologies (reducing emissions and improving fuel efficiency), and a fuel cell demonstration program for delivery vehicles in partnership with industry.[29] EPA has also invested in the development of the MOVES model to replace MOBIL (these models calculate mobile source emissions at the regional scale on the basis of estimates of VMT and speed derived from travel forecasts).

EPA's largest R&D investments in motor vehicles occur in its National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. In its Clean Automotive Technology Program, EPA conducts research primarily to achieve ultralow pollution emissions, increase fuel efficiency, and reduce GHG emissions.[30] The program strives to develop cost-effective technologies that would encourage manufacturers to produce cleaner and more fuel-efficient vehicles. EPA partners with industry to maximize the viability of targeted technologies for commercial production. The laboratory pursues research on hydraulic hybrid technology for trucks, engine emissions, and alternative fuels, and it provides technical and analytical support to EPA on these topics.

EPA also has had a small-scale ($3 million) research activity to support land use development that might reduce demand for motorized travel. It has developed model codes and ordinances as well as sketch planning tools to assist state and local planners in integrating land use and transportation plans. The latter has involved research to synthesize and interpret the literature examining the relationship between land development patterns and motorized vehicle travel.[31]

COOPERATIVE RESEARCH PROGRAMS AND STRATEGIC HIGHWAY RESEARCH PROGRAM 2

TRB manages cooperative research programs in highways, transit, and airports on behalf of the states, transit agencies, and airports, and it manages a small freight cooperative research program. In addition, TRB manages the Strategic Highway Research Program 2, a 7-year, $200 mil-

[29] http://www.epa.gov/otaq/, accessed Feb. 18, 2009.
[30] http://www.epa.gov/otaq/technology/#overview, accessed Feb. 18, 2009.
[31] http://www.epa.gov/livability/codeexamples.htm and http://www.epa.gov/livability/topics/sg_index.htm, accessed Feb. 18, 2009.

lion research effort focused on four themes, one of which includes environmental issues. The governance committees for these programs have 15 climate change projects under way or under consideration at the time of this writing. If all were funded, the total investment would be nearly $9 million, spread over several years. The research projects span a variety of applied topics of interest to practitioners. Nearly half of the total cost is for improvements in travel models to incorporate freight and transportation GHG emissions.

CONCLUSION

The research identified by the commissioned paper authors and discussed in subsequent chapters of this report is not directly addressed in any existing program. Various federal agencies and TRB-managed cooperative research programs do fund research on related topics; in particular, DOE funds R&D on vehicles, fuels, and sources of electric energy. Only a handful of scattered projects relate to policies designed to affect travel behavior or adapt to climate change. They are useful but of too small a magnitude to bring about the changes that will be required to meet transportation energy conservation and GHG emission reduction targets.

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Abbreviations

NRC National Research Council
TRB Transportation Research Board

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3

Mitigation Research to Inform Policy and Practice

The mitigation strategies of primary interest to this study are opportunities to (*a*) reduce travel on vehicles and modes with high emissions of greenhouse gases (GHGs) and (*b*) shift travel to modes with lower emissions. The climate change bill that passed the House of Representatives in June 2009, the similar Senate bill proposed in October 2009 by Chairman Boxer of the Environment and Public Works Committee and Senator Kerry, and the transportation reauthorization legislation introduced by Chairman Oberstar of the Transportation and Infrastructure Committee all would require new federal, state, and regional efforts to plan for and reduce transportation GHG emissions, over and above the reductions that will come from more fuel-efficient vehicles. Moreover, reauthorization legislation introduced in the Senate by Chairman Rockefeller and Senator Lautenberg of the Commerce Committee would require reductions in per capita travel, a provision that 60 members of the House have endorsed. Many states have also committed to reducing travel. Because travel and economic growth are so tightly linked, however, an understanding of the potential impacts of such policies on economic growth as well as on GHG emissions is important. Unfortunately, little guidance about the effectiveness and costs of various transportation mitigation policies to save energy and reduce GHG emissions is available, although such information is beginning to be produced (Cambridge Systematics 2009; Center for Clean Air Policy 2009).[1]

[1] Both of these reports appeared late in the committee's deliberations. Information about the assumptions and methods behind the estimates in the Cambridge Systematics (2009) report, which covers a broad array of mitigation measures, was not available for review at the time of this writing.

This chapter first provides a broad overview of strategies to make travel more energy efficient and identifies areas of uncertainty that research could address. It then indicates areas in which research is needed and describes criteria for how such research should be organized and managed.

INTRODUCTION

As an organizing scheme, it is useful to think about reducing transportation GHG emissions and energy consumption on the basis of a framework initially developed by Schipper et al. (2000) and employed by Eads (2008). The amount of CO_2 emissions from fuel combustion by transport can be represented as follows:

$$G = A * S_i * I_i * F_{i,j}$$

where

G = CO_2 emissions (or GHG emissions) from fuel combustion by transport,
A = total transport activity,
S_i = modal structure of transport activity,
I_i = energy consumption (fuel intensity) of each transport mode, and
$F_{i,j}$ = sum of GHG emissions characteristics of each transport fuel used by various modes (i = transport mode, j = fuel type).

Understanding the potential value of mitigating transportation GHG emissions and reducing energy consumption requires examination of each of these variables.

- A = total transport activity, which is a function of growth in gross domestic product (GDP) and population. It is also influenced by development and trade patterns (which determine the distance between origins and destinations).
- S = modal structure of transport activity. Strong growth has occurred in recent decades in aviation, in the freight mode share of trucks compared with rail and water, and in light-duty vehicle (LDV) (cars, SUVs, and pickup trucks used for personal travel) use compared with transit.

- *I* = energy consumption or fuel intensity of modes, which has stagnated in the highway mode in the United States for the past 25 or so years, a period when fuel prices were low and policy makers were unwilling to require increases in LDV corporate average fuel economy (CAFE) standards.[2]
- *F* = GHG emissions characteristics of modes and fuel types. Virtually all forms of U.S. transportation rely on petroleum-based fuels; thus, transportation GHG emissions are highly correlated with total fuel consumed.

Not only the amount of activity and vehicle energy intensity but also the operation, construction, and maintenance of the infrastructure itself have energy and GHG emission consequences. This chapter will focus primarily on research opportunities to affect total transport activity, mode structure, and energy consumption through changes in travel demand; the role that infrastructure construction, operations, and maintenance might play in energy and emission reductions will be touched on. A brief overview of vehicle fuel intensity and emissions characteristics is also provided to help place these topics in perspective.

TRANSPORTATION ACTIVITY

Total transportation activity is closely related to the national economy, population change, and development patterns. Although legislative goals call for reductions in energy consumption and GHG emissions from transportation, most projections assume that U.S. passenger and freight travel will increase as the economy, population, and built environment expand.[3] The section that follows gives an overview of the influences of population and economic growth and changes in urban form on travel

[2] The latter has changed with the passage in 2007 of sharply increased CAFE standards, which are intended to improve LDV new fleet fuel economy to 35 mpg by 2020, and with the announcement of the Obama administration in May 2009 that it would accelerate achievement of these standards to 2016.

[3] See, for example, the Department of Energy's *Annual Energy Outlook 2009,* whose forecast of a 10 percent increase in transportation energy consumption over current levels by 2030 is based on assumptions about economic and population growth. http://www.eia.doe.gov/oiaf/aeo/, accessed July 7, 2009.

demand. This is followed by a description of a broad set of options for moderating growth in travel and of the gaps in knowledge about how well such strategies might perform.

Background

Transportation both contributes to economic growth and is influenced by GDP as incomes rise (Eads 2008). The relationship between per capita real income and per capita travel can be expected to change as advanced industrialized nations shift to service economies. As a general rule, however, per capita real incomes are highest in nations with the most per capita travel (e.g., in North America) (Eads 2008, 219). One obvious way to reduce transport GHG emissions is to reduce travel or at least the rate of growth in vehicle miles of travel (VMT), but care must be taken in doing so to avoid harming economic activity. The American Association of State Highway and Transportation Officials has indicated that the highway system cannot manage more than 1 percent annual growth in VMT over the next two or three decades because of expected limited capacity growth; hence, efforts to moderate VMT growth may be necessary for reasons other than GHG mitigation, especially congestion management. Environmental advocates go a step further, seeking actual reductions in VMT through increases in the cost of travel and changes in urban form, which are discussed below.

Population growth will increase total transportation activity. The U.S. Census Bureau projects that population will grow between 0.8 and 1 percent annually from 2008 to 2050, which will result in a 56 percent increase over 2008 and a net increase in population of 135 million (U.S. Census Bureau 2009, Table 3). Thus, all other things being equal, one could expect total U.S. passenger travel to increase simply because of population growth by 2050. Indeed, in past decades VMT has increased much faster than population, presumably because of rising incomes (Memmott 2007).

Future travel will be affected not only by the nature of future development but also by the existing built environment, which changes slowly. Trends within and across most metropolitan areas in recent decades have generally been toward less densely developed areas. The United States is increasingly "urbanized" according to official statistics, but "suburbanized" would be a better descriptor given that the formal Census Bureau definition of "urban" is areas with at least 1,000 population per square mile, which is a low threshold for development density—about 1.6 people per acre or about 0.67 houses per acre at average household occupancy rates. Under this definition, metropolitan areas are continuing to suburbanize. From 1970 to 2000, the suburban population slightly more than doubled from 52.7 million to 113 million. This growth occurred mainly at the expense of nonmetropolitan areas; population in central cities grew, but only by about 55 percent, from 44 million to 68.5 million (Giuliano et al. 2008). In terms of relative share, suburban population increased from 54.5 percent of total metropolitan population in 1970 to more than 62 percent in 2000. As of 2000, 80 percent of the total U.S. population lived in metropolitan areas, and 50 percent resided in the suburbs of these areas. As origins and destinations become farther apart, travel distances necessarily increase. Obviously, trips are shorter and more are made by transit, walking, or biking in dense urban environments such as Manhattan or central Boston than in the suburbs or exurbs of metropolitan areas or in rural areas, but the trend in preceding decades has been toward suburban development. The trend could change with changes in preferences and public policy. The ever-growing share of population growth represented by immigration and the aging of the baby boom cohort could alter preferences for suburban living (TRB 2009). Research to examine such changes and inform public policy is suggested later in this chapter.

The United States has a large supply of inexpensive land, and vast distances separate population and economic centers, which depend on transportation connections. The nation's extensive highway system, the success of motor carriers in using this ubiquitous system to capture mode share, and the aviation system have allowed economic development to spread across the nation. The locations of major centers of trade and economic activity are no longer constrained by the requirement of proximity to a water port or adjacency to a railroad. The large supply of inexpensive land means that, without changes in land use policies, even high energy prices may not discourage the location of economic activity in low-density areas, simply because the costs of development are so low in comparison. This pattern of national economic development has allowed formerly less developed regions to become more prosperous but has increased the demand for transportation.

If reducing total travel, or at least the growth rate of travel, becomes a policy objective for the nation, an understanding of the feasible and acceptable options for reducing travel in the most efficient ways become important. Clearly, successful implementation of policies requires that they be acceptable to a significant proportion of the public. Some broad options for addressing travel growth as well as suggestions for research areas to reduce knowledge gaps are outlined below.

Options for Reducing Total Transportation Activity and Associated Research Needs

In this section broad strategies to reduce total demand for transportation are reviewed. Demand would be reduced by raising the cost of travel through higher fuel taxes or pricing use of the transportation system, by changes in land use to make travel more efficient, and by use of telecommunications technology to substitute for travel. A subsequent section of this chapter discusses strategies to influence travelers to shift to more fuel-efficient modes.

Reduce Motorized Vehicle Use by Raising the Cost of Fuel

Imposition of carbon taxes, or increasing the cost of fuels indirectly through a carbon cap-and-trade regime, will reduce travel by making fuel more expensive. Available analysis indicates that LDV demand is fairly insensitive to increases in fuel cost, however (Small and Van Dender 2007). In the short run higher prices do not appear to reduce travel much, and in the long run consumers shift to more fuel-efficient vehicles. Carbon taxes or cap-and-trade proposals that would raise fuel prices, of the type debated in the U.S. Senate in 2008, would have minor effects on total fuel purchases and VMT in part because the impact of such proposals on fuel prices would be modest and in part because the increases in fleet fuel economy standards that Congress enacted will significantly reduce future travel costs (CBO 2008). Another reason for the limited response is that small and mobile transportation vehicles depend on fuel with high energy density, which is not the case for fixed energy users such as power plants. The latter energy users have more substitute fuels at their disposal and, therefore, more cost-effective options for reducing GHG emissions.

Some argue that transportation should reduce its GHG emissions in proportion to its share of total GHG emissions. Others argue that this should not be a concern as long as emission reductions are taking place in the economy through the most cost-effective responses. Indeed, for reasons explained above it is likely that carbon pricing schemes (tax or a carbon cap-and-trade system) will not exert a proportional effect on transportation even if carbon prices are set to reflect the external cost of carbon emissions, including climate-related costs. Nevertheless, policy makers may be motivated to reduce energy use in transportation for other reasons. For example, concern about imports of petroleum, often from unstable parts of the world, also motivates interest in measures to reduce transportation petroleum consumption, including measures aimed at reducing VMT.

If policy makers wish to reduce total transportation demand beyond the levels that would be achieved through a carbon tax or cap-and-trade regime, questions arise concerning how much travel can be reduced and at what cost. It is largely unknown how much total personal and freight travel could be reduced, independent of changes in development and logistic patterns, without risking a reduction in GDP that is greater than the societal benefits from these actions. Clearly, some trip making is not highly valued by users but imposes higher social and environmental costs than the user is required to pay. Ideally, such travel would be the first to be reduced by pricing and other measures aimed at reducing overall VMT. Whereas people and shippers would not make or pay for trips if they did not value the end result more than the cost of the trip, it is important to ensure that they pay all of the costs.

As policy makers consider proposals that would reduce both personal and freight VMT, they need information about how changes in travel affect productivity and economic growth. A fundamental problem facing all proposals to reduce VMT is a lack of understanding about how they would affect travel behavior and the economy. Little research is supported in this area through federal programs; hence, the knowledge base is limited. This topic is further discussed in the research recommendations below.

Price Use of Transport Infrastructure

Pricing strategies (congestion pricing, areawide pricing, parking, tolling, or charging for mileage traveled), while controversial, could reduce total automobile travel by causing some trips to be forgone and by encouraging mode shift. Strategies for pricing highway transportation would probably be the most effective in reducing automobile travel and encouraging mode shifts (discussed separately below), although congestion pricing may mostly serve to shift travel to less congested times and places rather than to reduce trips.[4] These proposals are efficient in the sense that the affected parties decide on how best to respond.

The Federal Highway Administration (FHWA) Value Pricing Program has been funding research and experimentation at the regional level on a variety of approaches such as pricing high-occupancy vehicle lanes, parking pricing, and cashing out parking. Experimentation has demonstrated the effect of pricing strategies on traffic flow, but much remains to be understood about public acceptability, equity, environmental impacts, and the appropriate institutional arrangements for carrying out pricing programs (Bhatt et al. 2008). Road pricing has been tested and implemented on a broader scale in Europe, but whether the positive experiences in London and Stockholm would translate to the United States remains uncertain (Richardson and Bae 2008, 9). There is as much need to learn about whether and how pricing strategies can be made more palatable, perhaps through strategies based on how revenues are allocated, as there is to learn what effects such strategies have on demand and GHG emissions. An understanding of the potential cost per ton of GHG emission reduction under the full range of pricing strategies is also needed.

Interest in moving away from fuel taxes as the main revenue source for transportation trust funds to a charge on motorists for mileage traveled is growing. With such a system, the mileage rate charged could be

[4] The trial imposition of congestion fees in central Stockholm during 2006, for example, reduced total work and school trips by automobile into the central area, but virtually all these work trips shifted to transit (Eliasson et al. 2009, 245). In contrast, peak-period discretionary automobile trips (equal in number to work and school trips) made before the imposition of the charge did not shift to transit. The study was unable to determine whether the trips were canceled, delayed, substituted for, or combined with other trips.

adjusted to reflect environmental values. For example, some mileage charging approaches would permit supplemental charges based on vehicle fuel economy. If such a regime could result in a systemwide approach to charging for road use, road pricing across all road classes would be technically feasible. Appendix A describes research and demonstration programs that would test alternative mileage charging technologies and engage the public and key stakeholders in a process to determine the acceptability of such an approach.

Change Urban Development Patterns

The National Research Council (NRC) committee that produced estimates of GHG reduction and energy savings that would be achieved by a doubling of the residential density of 25 to 75 percent of future residential development by 2050 indicates that the effects will be modest (TRB 2009). The scenarios in that report indicate that such changes could result in reductions in VMT, energy consumption, and CO_2 emissions ranging from less than 1 to 11 percent by 2050, although the committee disagreed about the plausibility of achieving a doubling of density for 75 percent of future development.

Policy makers wishing to achieve decreases in VMT through urban form and transit investment strategies need to know much more about the ingredients necessary for success of such strategies and what their benefits and costs might be. Research has shown that a blend of regulation, design, and investment in alternative modes is necessary for achievement of successful compact, mixed-use development, but which elements are necessary and to what degree, and how they vary across different urban forms, are unknown. Successful smart growth has included allowance for mixed uses (stores, offices, and housing located together rather than separated), investments in improved transit accessibility, better physical design to encourage and support walking, and parking pricing and changes in zoning to constrain maximum parking rather than mandate minimum parking. What is not well understood is the precise formula, how it might apply in different metropolitan areas, or what it would cost. There are very considerable differences in how metropolitan areas are developing (Lee 2007; Giuliano et al. 2008). Atlanta's urban form, which is typical of fast-growing, sprawling metropolitan areas in the South, differs from that of areas such as New York City, Boston, Chicago, or even San Francisco and Los Angeles. Transit-supportive strategies for compact development that work well for older cities with central business districts built up before the automobile or constrained from expanding by topography would not necessarily be appropriate for Atlanta or Houston.

Research to address such questions would focus on detailed case studies of successes and failures of explicit transportation–land use strategies. A complete scholarly analysis of the successes that Portland, Oregon, has achieved would be especially valuable. Portland's success has apparently been the result of several factors: strong state leadership, state growth management policies with an urban growth boundary as part of these policies, a regional government with strong influence over municipal land use and transit planning and investment, a young workforce with a fast-growing high-tech industry, political consensus on growth policy, and others. Insight into the measures needed to replicate Portland's experience elsewhere would be useful to policy makers. To the extent that the measures used in Portland have been applied elsewhere, it would be valuable to know whether they succeeded or failed, and why.

Better tools are also needed by metropolitan planning organizations (MPOs) to analyze transportation and land use options for regional policy makers. [This is in large part a demonstration and technology transfer problem; sophisticated linked travel and land use models are employed in a few places, but they are not employed by many MPOs (TRB 2007).] TRB's 2007 study on travel model practice in MPOs recommended research, technology demonstrations, and technology transfer to improve modeling and the state of practice. Such model improvements will become essential if states and regions must analyze the effects of various taxes, fees, regulations, and other policies on travel.

At a more fundamental level, MPOs need much better models to capture behavioral responses. Models of trip generation need to become much more sensitive to how people change their trip making as circumstances change. In turn, development of such models requires more fundamental research into travel behavior (described later in this chapter). Models of intrametropolitan area freight travel and the data on which they are based are even less well developed.

Many advocates of smart growth believe that this form of development has many ancillary benefits—closer community ties, more affordable housing, healthier lifestyles, and so forth. Whether the changes would all be beneficial is uncertain since families would also be giving up some of the housing size, privacy, and open space that come with low-density development. A way to measure (better than do stated preference surveys) how different physical environments, including different transportation infrastructure and operations, affect well-being is needed. Analysis of the cost per ton of GHG emissions reduced by smart growth development should be accompanied by estimates of the other social and economic benefits and costs of this form of development.

As a general rule, little is understood concerning what might be thought of as "second-order" effects that might result from more efficient transportation and development. Would the coupling of such outcomes have significant multiplier effects?

Use Technology to Substitute for Trips

Telecommuting, videoconferencing, Internet shopping, and the widespread availability of information and communications technologies (ICTs) all appear to have the potential to substitute for or reduce travel. The relationships between travel and ICTs are more complex than is commonly assumed; there are as many arguments for how ICTs stimulate additional travel as for how ICTs reduce it (Mokhtarian 2009). Research has not provided any empirical evidence that telecommunications, on a net basis, substitute for private vehicle trips (Choo et al. 2007), although there is evidence of a modest impact in telecommuting (Choo et al. 2005). Good evidence of how ICTs affect total travel or whether they stimulate or substitute for travel is not yet available. Development of research methods is needed in this area, along with better understanding of how information and communications can substitute for trips. The need for such knowledge confirms the importance of the fundamental research program recommended later in this chapter.

Summary

Strategies are available that would affect demand in ways that could help achieve energy and climate goals efficiently, but understanding of their costs and benefits is highly conceptual. Much remains to be known, and state and regional decision makers will need a high degree of specificity to ensure that these strategies are cost-effective, feasible, and acceptable.

MODAL STRUCTURE AND ENERGY INTENSITY

Modal structure and modal energy intensity are considered together in this section because most of the relevant policy questions raised by climate change and energy conservation goals concern opportunities to shift trips from modes with higher to those with lower energy intensity. Shifting modal preferences could affect transportation GHG emissions, depending on the nature and magnitude of the shift. As Table 3-1 indicates, the highest energy-consuming modes are highway LDVs, freight trucks, and aviation, which collectively account for 86 percent of transportation energy and 84 percent of transportation GHG emissions.

The energy and GHG emission reduction benefits of shifting from automobile to transit bus, from automobile to intercity rail, or from aviation to intercity rail may not be as great as commonly assumed. For example, according to federal statistics, automobiles, on average, require energy per passenger mile comparable with that of bus transit (possibly even less according to some estimates) and only 26 percent more energy per passenger mile than rail transit (Table 3-1).[5] Such comparisons, however, are notoriously difficult because of data problems, the distortions of comparing averages, and the importance of including life-cycle energy and emissions in the calculations.[6] During the peak period when transit buses are full, for example, transit bus energy efficiency outperforms other passenger modes, but the off-peak performance of transit buses is

[5] Energy intensity estimates for transit bus differ across sources. In the *Transportation Energy Data Book,* 28th edition, the value of 4,253 Btu per passenger mile is given for 2006, but in *National Transportation Statistics,* the most recent value estimated is 3,262 for the same year (see http://www.bts.gov/publications/national_transportation_statistics/, accessed April 12, 2009). Furthermore, Btu per passenger mile for automobiles has been falling for decades, a trend that will continue given CAFE standards adopted in 2007; the energy consumed per passenger mile for bus transit has been rising over the same period (see *Transportation Energy Data Book,* 28th edition, Table 2.13).

[6] Estimates of transportation life-cycle energy and emissions attempt to include all sources of energy required for manufacturing, operating, and recycling vehicles as well as for constructing and operating their required infrastructure.

TABLE 3-1 Energy Intensity and CO_2 Emissions by Mode

	Btu 2007[a] (trillions)	Percent	Btu/Passenger Mile,[b] 2006	Btu/Ton-Mile[c]	Modal CO_2[d] (percent)
Highway	**22,293**	**80.0**			**78.9**
Light vehicles	**16,925**	**60.4**			**60.1**
Car	9,218	32.9	3,510		34.2
Light truck	7,676	27.4			25.8
Motorcycle	30	0.1			0.1
Buses	**194**	**0.7**	3,262[e]–4,259		**0.5**
Transit	91	0.3			
Intercity	30	0.1			
School	73	0.3			
Medium or heavy trucks	**5,274**	**18.8**		~3,000–4,000[f]	**18.4**
Nonhighway	**5,609**	**20.0**			
Air	**2,509**	**9.0**			
General aviation	244	0.9			0.6
Domestic air carrier	1,847	6.6	3,250		6.6
International carrier	419	1.5			
Water	**1,559**	**5.6**		304	**4.4**
Domestic freight	1,312	4.7		571	
Recreational	247	0.9			
Pipeline	**883**	**3.2**			**1.9**
Rail	**657**	**2.3**		330	**2.3**
Freight	570	2.0			
Passenger	90	0.3			
Transit	47	0.2	2,707		
Commuter	29	0.1	2,527		
Intercity	14	0.1	2,650		
Total	**28,002**	**100**			

[a] Davis et al. 2009, Table 2.6.
[b] Davis et al. 2009, Tables 2.13, 2.14.
[c] Davis et al. 2009, Table 2.16.
[d] Eads 2008, Table B-2.
[e] *National Transportation Statistics* (http://www.bts.gov/publications/national_transportation_statistics), Table 4-20.
[f] Davis et al. (2009) no longer provide energy intensity estimates for intercity trucks because of the difficulties of arriving at accurate estimates. The figures shown were calculated by using 2005 data as the most recent available. Btu's are from Davis et al., Table 2.16; ton-miles are from *Pocket Guide to Transportation 2008,* Table 4-4, Bureau of Transportation Statistics, U.S. Department of Transportation. However, more careful comparisons between truck and rail energy intensity for moving comparable loads over comparable distances find much smaller differences than the more than 10:1 or 12:1 ratio shown above. Babcock and Bunch (2007), for example, estimate a ratio of only 3:1 for comparable agricultural commodities.

the worst of the passenger modes (Chester and Horvath 2008). The energy required per passenger mile for aviation is about a quarter greater than that required for intercity rail (Table 3-1), but the net increase depends on several factors, including the distance over which trips are taken and the estimated market share of air and rail. Aviation is less efficient for shorter and more efficient for longer distances. [One comparison of the ability of high-speed rail to reduce aviation CO_2 emissions in short-haul markets (less than 620 miles) finds a reduction of less than 1 percent in aviation emissions if high-speed rail gained 30 percent of intercity passenger market share in these markets by 2030 (Jamin et al. 2004).] Whether the energy required for constructing new rail lines offsets energy advantages is also an important consideration.[7] These overall averages, however, tend to mask the outcomes in particular markets and appear to be highly dependent on load factors and methods. Previous attempts to compare intercity passenger modes on a full cost basis have shown aviation to be superior to rail and highway, although the analysis is highly dependent on which costs and benefits are included and how they are monetized (Levinson 1996). These examples highlight some of the counterintuitive outcomes in transportation and emphasize the importance of sound research that leads to good policy choices.

Freight

Mode shifts appear to be particularly relevant in freight, because trucking is the most energy-intensive freight mode and has a large and growing share of ton-miles. Trucking market share and total ton-miles have grown rapidly since deregulation of the surface modes in the 1980s; trucking's share of ton-miles increased from 19 to 29 percent between 1980 and 2005 (Table 3-2). Rail ton-miles have also been growing, but not as sharply, while domestic water transportation has been steadily declining in market share and ton-miles. International freight move-

[7] Whether rail or aviation is less energy intensive depends to a large extent on estimated load factors. Projections of load factors, however, have a poor track record. See Energy and Emissions in Transportation: How Mikhail Chester Makes it Easier to Be Green, *NewsBITS,* Vol. 4, No. 1, Fall 2008 (http://www.sustainable-transportation.com/), accessed April 13, 2009. The relative impact of the two modes on GHG emissions also depends on questions concerning the radiative forcing effects of aircraft contrails.

TABLE 3-2 U.S. Domestic Freight Ton-Miles, 1980–2005

	Truck	Rail	Water	Pipeline	Total
Trillions of ton-miles					
1980	0.63	0.93	0.92	0.92	3.4
1985	0.72	0.88	0.89	0.82	3.31
1990	0.85	1.06	0.83	0.86	3.6
1995	1.03	1.32	0.81	0.93	4.09
2000	1.19	1.55	0.65	0.93	4.32
2005	1.29	1.73	0.59	0.9	4.51
Percentage change, 1980–2005	105	86	–36	–2	33
Market share (%)					
1980	19	27	27	27	100
1985	22	27	27	25	100
1990	24	29	23	24	100
1995	25	32	20	23	100
2000	28	36	15	22	100
2005	29	38	13	20	100
Percentage change, 1980–2005	54	40	–52	–26	

SOURCE: BTS 2007, Figure 4.

ments, mostly by water, have been growing strongly, but there are no practical substitutes for most commodities moved across oceans, and GHG emissions per ton-mile for freight transported by oceangoing vessels are the lowest of all modes. Air freight has been growing faster than other modes, but domestic air freight ton-miles represent far less than 1 percent of the total (BTS 2007). Policy makers could benefit from better insight into the potential of policies that would shift freight from truck to rail or water. Because freight markets are highly competitive, commercial travel should be energy efficient, but there are market distortions, such as direct and indirect subsidies to different modes, inadequate competition in some corridors, and institutional barriers. Among the institutional barriers are budgetary impediments to investment of waterway trust fund revenues for improving channels and locks and for dredging harbors. The kinds of freight and the market distances that are candidates for diversion from truck to rail, and the costs and benefits of shifting modes, would be useful information.

National policy makers should have a better ability to weigh policy choices that would affect modal demand in order to understand their net benefits from environmental, economic, and safety perspectives. Available data on the energy intensity of various freight modes suggest that generalizations about the benefits of shifting modes are inadequate. Opportunities for improved energy efficiency per ton-mile depend on particular corridors and markets (Winebrake et al. forthcoming); understanding which corridors and markets would require better data on freight origin-to-destination (O-D) flows, econometric studies of potential freight mode shifts, and better insight into logistics patterns.

Most studies only compare GHGs per ton-mile emitted by the various modes; this metric shows water and rail to be vastly better than truck. Rail and water rates are also typically well below those of trucks. Commodities in shipment, however, carry inventory costs to shippers. Hence, shippers of high-value cargoes are usually willing to pay a premium to have goods moved by truck, which is the fastest mode for most domestic shipments of less than 1,000 miles. Delaying these shipments by moving them on slower modes also implies increased cost to the national economy: even though water or rail freight rates may be lower, consumers would have to pay for the extra inventory costs of goods that move more slowly.[8]

To appreciate the overall social benefit of policies to encourage mode shift, better quantification of the full external costs and benefits of the various modes is needed. This requires an understanding of the nature of existing subsidies and policies for reducing undesirable ones. The 1996 study *Paying Our Way: Estimating Marginal Social Costs of Freight Transportation* laid out a methodology by which the social costs and benefits of various freight modes could be compared on an O-D basis (TRB 1996). The collection of data and the analysis of a sample of freight O-D movements large enough to provide a better sense of the comparative social and environmental costs of the modes are still needed.

Passenger

Intercity

As Table 3-3 indicates, aviation and personal vehicles dominate trips of 100 miles or more; they account for about 96 percent of these passenger

[8] These modal comparisons are simplified to make a point. In fact, many long-distance freight movements (1,000 miles or more) rely on multiple modes, typically truck and rail.

TABLE 3-3 Long-Distance Passenger Travel in the United States by Mode, 2001

	Person Miles (percent)
Personal use vehicle	55.9
Commercial airplane	40.5
Bus	2.0
Train	0.8
Other	0.9

NOTE: "Long distance" for these data means round-trips to a destination at least 50 miles away.
SOURCE: *National Transportation Statistics* (http://www.bts.gov/publications/national_transportation_statistics), Table 1-39.

miles. Passenger rail currently accounts for less than 1 percent of such travel. Carbon taxes or cap-and-trade policies could affect total intercity trips and mode share, but the magnitude of the benefits is unclear. Amtrak currently operates at about 50 percent of capacity nationwide (Polzin 2008), so ridership could be doubled at low cost. Given the small market share, that would have little impact on national transportation energy consumption or GHG emissions. Furthermore, in many city-pair markets, air travel tickets (whose prices do not include external costs) are less expensive and door-to-door travel by air is faster. Road pricing could affect mode shift and make air and rail more cost-competitive, but the potential magnitude of the shift and how much difference it might make are uncertain. For example, for family vacation trips and many short business trips involving more than one person, the efficiencies of having a vehicle at the destination must be considered, particularly when the destination does not have a good transit system.

Short-Distance Travel

Opportunities exist for mode shift in personal short-distance travel. As Table 3-4 indicates, the automobile, which accounts for about 86 percent of trips, is by far the dominant mode for all short-distance personal trip purposes, followed by walking (8.6 percent), other (3.4 percent), and transit (1.6 percent). These mode shares reflect all person trips (urban, suburban, and rural). At the urban scale, transit has a larger share of trips, and because origins and destinations are closer together, other modes are

TABLE 3-4 Percentage of Total Person Trips by Mode and Trip Purpose, 2001

	Total	Work Commute	Work Related	Family, Personal	School, Church	Social, Recreational	Other
Private	86.3	92.4	91.2	90.9	71.3	80.7	67.2
Public transit	1.6	3.7	1.8	1.1	2.1	1.0	4.2
Walk	8.6	2.8	4.2	7.1	9.6	14.5	15.9
Other	3.4	1.0	2.7	0.9	16.9	3.7	12.3
Total	100	100	100	100	100	100	100

SOURCE: Hu and Reuscher 2004.

more competitive with personal vehicles. There are also opportunities to improve LDV passenger mile efficiency; the average LDV trip has a vehicle occupancy rate of 1.63 persons (Hu and Reuscher 2004), indicating considerable spare capacity and opportunity for ridesharing, which would be encouraged by carbon taxes, carbon cap-and-trade proposals, and pricing.

Improved Modal Efficiency

Modal fuel intensity and associated GHG emissions could be decreased by reducing congestion, smoothing traffic flow, and curtailing hard accelerations and high speeds. The benefits for highway transportation energy conservation could be important. Barth and Boriboonsomsin (2008), for example, estimate that applying these measures to Southern California highways could reduce the GHG emissions of such travel by up to 20 percent, although the degree of regulation required to achieve such efficiencies exceeds current policy and practice. Research may identify tangible benefits from operational strategies that are less controversial than automated speed enforcement. Some of this work is already under way at the U.S. Department of Transportation through the Intelligent Transportation Systems Program and FHWA's Operations R&D and program efforts; estimates of the energy-saving and GHG-reducing benefits of such strategies would be helpful to decision makers.

Life-Cycle Analysis

As already mentioned, accuracy requires that modal strategies be compared on a full life-cycle basis. For example, Lave (1977) pointed out that an enormous amount of energy is required to build subway systems; it is difficult to repay these energy costs from the subsequent energy savings per passenger mile unless ridership levels are high. Valuable research in this area is already under way (Chester and Horvath 2008), but future policy making would benefit from additional scholarship. A related issue requiring additional study is how the increased density of development that rail systems permit becomes translated into residential and commercial building energy savings.[9]

ENERGY CONSUMPTION (FUEL INTENSITY)

National policy makers have long relied on vehicle and fuel regulation to meet national clean air goals, and they are likely to place similar emphasis on vehicles and fuels to meet GHG emission reduction goals. Indeed, technology and alternative fuels are likely to be the largest sources of future reductions in transportation GHG emissions. Because LDVs account for the single largest share of energy consumption among transportation vehicles (about 60 percent) and are believed to be the most mutable, most past and current analysis focuses on this vehicle category. Whether technology and fuel strategies alone will be sufficient in meeting national goals once they are set, however, is a matter of ongoing debate and analysis.

A number of recent studies have illustrated the potential role of vehicle technologies and alternative fuels in reducing LDV energy consumption and emissions. Most use some form of scenario analysis that depends on making assumptions about technology development, cost, and market penetration. Analyses that have attempted to estimate the ability of new technologies and fuels to win market acceptance and be more or less cost competitive with the current gasoline-consuming fleet have shown that the growth of fuel consumption can be significantly reduced in the 2025 to 2035 time frame, despite growth in population and VMT (Eads 2008; Heywood et al. 2008; Plotkin and Singh 2009; Lutsey and Sperling 2009). Analyses that extend projections to 2050 indicate that the new technologies

[9] For example, the recent NRC report *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions* estimates that the residential building energy savings of compact, mixed-use development rival those of reduced VMT (TRB 2009).

and fuels can reduce LDV energy consumption to 1990 or 2000 levels by that time (Eads 2008; Plotkin and Singh 2009; Lutsey and Sperling 2009). However, the scenarios imply that CAFE and market forces would not accomplish anywhere near enough GHG emission reductions if policy makers decide that transportation GHG emission levels must be reduced to 60 to 80 percent below 2005 levels by 2050. If these scenarios prove reliable, nonvehicle and fuel-based strategies will be important in meeting such a reduction goal, but whether and how they can do so are open questions.

A recent scenario for an aggressive hydrogen and transportation fuel cell–based strategy developed by a National Academies committee suggests that gasoline could be largely replaced by hydrogen for the LDV fleet by 2050 and that LDVs could meet an 80 percent GHG emission reduction target by that time (NRC 2008). The scenario was not a description of what might or is likely to happen; instead, it was a description of what *could* happen if adequate resources and national attention were focused in this area. The analysis indicates that even if an adequate national commitment were made, scale economies and technological breakthroughs would not make hydrogen fuel cell vehicles cost-competitive with conventional technologies until the mid-2020s. Up until that time, there would be an implicit public-sector subsidy of about $10,000 per vehicle.[10] Reaching the GHG emission reduction goal would depend on many technological advances, including success in sequestering the CO_2 that would be emitted to refine hydrogen from natural gas, coal, and other fuels.

Even experts engage in considerable speculation in attempting to describe how technologies might mature and markets evolve over a four-decade period. However, the different outcomes that analyses such as those above suggest illustrate the importance of ongoing and improved research to guide public policy. Technologies should be monitored as they emerge and their direct and indirect costs and benefits estimated. Projections should be updated and policy makers provided with insight into regulatory or other means of enhancing GHG emission reductions, along with estimates of the costs per ton of emissions reduced. Such studies

[10] The subsidy would largely take the form of substantial public-sector investments in technology development. The production of hydrogen would also be subsidized.

need to become increasingly integrated across all the interacting technical areas.

How consumer preferences for vehicle attributes might change is also important to understand. Although the fuel economy of LDVs remained static in the United States for about 25 years, the performance of vehicles (acceleration, safety, electronic devices) improved dramatically during that period. GHG emission reductions from vehicles and fuels would be more readily achievable if consumers became content with a static level of vehicle performance and amenities. Addressing consumer preferences on this matter would be an important line of research.

RECOMMENDED TOPICS

This section further describes the kinds of research needed. The committee agrees with many of the research areas that Burbank (2009) describes, but it has organized some of these topics under different headings and includes research topics that she did not cover. The first section below describes research and information dissemination meant to educate policy makers and practitioners about available policy options and to provide practitioners with tools and information useful in developing and implementing new programs. The second describes a fundamental research program that would, over time, improve knowledge in all the relevant areas described in the previous section.

Policy Guidance and Outreach

What Burbank (2009) refers to as "foundational" research might also be described as the development of expert syntheses of existing information into guidance for policy makers, practitioners, and researchers. These individual projects can be thought of as building blocks for subsequent policy decisions based on the best available information and as guides to subsequent research, analysis, and data collection. The scale and magnitude of the challenge of reducing transportation GHG emissions and the long time dimensions involved in climate change indicate the importance of beginning to take sensible actions now and continuing to improve the knowledge base that will be needed in coming decades. This section describes R&D to develop policy guidance and to disseminate this information to policy makers at all levels. The next section describes a fundamental research program that would improve this guidance as new insights and information become available.

Policy Guidance Topics

A set of projects that would be conducted over the first few years of the program to develop specific guidance for policy makers and practitioners is described below.

Life-Cycle GHGs To a large extent, GHG mitigation focuses on opportunities to reduce automobile trips and shift travel to modes that emit less GHGs per passenger mile or ton-mile. An understanding of the full life-cycle GHG emissions associated with each mode is important in developing policy for mode shift. Life-cycle GHG emissions include those associated with the extraction, refinement or production, delivery, and consumption of fuel used by various modes; the construction of vehicles; the construction and operation of infrastructure; and the disposition or recycling of vehicles that have ended their useful life span. Extensive representations of emissions associated with vehicles, fuels, and modal alternatives are included in Delucchi's life-cycle emissions model, but it has fairly simple representations of the emissions associated with infrastructure construction and operations (Delucchi 2003). Valuable research is being done in this area (see, for example, Chester and Horvath 2008), but additional research is needed to build a robust foundation for policy analysis. This project would define the state of the art, provide the best available estimates to policy makers, and recommend research needed to improve understanding.

Cost-Effectiveness, Including Co-Benefits and Costs The goal of analysis in this context is to provide policy makers with the best possible information about effectiveness and cost per ton of GHG reduced by individual and collective strategies. Some work has been done on the cost-effectiveness of certain strategies, particularly in the vehicles and fuels area (Lutsey and Sperling 2009), but in many other areas considerable gaps remain to be filled to guide policy decisions. Many strategies are believed by their supporters to have benefits other than GHG emission reduction that society also values. They may also have costs that are not obvious. Typically, cost-effectiveness analysis is limited to a comparison of implementation costs to achieve a desired outcome and does not consider the full range of costs and benefits. This research project would provide the best available estimates of cost-effectiveness of individual strategies, which would necessarily draw on the life-cycle estimates described above, and would include estimates of co-benefits and costs. It is not assumed that all costs and benefits can be monetized, and therefore a full benefit–cost analysis is not practical. However, cost-effectiveness analyses alone provide incomplete information for policy makers. Implementation of various strategies typically requires trade-offs among valued goods and preferences, which policy analysis should also illuminate. Areas of uncertainty might mean that this guidance would be partial and incomplete, which would lead to the identification of gaps in knowledge that future research could fill.

Low-Hanging Fruit Burbank (2009) describes these as opportunities to reduce GHG emissions with "no regrets." This project would review the full range of possible transportation strategies to identify those that might be implemented in the near term, estimate their potential for reducing GHG emissions, identify barriers to implementation, and provide recommendations for overcoming the barriers.

Land Use and VMT This area of research has been the most influenced by value preferences, perhaps because most proposals for reducing travel associated with land use patterns involve changes in norms for housing style and location and personal vehicle use that have prevailed for decades. *Special Report 298* (TRB 2009) summarizes the knowledge base concerning the relationships among development patterns, VMT, energy use, and GHG emissions. Most studies have been unable to control for the many influences on the built environment and travel behavior (TRB 2009). The most rigorous studies imply that more compact, mixed-use development, coupled with good transit accessibility and policies to make automobile use less attractive, will reduce future automobile use modestly by 2030 and 2050 (TRB 2009).[11] The magnitude of

[11] The committee that prepared *Special Report 298* focused on estimating the impact that compact, mixed-use development would have on automotive VMT. It explicitly did not review the full benefits and costs of compact, mixed-use development.

the effect, however, will vary with local contexts, making generalizations about benefits and costs unreliable. Advancing society's collective understanding of these issues depends as much on the process for conducting credible research as it does on the results. Recommended is a project to (*a*) develop a process for involving expert stakeholders with different world views and perspectives in the design of future research and (*b*) conduct research to provide the most scientific approach possible to sorting out this complex, multifaceted topic. The land use–transportation area is value laden and difficult to research well because of the many policies, practices, and preferences that influence how areas develop and the long time periods involved in shaping the built environment. These characteristics make the research area something of a special case. It should be overseen by the diverse stakeholders mentioned above, and the research that is conducted should focus on fundamental issues about which reasonable people disagree. The research should be designed by professionals to ensure that it is well conceived and of the highest scientific rigor.

National and Local Data Gaps The transportation field suffers from poor and inadequate data. Much of the good behaviorally oriented research that occurs today is based on unique or locally specific data sets, from which it is difficult to generalize. Transportation policy, however, is made at all levels of government—federal, state, regional, and local—and the kinds of policies considered appropriate are often determined by geography, local political preferences, and institutional capabilities. Hence, passenger data are needed at different spatial scales and time periods, for which there are many gaps. Freight data are even less available than passenger data, in part because of the proprietary nature of much of the information. (Ways of dealing with this problem have been addressed in the freight rail area.) This project would define the key data about passenger and freight travel needed at all levels of government and in the private sector to make prudent decisions about reducing transportation GHG emissions. The results of this project would inform the data collection area described in Appendix B.

Educational Outreach for Policy Makers and Practitioners A series of workshops would likely be needed to reach decision makers with the information generated from the above projects (Burbank 2009). An extensive outreach effort may be necessary to reach all the individuals at various levels of government who make decisions about implementing programs. This activity would design appropriate materials and events to reach these audiences. The initial effort could be based on the results of the "low-hanging fruit" and "cost-effectiveness" projects. As additional policy guidance developed through the fundamental research program described later in this chapter is synthesized and interpreted, subsequent outreach efforts would be organized.

New Tools and Technologies The new understanding and improved tools for analysis developed by the fundamental research described below should be translated into practical revisions of handbooks, tools, techniques, and technologies that can be disseminated widely, along with appropriate training. Among the new tools might be improved guidance documents, sketch planning models, regional travel models used by MPOs to analyze policy options that are sensitive to how travelers adjust their behavior, and paving materials and techniques with reduced GHG emissions.

Structure

All these efforts would be best conducted through a research model that extensively involves stakeholders in the development of research agendas, requires merit review of competitively solicited proposals by peers, allows experts and practitioners to be represented on panels to oversee research efforts, and involves stakeholders in the peer review of the completed research.

Fundamental Research

Burbank (2009) recommends the creation of a university-based research program to conduct high-quality research addressing fundamental issues and questions that are important to resolve in analyzing, choosing, conducting, and evaluating mitigation efforts. The committee shares the belief that such research is greatly needed, but also believes that the organizations that conduct the research should be the most qualified proposers and should be selected through a competitive process based on merit and decided by peers regardless of their institutional affiliations.

The topics into which the committee has organized these research areas capture most of the topics Burbank (2009) identifies in her commissioned paper and adds others that the committee believes to be important. Most of the topic areas have been introduced in the preceding sections of this chapter. Examples of the kinds of research that would be conducted through this program are described in the following paragraphs. Topics are grouped under various headings, but much of the research would span multiple topic areas. The topics are examples of the kinds of research that the committee expects would be conducted once the program becomes operational. The committee expects that experts would be convened early in the program to identify the most promising areas of investment.

Measurement and Estimation

- *Cost-effectiveness of individual mitigation strategies and combinations of strategies:* If the nation comes to support the need to mitigate transportation GHG emissions and reduce energy consumption, the most important research task in the mitigation area will be to inform the selection of strategies that require the least resources. Developing these estimates will require considerable analysis and research and will depend on improved understanding of other topics listed below.
- *Life-cycle analysis for modal comparisons:* Analysis is needed to refine estimates that cover all the dimensions of vehicle and modal energy consumption in obtaining fuel; in building, operating, and disposing of vehicles; and particularly in building, operating, and maintaining the infrastructure on which vehicles operate.
- *Full social cost accounting:* Transportation in the United States is market driven to a considerable degree, particularly in the freight sector. However, the market transactions do not include the cost of emitting GHGs or the impact on the national economy and national security of being so highly dependent on imported fuels, much of which comes from unstable parts of the world. Improved understanding of the external costs and benefits of transportation is important in making decisions about tax rates, pricing strategies, and regulatory analyses. Considerable effort has gone into developing esti-

mates of transportation externalities (see the volumes prepared by Delucchi et al.),[12] and more fundamental research is needed to update and extend past work, address freight transportation, and narrow the differences of opinion that exist among experts about how to value nonmonetary costs and benefits.

- *Co-benefits and costs:* As indicated above, the mitigation strategies favored by some to reduce travel may have ancillary benefits. "New urbanist" designs of residential development, for example, are thought to foster healthier lifestyles (more walking) and stronger community bonds among neighbors. Whether this is true is an empirical question that can be tested. There may also be costs that need to be better understood, such as whether families' preferences for open space, privacy, quiet, organized children's sports and other activities, and other amenities of suburbia are also well served in such developments.

Travel Behavior and Modeling

At the most basic level, mitigation policies are designed to modify behavior, but whether they will do so and whether the changes will be those anticipated are difficult to predict. Scholarly research in this area has not been well supported by transportation research programs in the past. Hence, the knowledge base is not as robust as needed to understand the implications of some of the mitigation proposals being suggested.

- *Individual, household, and life-cycle activities:* Basic research is needed to better understand the individual, family, and life-cycle activity patterns that drive transportation demand.
- *Demographic changes:* The aging of the baby boom and projected growth in immigration will affect the magnitude and nature of future travel demand, which needs to be well accounted for in forecasts of VMT and in strategies to address it.
- *Urban goods movement:* The magnitude and nature of freight movements, both through and within metropolitan areas, are largely unknown due to data constraints. In addition to the data collection needs identified later in this report (Appendix B), research projects

[12] See the listing of reports at http://www.its.ucdavis.edu/people/faculty/delucchi/index.php. Accessed April 22, 2009.

are needed to help understand goods movement in general and how it is changing (e.g., with growth in Internet shopping).

- *Land use interactions:* Of the many studies on how land use and transportation behavior interact, the small number that are well designed are unable to control for all the interacting influences that affect travel outcomes (TRB 2009). Even the best studies are cross sectional (examining relationships between variables at a single point in time), but they can only suggest associations. Longitudinal studies (which examine relationships over time) are required to establish causal relationships in hopes of understanding how to design policies that will affect outcomes, but such studies are rare in the United States. Research would initially be needed to design appropriate longitudinal studies, as recommended by *Special Report 298* (TRB 2009).

  A separate set of research projects would focus on key questions for local policy makers interested in achieving VMT reductions through changes in urban form. Among such questions are the following:
  - What would be appropriate parking prices and parking maximums, and how would they vary by the density of development?
  - What changes in zoning laws, regulations, and practices are needed to encourage appropriate mixed uses of development?
  - What kinds of regional land use controls are necessary to concentrate development (see discussion of Portland and urban growth boundaries above)?
  - What elements of urban design make dense, multifamily residential areas more appealing and attractive?
  - What mix of development types (housing, retail, employment) is needed and in what proximity to residential development to create the desire for people to walk?
  - What design features of the environment are most successful in inducing walking trips?
  - How should transit be best designed to foster more compact, mixed-use development?
  - At what residential and employment density levels are different types of transit service (bus, light rail, subway) most cost-effective?
  - Little is currently understood about the magnitude of freight emissions and energy consumption within metropolitan areas and how they change with spatial structure (Bronzini 2008). Are decentral-

ized areas more or less energy efficient from a freight distribution perspective? Do the congestion disadvantages of density outweigh the greater trip lengths of low density?
  - Demand for compact, mixed-use development appears to be underserved (Levine 2006); how could transportation energy efficiency be maximized to meet such demand?
- *New, cost-effective approaches to data collection and dissemination:* Understanding travel behavior is a data-intensive area of research. The development of more cost-effective and accurate ways to collect information from representative samples of volunteers is critical in obtaining such data. Research is under way in this area, but additional work is needed to bring down costs.
- *Next-generation trip generation models:* Tools for predicting travel behavior can be improved as new understanding and data are obtained. Current models are based on simplistic representations of decision making.
- *Opportunities for passenger and freight mode shift:* Improved understanding of the effects of policies designed to encourage shifts in travel to modes requiring less energy and with lower emissions of GHGs (transit, water, rail) is important. Policies to be examined would include road pricing, road tolling, parking pricing, increased fuel taxes, and others designed to raise the cost of road use to incorporate externalities. In the freight area, research could examine the potential benefits and costs of raising heavy-vehicle use taxes to ensure that motor carriers pay both the cost imposed on the infrastructure and the external costs imposed on others (congestion, pollution, GHGs emitted, and so forth). Changes in regulation to encourage efficiency through increased competition and the benefits and costs of direct subsidies, such as costs for waterways infrastructure and operations not borne by users, are also worth examining.
- *Potential for trip substitution:* As described earlier in this chapter, many expect that pervasive information and telecommunication technologies will substitute for trips, but so far no significant effects have been established. The research in this area is difficult, so advances in methods and data are needed to develop a better understanding of the relevant relationships.
- *Incorporating uncertainty in models used for policy analysis:* The complex and global challenges of responding to climate change imply that

they require analysis of options over a much longer time period than the 20- or 30-year horizon often used in transportation planning exercises. Adopting a long-range perspective introduces deep uncertainties about the effects of climate and technological change and how societies will respond. Methods are in development that incorporate these uncertainties into models that guide policy makers through consideration of a wide range of possible futures and adaptive strategies (Lempert et al. 2003). The choices such exercises develop for the long term can be very different from those that seem appropriate over analysis periods of only 10 or 20 years. Dewar and Wachs (2006) have suggested how these approaches to incorporating uncertainty could be applied to transportation planning in response to climate change. They criticize the transportation models currently used for regional and state long-range planning for their deterministic nature and inability to incorporate the uncertainties that characterize the challenges of responding to climate change. Fundamental research on such modeling approaches would address how they might be developed to analyze transportation policy options to respond to climate change over the long term, taking into account uncertainties about climate, technological, social, and economic changes.

Policy Analysis

Grouped together under this heading are a variety of analytical tasks needed to inform policy makers:

- *Successes and failures of past transportation interventions to meet federal air quality standards:* For nearly 40 years the nation has struggled to reach national air quality standards through transportation and other measures. The mitigation strategies to reduce GHG emissions are similar to those implemented to reduce criteria emissions from vehicles. Many of these strategies are embedded in the existing federal–state policy framework, but whether they are all effective is an open question. Clearly, vehicle emissions and CAFE standards have gone a long way toward meeting Clean Air Act goals. Mandates to reduce ozone precursors have been effective in requiring local officials to become creative in addressing problems, but the so-called conformity test remains controversial. Much could be gained from scholarly evaluations of the effectiveness, costs, feasibility, and acceptability of past interventions.

- *Lessons from abroad:* Most industrialized nations are already engaged in mitigating transportation emissions. Although international comparisons can be fraught with problems, much can be learned if the research is well designed. Much can also be learned about how other nations organize research to provide local policy makers with information that will help them implement the most cost-effective GHG-reducing strategies at the local level.[13]
- *Implementing user charges:* The discussion of full social cost accounting above describes the need for research to improve the ability to quantify difficult-to-value social and environmental costs. Even if they were better known, there is a political reluctance to impose such costs. International experience with cordon tolls indicates that public support for pricing measures improves once they are implemented. The introduction of congestion pricing in Stockholm through a pilot program before the holding of a public referendum appears to have shifted support to a majority position. These examples need to be examined more closely to improve understanding of how public acceptance was achieved. More generally, research is needed to improve understanding of whether and how the public might accept marginal social cost approaches in any sector and to suggest strategies that might help move society in this direction for pricing transportation. In addition, many regulatory approaches, such as motor vehicle fuel economy standards and safety standards, have the effect of raising prices to require consumers to pay for social costs they might not fully value. Although these approaches are less efficient, they do not suffer from the same broad lack of public support as do pricing measures. The merits of these kinds of approaches should be evaluated.
- *Integrated vehicle–fuel scenarios:* As indicated in the section on vehicle and fuel energy intensity, there will be an ongoing need for assessments of the potential of alternative vehicles and fuels to meet GHG emission reduction targets. As useful as such analyses are, they often have to make simplifying assumptions that may not prove realistic.

[13] For example, May et al. (2008) describe how the United Kingdom developed a research initiative to help local officials make informed decisions about urban transportation and land use strategies.

Refinements can be made through research to integrate more fully all the required dimensions of cost, rate of technology innovation, safety, performance, and so forth.

- *Equity:* Many of the potentially most effective strategies aimed at modifying travel behavior involve increasing the cost of driving, which could be inequitable. There are surely ways to minimize inequitable impacts, but they are not always the obvious ones (Schweitzer and Taylor 2008). Sales taxes, for example, which are increasingly levied as an alternative to raising gasoline taxes, can place an extra burden on the poor. Research and analysis can lead to the design of policies to meet GHG emission reduction goals without placing a special burden on the least advantaged.
- *Institutions:* Enacting policies that would result in significant changes in travel behavior may also require significant changes in institutions that develop such policies. Regional strategies are required in addressing travel behavior at the metropolitan scale, but MPOs are weak institutions, and most have little influence over land use policy within their regions. Furthermore, transit authorities and state, county, and city highway departments are responsive to differing legislative mandates and funding streams. Harmonizing these institutions at the regional scale is a difficult challenge that few regions have mastered. Research could inform policy makers about the consequences of reforms that have been tried in some regions.
- *Benefits of new investments in less energy-intensive modes:*
  - Transit has the potential to save energy, particularly in places that support efficient and cost-effective transit. Transit currently captures about 11 percent of metropolitan area work trips and only 2 percent of trips overall, but it captures 23 percent of work trips in central cities of 5 million or more (Pisarski 2006, Table 3-23). Of course, a massive expansion of transit would be required to make a significant dent in the GHG emissions of passenger vehicles overall, given the small share of total trips that transit represents. Analysis of the particular settings in which transit strategies pay off in terms of energy savings and GHG emission reductions is needed.
  - Rail transit systems have better fuel efficiency per passenger mile than do buses. However, they are capital intensive and take decades to plan and build out to a system level, and subways require enor-

mous energy to construct. The best near-term opportunities exist in places that already have rail systems, so research should focus initially on where and how system expansions make the most sense from a GHG-reduction perspective.
- Although intercity passenger rail is about 24 percent more energy efficient than LDVs, expansion of the passenger rail network is problematic for a number of reasons. New rights-of-way for high-speed passenger rail are expensive, are difficult to obtain because of the required nearly straight and level alignments, and face significant environmental barriers. The energy costs required for the construction of the new capacity also need to be considered.[14]

- *Program evaluation:* If the experience with the Clean Air Act is a guide, some programs implemented to influence travel will not work or will not be as effective as needed. Interventions should be rigorously evaluated by independent researchers so that ineffective programs can be discarded and potentially more effective ones implemented.
- *National-level analysis:* In addition to the topics suggested above, there is a need to encourage consideration of broad, national-level strategies that encompass all of transportation—travel demand, vehicle technologies, alternative fuels, substitutes for travel—to address fundamental questions of how the transportation system, considered as a whole, could respond to the problem of climate change. The intent would be to encourage creative reconsideration of how transportation is conceived and provided in a world where carbon emissions are a binding constraint.

System Management and Operations

Many regions have implemented elements of intelligent transportation system technologies that could allow greater fine-tuning of traffic flows. To achieve the 20 percent GHG emission reduction potential cited earlier,

[14] Almost all intercity rail now operates on tracks that service both passenger and freight trains. This makes introduction of intercity passenger rail more feasible, but it reduces the speed at which passenger trains can operate and raises safety concerns. Most intercity rail lines are owned by private freight railroads, and many corridors operate near capacity for freight alone. For safety and capacity reasons, private railroads are not anxious to share tracks with passenger trains. Policy makers need information about the potential of intercity rail—particularly the cost per ton of GHGs reduced when the costs of obtaining rights-of-way, addressing safety issues, and other issues are included.

information would probably have to be combined with speed management in ways that are becoming more common in Europe but that are not being used in the United States. Among other possibilities are more intensive management of freeway access to reduce congestion, improved incident and special event management, and real-time travel information (see Burbank 2009, Appendix A). Research on advances in these areas is needed to inform managers about the potential of different strategies, to evaluate new strategies when they are tried, and to share information with others.

Materials, Maintenance, and Construction

Research is already under way worldwide on new forms of concrete with lower GHG emissions during cement production, and asphalt pavers are already adopting European warm-mix asphalt practices that require less energy to produce and deploy. New paving materials, of course, also have to meet performance and durability standards, so evaluating these new products will remain an important line of research. The benefits from a life-cycle maintenance and GHG emission reduction perspective of switching to illumination with light-emitting diodes should be investigated. Largely underinvestigated are practices that could substantially reduce energy requirements for maintenance, such as median and right-of-way plantings that require less energy for mowing. The energy required for construction and whether there are opportunities for major savings in this area are also largely underinvestigated.

Structure

The committee concurs with Burbank's recommendation that the fundamental research identified above should be organized along the National Science Foundation model. Under this approach, proposals would be solicited through Broad Agency Announcements (BAAs) within each topic area, the proposals would be evaluated by expert peers, only the best proposals would be funded, and the research results would be peer reviewed before publication. The illustrative topics described above are meant to identify promising areas of inquiry to inform future policy decisions. It is expected that the BAAs would identify such areas as in need of research and that the research undertaken would be based on the quality of the proposals submitted, as judged by peers in a merit review process.

CONCLUSIONS

The effects of expected population and economic growth on transportation demand and the importance of transportation in meeting social needs will make mitigation of GHG emissions and the saving of energy in the transportation sector extraordinarily challenging. Expected improvements in technologies and fuels could make reducing transportation energy consumption and GHG emissions by 2050 to the levels of 1990 or 2000 possible, although such a goal will be difficult to achieve. Reducing them another 60 to 80 percent, if required, may not be feasible with technology and fuels alone, hence the frequent calls for reducing future travel demand or shifting it to more fuel-efficient modes. Significant carbon taxes or a carbon cap-and-trade program resulting in elevated fuel prices will stimulate demand for new vehicles and fuels. These fuel prices can be set by policy without necessarily investing more tax dollars in research on travel behavior. However, if policy makers determine that significant reductions in future travel demand are necessary, the selection of the most effective and beneficial strategies will be critical, because reductions in travel by themselves can be harmful to economic and social welfare. Unfortunately, the knowledge base for advising policy makers in this area is weak. Basic research in the area of travel behavior has not been supported, and data for policy analysis have many gaps and flaws.

Investments in surface transportation mitigation research in two main areas are recommended in this chapter. The first would provide initial guidance to policy makers and practitioners and help shape the direction of the other recommended research areas. It would also develop information and guidance for policy makers and administrators about strategies that can be implemented on the basis of available information. Transportation policy decisions are made by the federal government, all 50 states, and tens of thousands of cities and counties, and land use decisions are typically guided at the metropolitan scale but enacted at the city and county scales. Thus, the audience for this research is broad and has diverse responsibilities. Under this program, guidance would be continually updated as new data are collected and research results are provided from the recommended fundamental research program, and outreach activities to state and local decision makers would be conducted. The second would guide the conduct of the fundamental research recommended earlier in the chapter, which would provide new information and insight for policy analysis and guidance.

As important as identifying topics for research is managing the research in a way that is most effective in asking the right questions and employing rigorous quality control measures. Asking the right questions requires that programs be shaped by stakeholders. Employing the most rigorous quality-control measures requires allocating funds to the best among competitively solicited proposals, with awards being based on merit and decisions being made by peers. Criteria for organizing and administering a research program that meets these standards are described in Chapter 5.

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Abbreviations

BTS	Bureau of Transportation Statistics
CBO	Congressional Budget Office
NRC	National Research Council
TRB	Transportation Research Board

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4

Adaptation Research and Development

The mitigation efforts described in the previous chapter are necessary in reducing transportation's future contributions to climate change and energy consumption. The greenhouse gases (GHGs) emitted by industrialization over the past century, however, will persist for decades because of the long-lived nature of some GHGs and will result in temperature rise and associated climate change regardless of future mitigation. Thus it is necessary to plan for adapting to climate change.

The report prepared by a National Research Council Committee, *Special Report 290: Potential Impacts of Climate Change on U.S. Transportation* (TRB 2008), identified the kinds of changes that are likely to occur and recommended actions that the transportation community and others should take to prepare. This chapter draws heavily on the findings and recommendations made in that report. The committee also commissioned a paper by McNeil (2009) to build on the recommendations of *Special Report 290* and develop a detailed framework for an adaptation research and development program. This chapter draws on McNeil's paper but does not follow it in all details.

This chapter first provides a brief summary of the main findings and recommendations of *Special Report 290,* with emphasis on those relating to research. It then outlines a program that responds to those findings and recommendations: it identifies research topics, estimates the cost of the research, and identifies criteria for a successful research program.

EXPECTED CLIMATE IMPACTS ON TRANSPORTATION INFRASTRUCTURE AND RESPONSES

Impacts and Consequences

Special Report 290 identifies five future climate changes relevant to transportation infrastructure and operations:

1. Increases in very hot days and heat waves,
2. Increases in Arctic temperatures,
3. Rising sea levels,
4. Increases in intense precipitation events, and
5. Increases in hurricane intensity.

The committee that prepared the report emphasized that, contrary to the general perception that climate change will result in gradual changes in temperature and sea level rise in coming decades, the key concerns for transportation are temporary, abrupt, and unanticipated extremes of temperature, precipitation, and storm intensity that could occur at any time and that will become more frequent.

The committee that prepared *Special Report 290* concluded that the greatest climate change impact on North American infrastructure will likely be flooding of coastal roads, railways, transit systems, and runways because of global rising sea levels coupled with storm surges, exacerbated in some locations by land subsidence. Roughly half of the U.S. population resides in coastal counties; hence, a substantial share of the nation's population and infrastructure is at risk. Among the challenges posed in responding to climate change are deep uncertainties about its impacts as well as about the effectiveness of various adaptations (Dewar and Wachs 2006).

For example, climate change will alter weather patterns so that historical records will no longer be reliable guides to 100- and 500-year floods. Such rare events are the basis of designing facilities to withstand maximum likely storms. They will become more frequent than history suggests, but climate scientists are unable to forecast where and when such changes will occur at the temporal and spatial scales that planners, designers, and operators of infrastructure require. The limited ability to predict the location and frequency of more intense storms will result in higher degrees of uncertainty with regard to severe outcomes than transportation engineers are accustomed to. Intelligently managing infrastructure in these circumstances will require new tools that incorporate rather than attempt to exclude uncertainty (Dewar and Wachs 2006).

Identified Adaptation Responses

Special Report 290 made the following recommendations that pertain to this chapter:

- Transportation officials at all levels of government and in the private sector should inventory potentially vulnerable critical assets.
- Transportation officials should incorporate climate change into their long-range plans for new facilities and maintenance.
- Transportation officials should rely on more probabilistic techniques to guide decisions that weigh the cost of upgrading or protecting assets against the risk and consequences of failure.
- Research programs should invest in developing monitoring technologies that can measure stresses and strains on key infrastructure assets and provide warning of pending failures.
- Transportation professional associations should develop procedures to identify and share best practices in managing assets.

The committee also laid out a decision framework for transportation professionals to use in addressing impacts of climate change on U.S. transportation infrastructure:

1. Assess how climate changes are likely to affect various regions of the country and modes of transportation.
2. Inventory transportation infrastructure essential for maintaining network performance in light of climate change projections to determine whether, when, and where the impacts could be consequential.
3. Analyze adaptation options to assess the trade-offs between making the infrastructure more robust and the costs involved. Consider monitoring as an option.
4. Determine investment priorities, taking into consideration the criticality of infrastructure components as well as opportunities for multiple benefits (e.g., congestion relief, removal of evacuation route bottlenecks).

5. Develop and implement a program of adaptation strategies for the near and long terms.
6. Periodically assess the effectiveness of adaptation strategies and repeat Steps 1 through 5.

R&D is needed to provide tools and guidance for carrying out each of the first five steps in this decision framework. A program to address these and other adaptation needs is developed in the next section.

R&D TO GUIDE ADAPTATION

McNeil (2009) identifies a number of research initiatives that should be conducted early in the program to serve as foundations for policy guidance to decision makers and practitioners as well as for subsequent R&D. These foundational topics derive from the research that needs to be done to assist transportation officials in carrying out the recommendations and decision framework in *Special Report 290*.

Foundational Research

Identification of Vulnerable Assets and Locations

The first step recommended in *Special Report 290* is for transportation officials to identify infrastructure potentially threatened by climate change. The task is more difficult than may be apparent because the severity of impact can be increased by a confluence of events. In the Gulf Coast region, for example, storm surges will be compounded by the land subsidence already occurring, increased wind speeds from more intense storms, and heavier precipitation. These interacting effects require careful and extensive analysis, as illustrated by the Global Change Research Program study of Gulf Coast infrastructure vulnerability (Savonis et al. 2008). The need to consider and portray the vulnerability of infrastructure in probabilistic terms adds to the complexity (Meyer 2006). Furthermore, every region will be affected in its own way. In Southern California, for example, the sea level may rise; in addition, the frequency of drought and dry winds may increase, which in turn could increase the frequency of brush fires and smoke hazards on freeways and subsequent mudslides in rainy seasons that can inundate and wash out roads.

The objective of this research would be to develop a process for identifying assets and locations that are vulnerable to climate change. Developing the process will necessarily involve climate change scientists, experts in risk assessment, and engineers. Once a methodology has been developed, it could be adapted to and replicated in other regions.

Identification of Opportunities for Adaptation of Specific Facilities

Once vulnerable assets have been identified, policy makers will need a range of options for responding, which entails the conduct of a comprehensive review of policy, engineering, and other options for addressing risk. The objective would be to develop a database of options for specific facilities and regions that transportation officials could draw on.

Understanding Changes in the Life Span of Facilities Caused by Climate Change

The expected life span of facilities can be changed by climate influences such as heat, drought, wind loading, and flooding. Understanding infrastructure life spans is a challenging problem even in the absence of the effects of climate change. Guidance may initially have to rely on judgment while this area of more basic research develops.

Understanding the Modes and Consequences of Failure

Better understanding of potential modes of failure and its consequences is key to informing the evaluation of options. Failure in this sense is not necessarily a catastrophic failure; it could be structural, functional, or economic. This research would summarize available understanding, both experiential and theoretical, to provide guidance on what transportation officials would need to prepare for.

Assessing the Risks, Costs, and Benefits of Adaptation

Once assets have been identified as vulnerable to climate change, possible effects on their future performance have been assessed, and options for responding to risk have been arrayed, policy makers need guidance on the costs and benefits of the various options. The objective of this research area would be to develop a framework for producing and refining estimates of costs and benefits. Such estimates may have to rely on judgment initially, but they should be refined with experience and research.

Models and Tools to Support Decision Making

McNeil defines this area as an essential component of her applied research agenda, but the committee views this research area as a cornerstone of adaptation planning and analysis. The necessity of managing uncertainty in many dimensions of decision analysis transforms this from an applied to a foundational topic for several reasons. The timing, location, and severity of climate change are uncertain. The costs and benefits of adaptation options may be definable with less uncertainty, but the estimates will not be precise. The costs of many measures to reduce the risk of failure—raising bridges; relocating highways, transit stations, or rail lines; adding berms and levees—could be high while the risks themselves will be uncertain and difficult to quantify. Furthermore, policy makers will have to weigh the cost of reducing risk against the opportunity cost of applying those resources elsewhere. Analysis tools appropriate for policy problems that encounter such fundamental uncertainty are being developed (Lempert et al. 2003; Dewar and Wachs 2006). Extension of these approaches to transportation adaptation will require fundamental rather than simply applied research.

Monitoring and Sensing

Another area that McNeil defines as applied is considered by the committee to be a cornerstone of adaptation. In many cases, monitoring condition and performance will probably turn out to be the smartest "no regrets" approach. Sensors for monitoring infrastructure condition and performance are already in use. Advances in technology allow sensors to report on water pressures, saturated soils, thermal and wind stresses, and scouring of bridge supports. As McNeil (2009) points out, however, the "challenge lies in how, where, and when to deploy the sensors and how to interpret the signals and then how to communicate the information provided by the sensors." To this challenge can be added the need to improve understanding of what to measure and how to maintain the sensor systems cost-effectively. Sensors are already in place to monitor scour of critical bridge foundations, but understanding of which phenomena to monitor can be improved, and reliable and more cost-effective sensors are needed (Hunt 2009).

Applied Research

McNeil (2009) identifies a number of applied research topics that follow, for the most part, categories of research typical in transportation civil engineering:

- Planning and environmental decision making,
- Design standards and practices,
- Construction,
- Maintenance,
- Operations,
- Renewal and rehabilitation,
- New infrastructure to support mitigation measures,
- Best practices,
- Long-range planning related to transportation and land use,
- The influencing of land use decisions, and
- The funding of adaptation.

These topic areas are described briefly by McNeil (2009) and are not repeated here. McNeil's suggestions for applied research in each of these topic areas, however, might be best considered as placeholders. As she emphasizes, expert and practitioner stakeholders need to be intimately involved in the development of a research agenda to ensure its relevance. If a research program for adapting transportation to climate change is funded, a necessary first step would be to develop a detailed research agenda in these areas through extensive stakeholder engagement. One area not specifically referenced by McNeil that should be incorporated into the applied R&D agenda is the principles of "green infrastructure" design (EPA 2008; Gill et al. 2007). Green infrastructure design, among other things, attempts to minimize urban water runoff through strategies to better capture or divert water from heavy rains into floodplains or catchment areas. Improving the permeability of pavements and wider use of grassy medians, for example, could be part of a larger strategy to minimize flooding.

Supporting Research

Supportive activities that McNeil (2009) foresees as part of an adaptation research program include the following:

- An information clearinghouse to facilitate exchange of relevant scientific information among researchers in different fields and disciplines and across levels of government;
- An ongoing dissemination activity to share the results of the research, which would include education and outreach to the public and decision makers;
- Proactive engagement of stakeholders in project scoping, research, evaluation, and dissemination;
- Coordination and analysis of cross-cutting issues; and
- Evaluation of ongoing and completed research to manage and direct the program.

The section of this chapter on research program design expands on the extensive role of stakeholders envisioned by McNeil.

RESEARCH SCHEDULE

McNeil's schedule begins with foundational research and supporting research activities, with most of the applied research gearing up after the second year and some even later. Most of the foundational research would be completed by the fifth year, but the more basic research on understanding facility life spans and the costs and benefits of adaptation would extend for the full 20-year period. The committee prefers a different schedule, with the greatest initial emphasis on the foundational research elements that build up to the tools and methods for evaluating vulnerabilities and for assisting in decision making.

RESEARCH PROGRAM DESIGN

To ensure the credibility of the research program and to maximize quality control, the conduct of the research should be open to all potential research organizations, research teams should be selected on the basis of merit as judged by peers, and completed research should be subject to peer review.

McNeil stresses throughout her paper the importance of involving stakeholders in development and execution of an adaptation research program:

> Stakeholder engagement—proactively engage stakeholders in project scoping, research, dissemination and communication to ensure that products meet the needs of the audience, ongoing research is not ignored, and unintended consequences are minimized (Natural Resources Canada 2004). In the words of the California White paper on climate change (Luers and Moser 2006) "collaborative and participatory research" should be encouraged. Stakeholder engagement also includes education of and outreach to the public and decision makers focusing on climate change science, potential impacts and the importance of action.

The stakeholder involvement that McNeil suggests for adaptation research is modeled on the processes used by the cooperative research programs managed by the Transportation Research Board and other applied research programs, such as those of the Association of American Railroads and the Electric Power Research Institute. In these programs, expert and practitioner stakeholders are engaged in suggesting research topics ("problem statements"), developing the problem statements into requests for proposals, providing merit review of submitted proposals, monitoring research as it is conducted, and evaluating research when it is completed. The availability of an expert staff to scope out and manage the contracting and project delivery process, open competition to find the best research teams, selection of proposals by expert peers, and peer review are important in ensuring quality control.

CONCLUSIONS

Climate change is already occurring, and GHGs persist in the atmosphere for long periods. For these reasons, adaptation has become a necessity. A research program based on the recommendations in *Special Report 290* is needed, with emphasis on development of decision tools incorporating probabilistic outcomes and options to help state and local officials make prudent decisions about adapting infrastructure to climate change. Because of the diversity of officials responsible for transportation infrastructure and the need to ensure the relevance of the research to varied perspectives, stakeholder involvement is critical in developing an effective applied research agenda and carrying out an adaptation research program. Stakeholder involvement at all levels, open competition, merit review, and peer review are important criteria for the success of these research activities.

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Abbreviations

EPA	Environmental Protection Agency
TRB	Transportation Research Board

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5

Estimated Research Program Cost and Criteria for Effective Management

As demonstrated in previous chapters, mitigation of greenhouse gases (GHGs) emitted and conservation of energy used in transportation will most likely have to involve more than vehicles and fuels if society commits to 60 to 80 percent reductions in transportation GHG emissions by 2050. Legislation introduced in both the House and the Senate in 2009 implies substantial reductions in transportation GHG emissions. House Energy and Commerce Committee Chairman Waxman's and Congressman Markey's proposed bill (H.R. 2454) passed the House of Representatives in June 2009. It would establish a carbon cap-and-trade program, encourage introduction of electric vehicles, require Environmental Protection Agency (EPA) regulation of GHG emissions from heavy-duty transportation vehicles, and require states and metropolitan planning organizations (MPOs) to follow EPA's guidance in setting targets and planning for reductions in transportation GHG emissions. The bill establishes a goal of reducing GHG emissions by 83 percent from overall 2005 levels by 2050. The legislation does not set transportation-specific requirements, but it requires EPA to set transportation GHG emission reduction targets that states and MPOs should meet. In addition, it outlines a variety of transportation mitigation efforts that states and MPOs could analyze and that regions could implement in pursuing their own GHG emission reduction goals. Senate Environment and Public Works Chairman Boxer and Senator Kerry unveiled a bill in October 2009 that has similar provisions.

The surface transportation reauthorization bill introduced in the House of Representatives by Chairman Oberstar of the Transportation and Infrastructure Committee has planning and target-setting goals that mirror those of Waxman–Markey. The surface transportation reauthorization bill introduced by Chairman Rockefeller of the Senate Commerce, Transportation, and Science Committee and Senator Lautenberg (S. 1036) calls for annual reductions in per capita vehicle miles of travel, a 40 percent reduction in transportation GHG emissions by 2030, increased use of public transportation, and an increase of 10 percent in the proportion of freight moved on nonhighway modes. In addition, various states have adopted plans to reduce future vehicle miles of travel.

As described in Chapter 3, the effectiveness, costs, feasibility, and acceptability of most strategies to mitigate transportation GHG emissions have not been established. Because travel and economic growth are tightly linked, implementing the most cost-effective mitigation policies would help minimize reductions in future prosperity. The federal government, states, MPOs, cities, and counties will all set transportation policies. Thus, the audience for transportation policy guidance is large and diffuse. The research areas identified in Chapter 3 would provide guidance for policy decisions at all levels of government.

The climate will continue to change for decades because of GHGs already in the atmosphere. Therefore, well-designed adaptation to climate change needs to begin. The infrastructure capital costs of raising or replacing bridges, roads, and guideways vulnerable to flooding, for example, are high, and climate impacts at the spatial and temporal scales that transportation officials require cannot be predicted. The recommendations in Chapter 4 provide a framework for conducting research that can guide decisions about effective transportation adaptation strategies.

RESEARCH PROGRAM COST

The committee believes that the urgency of responding to energy and climate change goals requires initiation of the research identified in previous chapters in short order. The technical information to inform policy decisions and practice could be significantly enhanced over the course of the next surface transportation authorization cycle, although at least two such cycles would likely be required to complete the envisioned fundamental and applied research. Some of the recommended research will probably need to continue on a regular basis, much as safety, operations, and other subjects are ongoing topics of research.

The committee was charged with developing approximate costs of the research programs it recommends. As a first step in developing these estimates, the committee asked each of the commissioned paper authors to develop a "bottoms up" estimate derived from the research topics the authors' recommended and their judgment as experienced researchers and research managers.[1] The committee relied on these estimates, in part, and applied its judgment, as explained below.

As indicated in Chapters 3 and 4, the topics suggested for research are examples of areas where facts are unknown or in dispute or the committee judges that genuine progress in understanding can be made. A rigorous cost estimate would have required more detailed research road maps than the committee had the time or resources to develop. There is a compelling need to initiate research and analysis to provide the best possible guidance for policy makers based on existing literature, available data, and professional judgment. The committee believes that this cost can be reasonably approximated on the basis of previous experience.

Estimates of the cost of the fundamental mitigation research and the applied adaptation research are necessarily more speculative. The committee believes that scholars and experts will need to be convened to provide guidance on the most promising areas. Nevertheless, transportation research programs are typically authorized for periods of 5 or 6 years, and progress in addressing climate change and energy conservation needs to commence as soon as possible. Therefore, the committee has expressed its judgment with regard to the appropriate scale at which to start these activities in the upcoming authorization. The experience that will be gained will help inform subsequent authorizations.

Mitigation

In the mitigation area, a program with two main components is suggested. The first, policy guidance and outreach, would initially provide policy makers with technical guidance for implementing mitigation policies based on available research. It would also provide practitioners with guidance for analyzing and implementing mitigation strategies and

[1] See the detailed estimates prepared by Burbank (2009), pp. 16–32 and Table 2; estimates prepared by McNeil (2009), Table 7; and those prepared by Whitty and Svadlenak (2009), pp. 117–119.

improving technical tools. These tools would initially be based on the best available information and would be improved as new information emerges from the fundamental research program described below.

The committee has drawn on Burbank's (2009) discussion of needed areas of research and her estimates of program costs, but it suggests a considerably scaled-back approach at the outset. She identifies a large-scale program of activity and technical assistance that would exceed $50 million per year. The committee suggests starting with a smaller set of the most critical policy research activities described in Chapter 3 in the section on policy guidance and outreach. The committee estimates that the five applied policy research topics in that section could all be completed within a total cost of $5 million. Outreach to policy makers at the state, regional, and local levels could be conducted for $1 million annually once new guidance had been developed; hence it would not gear up until the third year or so. Updating technical tools for practitioners would require at least $9 million annually, for a total of $53 million over 6 years.[2] Thus, as a starting point, these activities are judged to cost about $60 million, for an average cost of about $10 million during the upcoming authorization cycle. Should this area be funded, a more refined estimate based on experience and need should be developed before subsequent authorizations.

A fundamental research program is recommended that would be modeled on the way basic research is organized and conducted by the National Science Foundation (NSF). Burbank recommends a program of $50 million annually, but the committee believes that the existing research institutions would not be able to absorb this much funding productively at the outset. Instead, the committee recommends that funding begin at $10 million in the first year, grow by $5 million annually for the second through the fourth years, and then level off at $30 million annually in subsequent years. The committee suggests that the first couple of years of this research area be devoted to commissioning critical

[2] The committee recognizes that this is a conservative estimate for the cost of improving technical tools relied on by practitioners. For example, the committee that prepared *Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction* (TRB 2007) estimated that the federal share of investment needed to improve travel forecasting models and get them into practice would be on the order of $20 million annually, and this is only one of the tools where improvements would be needed by practitioners.

surveys of the literature and convening panels of scholars and experts. The most promising areas based on priority topics would be identified, drawing on those identified in Chapter 3 that are most amenable to advancing through expanded investment. The committee believes that $30 million per year is an appropriate scale of investment for fundamental mitigation research at the outset, but it recognizes that this level of investment needs to be reevaluated toward the end of the first authorization to determine the appropriate level in subsequent years.

Adaptation

An adaptation research program is needed that would (*a*) summarize and build on existing knowledge to guide decision making, particularly in the area of developing decision tools for policy makers that incorporate probabilistic approaches to risk management, and (*b*) conduct applied research in the traditional areas of transportation programs (construction, operations, maintenance) and for the revision of standards. The first priority for this research should be to develop guides to decision making based on existing research. Decisions about how to protect, move, or extend the life of existing infrastructure at risk from climate change–related damage could be both expensive and controversial. The risks involve uncertainties beyond those normally encountered in transportation infrastructure decisions. Tools to guide decision making that incorporate these risks and uncertainties are needed. In parallel, more fundamental research should be undertaken to improve these tools. Technical guidance at the operational level is also needed. Stakeholders involved in building, operating, and maintaining transportation infrastructure need to be involved in the development of a detailed applied research agenda, which would occur during the upcoming authorization cycle. The identified research would be conducted during the following cycle.

The foundational research, as rearranged in accordance with the suggestions of Chapter 4, would cost roughly $31 million over the first 6 years, according to McNeil's (2009) estimates of the cost of each research topic (see Table 7 of her paper). During the initial 6-year period, expert and practitioner stakeholders could also flesh out the recommended applied research topics and develop a research road map with detailed cost estimates and schedules and a request that the program be funded in a second authorization. Development of detailed applied adaptation research plans and individual project scopes would cost roughly $3 million. The applied research program could also begin work on revision of design standards and identification of best practices, with a combined cost of about $13 million. Over the first 6 years, these activities, along with supporting research activities[3] and administration, would total roughly $60 million, or about $10 million per year. In the second 6-year period, emphasis would be placed on the applied research topics based on a detailed program plan developed in the interim by experts and stakeholders and completion of the foundational research. The actual cost of these activities will depend on the development of the research program plan.

Summary

The committee believes that an investment of $40 million to $45 million annually over an initial 6-year period is appropriate in starting a research program of this nature (Table 5-1). During this authorization period the program will be able to provide initial guidance to policy makers and begin conducting applied and fundamental research. The guidance will be updated as research projects are completed, but such research will need to continue beyond the first authorization period. The cost of the program for a subsequent authorization will depend on the experience gained in the first round and the detailed research program plans to be developed.

The committee believes that the research should be organized as a single program and given high priority. Because of the importance and nature of the research, University Transportation Centers should also be encouraged to fund transportation energy conservation and climate change–related research. The recommended program may appear substantial but would represent only about 9 percent of all the surface transportation research programs of the U.S. Department of Transportation (USDOT). The decisions to be made with the information developed will

[3] Supporting research activities are defined to include the information clearinghouse and dissemination activities recommended by McNeil (2009) as well as the cost of travel for stakeholder involvement in development and review of requests for proposals and meetings to evaluate final reports.

TABLE 5-1 Estimated Cost of Research Programs ($ millions)

Program	6-Year Total	Annual Average
Mitigation[a]		
Guidance and outreach	60.0	10
Fundamental research	130.0	21.7
Subtotal	190.0	31.7
Adaptation		
Research	60.0	10
Total	250.0	41.7

[a]The mitigation research cost estimate does not include the cost of collecting travel data for research and improved modeling practice purposes. The cost of such data collection could be $300 million annually (see Appendix B). The estimates also do not include the cost of a mileage charging demonstration program (see Appendix A).

involve costs and benefits of much greater magnitude than the cost of the research.

CRITERIA FOR RESEARCH PROGRAM MANAGEMENT

Three main interrelated themes about research organization emerged from the papers commissioned for this study and the committee's deliberations:

1. *Broad and diverse audience:* Transportation system governance is decentralized, and it plays an indispensable role in the daily lives of all Americans. In addition, transportation has a significant impact on national petroleum imports and energy consumption. For these reasons, the audience for the necessary policy and implementation guidance spans all levels of government, private industry, and the public.
2. *Need for stakeholder involvement:* Stakeholder perspectives and interests are diverse. Individuals at different levels of government, in industry, and in nongovernmental organizations have different kinds of responsibilities, and some of the measures to be studied are potentially controversial. Stakeholder involvement in the research programs needs to be broad and deep to ensure relevance to this diversity of interests. Relevance can be encouraged through stakeholder involvement in a research program and virtually guaranteed through stakeholder

governance of a program. (Involvement implies an advisory role, whereas governance implies a decision-making role.)

3. *Need for credible, objective research:* Because of the controversial nature of some of the topics and the differences in perspective of some of the stakeholders, the research program needs to be as credible and objective as possible. Objectivity can be achieved by following the highest standards of scientific quality control: scoping of requests for proposals by qualified research managers, open solicitation and competition for funding, merit review of proposals by peers, and peer review of completed research.

The above themes can be reduced to two essential criteria for organizing and managing the research: extensive stakeholder involvement and processes to ensure scientific rigor. To these criteria could be added an important aspect of research management: an ability to shift direction, reorder priorities, and reprogram funds as new information is gained. Finally, the programs must be accountable to the elected officials who provide the funds and the stakeholders who need the insights from research to make decisions.

Stakeholder Involvement

Stakeholder involvement may vary across the different program areas, as described below, but in each case it needs to be extensive. Expert and practitioner stakeholders should participate in prioritizing and selecting areas of emphasis, in merit review of proposals, and in evaluating projects as they near completion.

Mitigation Policy Guidance and Outreach

Critical in this area is the recognition that transportation decisions are made by policy makers at all levels of government—national, state, regional, and local—as well as in the private sector, and their views about priorities should be reflected in the research undertaken.

Fundamental Mitigation Research

Research to advance knowledge in mitigation would be best organized on the NSF model, in which requests for proposals are shaped by subject matter experts, panels of experts serve as merit reviewers, proposals are openly solicited, and only the most qualified proposals receive funding. The panels would be mostly composed of scholars, but inclusion of some practitioners would be vital in ensuring that the research is relevant to people who must implement transportation programs.

Adaptation

In the foundational research category, a small number of research projects would develop methodologies that would be helpful in providing policy makers and practitioners with advice on how to inventory vulnerable assets and in making informed decisions about adapting infrastructure. Stakeholders should be engaged in selecting areas of emphasis, and they should participate in merit review panels along with subject matter experts and in peer review. Included in this area are fundamental research projects on adaptation that could be organized along the lines of the fundamental mitigation research described above.

The planning for the applied adaptation research program should be based on extensive interaction with practitioners and experts in the relevant fields, who would help develop a detailed research plan, participate in merit review, oversee research projects as they are conducted, and help evaluate the research as it nears completion.

Scientific Rigor

The best practice in research management is to have open solicitations for the conduct of research, to rely on merit review by peers for the selection of the best proposals, and to involve experts—and, in the applied areas, practitioners—in the evaluation of the research.

Management Capability, Flexibility, and Focus

By its nature, research, whether fundamental or applied, is a process of discovery. Often the most carefully developed plans will have to be adjusted as knowledge is obtained. Thus, research managers need the capability and flexibility to shift direction. Such decisions should not be undertaken lightly and should be predicated on extensive dialogue with expert and practitioner stakeholders, but the capability is essential. Highly detailed legislative designations in the authorization of the programs could limit this flexibility.

The committee also considered whether the various research programs could be folded into the ongoing activities of the USDOT modal administrations. It concluded that such a decision risks fragmentation and loss of focus of the activity.

Accountability

If the programs are funded, they should be designed to be accountable to Congress and to stakeholders. The engagement of stakeholders in decisions to be made about priorities and in evaluation of completed projects will satisfy their accountability needs. To ensure accountability to Congress, evaluations at the program level should be conducted by independent third parties capable of analyzing research activities of this nature. The peer review should be conducted at least every other year, and reports should be provided by the evaluators directly to Congress.

RELATED ISSUES

Mileage Charging

Interest in mileage charging as an option to replace or supplement the gas tax in funding surface transportation infrastructure and operations is growing. Implementation of a mileage charging system would provide a pricing mechanism for road use on the entire network; this system could become an element of a mitigation strategy, whereby vehicles with low or poor fuel economy could be charged a premium over a base charge for road use. As described in Appendix A, several recent reports by congressional commissions and others have recommended a broad research and demonstration program to test the feasibility of this concept.

An R&D program is needed that would inform the design and operation of a series of mileage charging demonstration programs. The research would give policy makers information about how issues such as privacy, efficiency, public acceptance, and equity affect the design and implementation of a mileage charging program. It would also recommend strategies for addressing public concerns. Extensive demonstrations would be required to test alternative concepts and engage key stakeholders and the public in determining the acceptability of such an approach.

Data

The transportation field suffers from inadequate data with regard to system performance and travel behavior. Rough indicators are available, particularly at the national level, but they are less reliable at the state and local levels at the detail required for good decisions. If legislation that requires reductions in per capita travel at the national, state, and regional levels is enacted, better baseline measures of passenger and freight travel will become necessary. Most data systems designed to provide national statistics are only representative at the national level and sometimes at the state level. For regions to monitor passenger and freight travel reliably, larger and more frequent samples would be necessary. Furthermore, if regions are to use transportation and land use strategies to reduce GHG emissions and energy consumption, the modeling needed to develop reasonable forecasts of travel and land use patterns and how they might change under various policy regimes will require much more extensive data than are currently collected. Because the United States is a large and diverse nation with more than 300 million residents, 250 million vehicles, and thousands of jurisdictions, data collection will entail considerable costs (see Appendix B). Such data serve many transportation purposes; the need to address climate change and energy conservation may serve as the impetus to make the appropriate level of investment in data collection.

SUMMARY

Transportation mitigation and adaptation research programs would cost $40 million to $45 million annually for the upcoming authorization. The investment would be worthwhile given the risks posed by climate change and energy dependence and the link between transportation, the economy, and the lifestyles of hundreds of millions of people. Many mitigation strategies are possible, but not all are necessarily politically acceptable, likely to be effective, or good public policy. Because of the dearth of data and research in this area, policy makers do not have good information about which policies would be most cost-effective, feasible, and acceptable. The recommended research programs would begin to fill this gap but would not be completed within a single authorization period. The committee recommends that this research be given high priority and hopes that new funds can be found to fund this research as a single, unified program. It believes that University Transportation Centers should also be funding transportation energy and climate change–related research. The required investment for subsequent authorizations will depend on the experience gained and on development of more detailed research plans for a second authorization period.

The organization of the research is as important as the topics and the funding level. The audience for the research is broad and diverse, as are the entities that would have to implement the results. Thus, extensive stakeholder involvement in the research program is critical to its success. Furthermore, because the topics are important and even controversial, the research should be conducted at the highest standards of scientific inquiry. The management of the research program should be capable of shifting direction as knowledge is obtained and should have the flexibility to do so. It should be accountable to Congress and stakeholders.

Mileage charging has emerged as a possible supplement to or replacement for the fuel taxes that are the principal sources of revenue for highway and transit programs. Such a program could become a key element of a mitigation strategy by allowing for additional fees on fuel-inefficient vehicles. Prominent groups, including two commissions chartered by Congress, have recently recommended an accelerated demonstration program to test various technologies and engage policy makers and the public in determining whether such a system would be technically feasible and acceptable. (See Appendix A.)

Collection of the data necessary to carry out the kinds of initiatives envisioned in proposed legislation would cost considerably more than the mitigation and adaptation research identified above (see Appendix B). Data collection would help governments in carrying out the planning and analysis requirements in draft legislation and would make mitigation research much more successful. The committee recommends that Congress authorize funding for the collection of data adequate to meet the needs of federal, state, and local governments as they analyze options and plan mitigation strategies.

The nation faces a challenge as important and complex as any national priority in achieving transportation GHG emission reduction and energy consumption goals through significant changes in travel demand. Transportation is deeply woven into the fabric of the economy and the daily lifestyles of Americans. Whole metropolitan areas, residential neighborhoods housing more than 100 million people, and mobility preferences have been shaped by decades of history and transportation, energy, and housing policies. The Interstates and other intercity highways have allowed industrial and commercial development to occur in areas without the advantages of a natural harbor or proximity to a rail hub.

Because transportation is such a large contributor to GHG emissions and energy dependence, significant changes in federal, state, and regional transportation policy may well become necessary. Such changes will surely require difficult choices among values and desired outcomes. Adapting the transportation system to climate change will be necessary, and the high costs and levels of uncertainty imply difficult choices for policy makers. Furthermore, mitigating transportation's impacts and adapting to a changing climate will be ongoing challenges for decades to come. The system built over the past century is too large, its effects too pervasive, and its economic significance too high for it to change quickly or easily.

Investment in the research and data collection recommended in this report will inform the federal, state, and regional policy makers of today and tomorrow who will be confronted with making such decisions—decisions that will affect not only the feasibility and cost of achieving climate and energy goals but also the future prosperity of the nation and the quality of life of every citizen. These decisions will have a better chance of leading to desired outcomes if they are based on the best knowledge science can provide. The cost of the recommended research investment pales in comparison with the importance of informing the best possible choices for the future.

REFERENCES

Abbreviation

TRB Transportation Research Board

Burbank, C. J. 2009. *Greenhouse Gas (GHG) and Energy Mitigation for the Transportation Sector: Recommended Research and Evaluation Program.* Transportation Research Board of the National Academies, Washington, D.C.

McNeil, S. 2009. *Adaptation Research Programs and Funding.* Transportation Research Board of the National Academies, Washington, D.C.

TRB. 2007. *Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction.* National Academies, Washington, D.C.

Whitty, J. M., and J. R. Svadlenak. 2009. *Discerning the Pathway to Implementation of a National Mileage-Based Charging System.* Transportation Research Board of the National Academies, Washington, D.C.

APPENDIX A

Pricing Road Use for Mitigation and Revenue

Interest in the use of road pricing as a central element of a climate change and energy conservation mitigation strategy is growing at the same time that state departments of transportation are seriously considering replacing or supplementing fuel taxes with charges for distance traveled. (As described below, fuel taxes are the principal source of revenues to pay for highway and transit systems.) For any road pricing policy to be implemented, an efficient charging mechanism is needed. Road pricing can be fairly readily done on existing corridors by using smart card technologies (e.g., E-ZPass), which are heavily relied on by toll roads throughout the northeastern states. Pricing road use beyond specific corridors, however, requires additional development and testing.

Mileage charging concepts in development that are designed to raise revenues could be readily adjusted to incorporate energy conservation and environmental goals. Two commissions created by Congress in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users to address anticipated revenue shortfalls to the Highway Trust Fund endorsed the concept. The National Surface Transportation Infrastructure Financing Commission (2009, 7) endorsed an aggressive R&D program to test different mileage charging concepts to serve both environmental and revenue goals. The National Surface Transportation Policy and Revenue Study Commission (2008, 52–54) also endorsed the concept of mileage charging and recommended a follow-up study to evaluate technical feasibility and to address privacy concerns.

The first section of this appendix provides an overview of the reasons why mileage charging has emerged both as a promising concept for raising revenue to fund surface transportation infrastructure and as a central element of a mitigation program. The second section outlines the main unanswered policy and technical questions about mileage charging mechanisms that an R&D program could address. The final section outlines the key elements of such an R&D program, what it might cost, and management principles that would produce the most effective results.

BACKGROUND

Fuel taxes (gasoline and diesel) provide about two-thirds of the total user fees and about half of all the revenue collected by all levels of government and used to fund highway and transit infrastructure (TRB 2006). Thus, fuel taxes are central to the more than $160 billion invested annually by government agencies in roads and transit. The long-term viability of fuel taxes as a principal source of funding is threatened by political resistance to raising these taxes periodically to adjust for inflation and increased fuel efficiency of the motor vehicle fleet, which is causing less revenue to be collected per vehicle mile traveled. Inflation alone has eroded the buying power of federal fuel tax revenues by 33 percent since the federal gasoline tax was last increased in 1993 (National Surface Transportation Infrastructure Financing Commission 2009, 2). Even as buying power has eroded since 1993, national vehicle miles of travel (VMT) have increased 27 percent.

The committee that prepared *The Fuel Tax and Alternatives for Transportation Funding* (TRB 2006) recognized the threats to the fuel tax as a revenue-raising approach but concluded that fuel taxes could continue to be an important source of funding for transportation programs for another 15 years; it also concluded that "travelers and the public would benefit greatly from a transition to a fee structure that more directly charged vehicle operators for their actual use of roads" (TRB 2006, 3). The committee concluded that mileage charging appeared to be "the most promising technique for directly assessing road users for the costs of individual trips."

In federal surface transportation reauthorization legislation of 2005, Congress created the National Surface Transportation Infrastructure Financing Commission to provide guidance on the future of the motor fuels tax, among other things. The 2009 commission report concludes that because of the backlog in infrastructure rehabilitation and expansion needs and the eroding buying power of motor fuel tax revenues, the nation faces a genuine crisis (National Surface Transportation Infrastructure Financing Commission 2009, 2). The commission concludes that the nation is underinvesting in infrastructure and underpricing road use. It recommends that the nation

> commence the transition to a new, more comprehensive user charge system as soon as possible and commit to deploying a comprehensive system by 2020. Because of the complexity inherent in transitioning to a new revenue system and the urgency of the need, the Commission recommends that Congress embark immediately on an aggressive research, development, and demonstration (RD&D) program. (National Surface Transportation Infrastructure Financing Commission 2009, 9)

At the same time that the nation is grappling with how to fund infrastructure, it is beginning to come to grips with how to mitigate transportation's role in energy dependence and greenhouse gas (GHG) emissions. As described in Chapter 3, pricing users directly for road use is likely to be central to any successful mitigation strategy. In the past, proposals to charge for road use were infeasible because of the high administrative cost of establishing tollbooths and the user delays they cause. Advances in electronics and telecommunications technology, however, have made it possible to charge users efficiently, as millions of daily users of E-ZPass toll tags can attest. Still open to question is how to charge users for the use of all roads in a way that is politically acceptable (protects privacy), that is affordable, and that best incorporates policy goals to mitigate energy demand and GHG emissions.

QUESTIONS TO BE RESOLVED

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The Transportation Research Board (TRB) committee that recommended mileage charging concluded that conversion to mileage charging would require a sustained national effort (TRB 2006, 191–192). Policy and technical issues to be resolved include determination of goals, authorities for setting fees and controlling revenue, and how to best include the private sector. The following were among the most challenging issues identified:

- Gaining public acceptance of a new and unfamiliar system that could be perceived as a threat to privacy, be perceived as charging some users unfairly, and result in substantially higher charges for some users;
- Transitioning from a simple system of collecting fuel taxes from a few distributors to charging more than 100 million daily users, which would require equipping some 250 million vehicles with new technologies over an extended period of time; and
- Setting appropriate prices for road use for a system that has never been priced in such a way.

The committee recommended that the federal government take the lead in funding an R&D program that would involve the states. It recommended large-scale system demonstrations that would build on the mileage charging pilot programs completed and under way and learn from implementation of the truck mileage charging system in place in Germany. The objectives would be to evaluate reliability, flexibility, cost, security, and enforceability of various designs and to gain information about institutional requirements for administering such systems, user acceptance, and costs.

Pilot studies would be needed that simulate the important aspects of systems as realistically as possible, including setting rates, billing and collecting fees, enforcement, and coping with malfunctions. Research would also be undertaken on how fees should be set and a program administered.

Financing Commission

The Financing Commission (National Surface Transportation Infrastructure Financing Commission 2009, 218–219) identified the following list of key issues and concerns about mileage charging to be resolved through R&D:

- Protection of privacy;
- Impact on rural drivers who lack options to driving;
- Optional methods related to method and point of collection;
- Provision for multiple means of payment;
- Administrative costs;

- Whether to transition all vehicles at once or through a staggered schedule;
- Avoidance of the requirement to pay both a mileage charge and fuel taxes;
- Potential for introducing mileage charging as an optional payment over fuel taxes;
- Whether and how to charge different vehicles (cars and trucks) different rates; and
- How to provide the positional accuracy necessary to support federal, state, local, and private charges for specific facilities.

The commission also recommended research on closely related policy topics, particularly on "the true transportation cost impacts of various classes of vehicles, including the costs of environmental impacts, as well as the behavioral response to cost (i.e. price elasticity) so that Congress can decide to what extent the future system should take these full costs into account and facilitate the transition to pricing strategies" (National Surface Transportation Infrastructure Financing Commission 2009, 219).

Both the TRB committee that prepared its 2006 report and the Financing Commission recognized that many technical issues that would have to be resolved through research and demonstration projects are embedded in these questions.

Policy and Revenue Study Commission

The National Surface Transportation Policy and Revenue Study Commission endorsed the general concept of mileage charging but pointed out some important issues that would need to be studied and resolved. The commission recommended a two-phase effort that would begin with a study to determine technical feasibility and address privacy concerns, potential evasion, and the ability to adjust fees to account for wear and tear on highways caused by different classes of vehicle (National Surface Transportation Policy and Revenue Study Commission 2008, 52). If the first-phase study concluded that mileage charging was feasible, a second phase would

> conduct several large-scale pilot programs to test alternative mechanisms for levying a VMT fee. These pilot programs should include both passenger and freight vehicles and should evaluate the full range of potential issues that

> might arise in the implementation of a VMT fee. The study should also assess necessary standards that must be set, the roles of public and private sector organizations in implementing the tax, transitional techniques such as incentives for rental and leased fleets, and other key elements of a transition strategy. Results should be mandated within 3 years. If questions still remain about the feasibility of a VMT fee, the Phase II study should develop transition strategies for implementing other recommended alternatives. (National Surface Transportation Policy and Revenue Study Commission 2008, 53)

Whitty and Svadlenak

To assist the committee in developing an R&D proposal in this area, the committee commissioned a paper by James Whitty and John Svadlenak of the Oregon Department of Transportation (Whitty and Svadlenak 2009). These authors were centrally involved in a 6-year, large-scale pilot program of mileage charging in Oregon that was completed in 2007. The authors were asked to provide a detailed list of the topics that need to be better understood through research, development, and demonstration programs. A summary of key research topics is provided below; more detail can be found in their paper.

System Governance

Under this heading are fundamental questions about who should design and implement a system and whether it should be federal, be allowed to develop on a state-by-state basis, or be designed at the outset as a federal system that states and local jurisdictions could opt into or out of. Implicit in any design are significant questions about how revenues would be generated and allocated and the nature of the rates to be applied (flat rate per mile, an environmental charge to reflect vehicle fuel efficiency, and whether to include congestion or time-of-day charges). Any system combining federal, state, and local charging systems adds to the complexity of governance; how these relationships should be sorted out is an important topic for the proposed research.

Transition Strategy

Most system concepts for full-scale mileage charging envision an onboard device that would measure VMT or allow VMT to be estimated, which implies an extended period over which a program would be phased in.

If such devices had to be built into new vehicles (to avoid or minimize tampering), it would take more than 15 years to turn over the majority of the personal vehicle fleet once a decision is made to introduce new technology. Moreover, the technology to be required is far from being defined. Thus, it could take two decades or more to transition fully to a system that is based on built-in onboard devices.

To address the lengthy transition problem, Whitty and Svadlenak propose one interim system based on electronic tags that can be added to vehicles, perhaps on license plates, and Donath et al. (2009) have proposed another design based on relatively simple add-on technology that could estimate VMT without requiring the Global Positioning System (GPS).[1] (Although a GPS receiver by itself does not compromise privacy since it does not send a return signal, it is widely perceived by the public to allow for tracking of individual movements and therefore to be a threat to privacy.) Clearly, some sort of interim system will need to be designed, tested, and administered while the vehicle fleet is being outfitted with onboard technologies capable of more sophisticated pricing alternatives. [Note that Donath et al. (2009) believe that their interim system could be adapted to allow environmental charges to be added on the basis of vehicle characteristics. They also believe that simple congestion pricing schemes could be added to the mileage charge unless they require information about traveling on specific routes. Travel on specific routes or classes of roads may require GPS.] A recent report (Sorensen et al. 2009) outlines technology and implementation options for moving to an interim system of mileage charging as soon as 2015.

Technology and Subsystems

Whitty and Svadlenak urge that system design be driven by policy choices rather than by the features of available technologies, but they recognize that there are many technology options that need to be explored with

[1] Whitty and Svadlenak suggest a model whereby an electronic tag embedded in the license plate would be read at the gas pump. The tag would allow a computer at the pump to estimate VMT on the basis of the average fuel economy of that vehicle and fuel purchased; the fuel tax paid could be deducted on the basis of the mileage charge assessed. Donath et al. (2009) have proposed a system based on a relatively simple device that could be plugged into an existing vehicle port that could calculate VMT on the basis of vehicle speed and elapsed time. Estimated VMT would be reported with wireless technology. No GPS is required in these proposed systems.

regard to cost, reliability, ability to audit, and privacy protection. (Very different systems with different technologies could be used for personal vehicles as opposed to commercial trucks because of the differences in privacy concerns and the higher degree of regulation that applies to commercial transportation.) Also important to understand are which technologies are available "off the shelf" and which would require further development, such as the devices that would be needed on board vehicles that would register distances traveled (and possibly the route and time of travel) and communicate this information to a billing system.

The following are other technology topics to be investigated:

- Whether there are technologies other than GPS, such as the concept proposed by Donath et al. (2009), that could recognize jurisdictional boundaries.
- Whether GPS, odometers, or some other technique should be relied on to register mileage. (In tests in Oregon's pilot project, GPS was more accurate than odometers, which can vary with tire pressure, but GPS may not end up as a design element for the privacy reasons cited above.)
- Whether and how onboard devices for registering distance traveled can be designed to be tamper-proof or at least highly resistant to tampering, and whether a retrofit of tamper-resistant technologies could be added to existing vehicles at an affordable cost. (If inexpensive tamper-resistant devices could be added to existing vehicles, a mileage charging system could be implemented more readily.)
- How the vehicle and the billing system can communicate most efficiently, cost-effectively, and securely (e.g., cellular, wireless, smart card, shortwave radio frequency).
- Possible integration with the technologies being developed jointly by the U.S. Department of Transportation (USDOT) and the automobile industry under the vehicle–infrastructure integration (VII) initiative.

System Design

Many system designs are possible, and they should be determined on the basis of policy objectives. Systems for commercial vehicles could follow the model of the proven system in place for the German Autobahn, although Donath et al. (2009) believe that their proposal could be considerably more cost-effective. Systems for personal vehicles could follow the model to be tested in the Netherlands, in which vehicles communicate directly to a central billing system. Alternatively, a personal vehicle charging system could follow the "pay at the pump" model developed and tested in Oregon or the system proposed by Donath et al. (2009). In the Oregon system, which was designed to accommodate a lengthy phase-in period, vehicles could be charged at the pump while they were refueling (and the fuel taxes deducted at payment) or, if they were not outfitted with onboard technologies, could simply pay the fuel tax. Donath et al. suggest that their interim system could also employ this feature by using different technologies and a less cumbersome billing system (by relying on credit cards). The relative net benefits of these models should be compared on the basis of the criteria a system would be expected to meet.

Components of any of these systems require further evaluation, such as

- The optimal location of information transfer between vehicles and the central billing system (roadside, gas pump, commercial stations);
- How environmental or congestion prices could be layered on top of a flat-rate mileage fee;
- How to charge hybrid and electric vehicles, motorcycles, and vehicles pulling trailers; and
- How to integrate mileage charging with toll road charging systems to avoid overcharging.

Capital and Operating Costs

The current fuel tax system has a considerable advantage over alternatives for collecting user fees because it is a relatively simple and inexpensive program to design and administer. The charges are assessed to a few fuel suppliers and evasion is difficult. The cost of administering Oregon's system is roughly $1 million annually (Whitty and Svadlenak 2009); this suggests that the administrative cost nationwide of administering the current fuel tax collection system is in the neighborhood of $50 million to $100 million annually, which is far less than 1 percent of fuel tax revenues. Administration of road mileage charging systems would be much more costly. If onboard devices cost as much as $50 for a design based on cellular communication with a central billing system, the cost of equipping the entire fleet of 250 million vehicles would be at least $25 billion, to say nothing of the cost of developing and administering a billing system, managing and distributing revenues, enforcement, auditing, and other operational costs (Sorensen et al. 2009).

A simpler interim system that is based on installing an electronic vehicle identifier (perhaps on license plates), tag readers at gasoline pumps, and connections between the readers and a centralized billing system was proposed by Whitty and Svadlenak. Such a system might be only one-fifth as expensive as the cellular–central billing model, but the expense would still be an order of magnitude greater than that of the current system.[2] [A cost estimate of the interim system developed by Donath et al. (2009) is not yet available.] Total system cost will depend on system design, and the cost of billing, collecting, and adjudicating fees would have to be added. Such detailed cost estimates will need to be developed for a range of options.

Public Understanding and Acceptance

The transition from a well-understood and accepted system of taxing road users (the gas tax) to an unfamiliar model, such as mileage charging, can be expected to be difficult. Whitty and Svadlenak report that the pilot program tested in Oregon was met with a good deal of media and public misunderstanding and hostility. For any transition of this magnitude to be acceptable, multiple elements would be required: careful system design based on elements the public would accept; a communications strategy to educate and prepare the public for change; and, possibly, a gradual system of introduction to build public understanding and acceptance.

Research in this area would begin with trying to discern what issues the public is most concerned about (privacy, equity, accuracy), what technologies or system designs it finds most threatening, and which system approaches it might find most acceptable. Presumably this research would be conducted through focus groups and well-designed opinion surveys and would begin with public opinion concerning simple flat-rate mileage charging and then move on to public reaction to environmental or congestion charges.

[2] On the basis of numbers provided by Sorensen et al. (2009), the simple interim model for mileage charging proposed by Whitty and Svadlenak would require $2.4 billion for installation of technology at gas pumps and electronic tags. Tags would cost $10 at most and possibly much less, but on the basis of the higher estimate and with 250 million vehicles to equip, the maximum cost of tags would be $2.5 billion.

A communications strategy is not really a research topic, but research could help inform the design of the most effective strategy. Moreover, research, particularly large-scale demonstration programs that include considerable public outreach and information sharing as a central component, could be an integral part of a communications strategy.

A gradual phase-in of mileage charging is also not in and of itself a research topic, but research could test approaches to phasing in mileage charging to determine the most promising ones from a public acceptance perspective.

Socioeconomic Topics

Included in this category are a variety of economic and policy-oriented topics, such as addressing the equity implications of alternative mileage charging designs; estimating travel demand (price elasticity) at various pricing levels to forecast revenue; analyzing and forecasting possible land use impacts of various pricing programs; developing appropriate charges for environmental impacts; and analyzing congestion pricing options, including how additional revenues raised with congestion pricing should be used.

R&D DESIGN, COST, AND MANAGEMENT

All four of the references relied on above (TRB 2006; National Surface Transportation Infrastructure Financing Commission 2009; National Surface Transportation Policy and Revenue Study Commission 2008; Whitty and Svadlenak 2009) consider large-scale demonstration programs and related research on policy and technical issues to be essential in advancing the concept of mileage charging. This section compares the design approaches the various authors recommend and provides estimates of research program cost, when they are included as part of these reports.

Design

The committee that prepared *Special Report 285* suggested a phased approach that would begin with small-scale technology demonstrations and then move to large-scale trials at the metropolitan, state, or multistate level. The trials were envisioned as a necessary part of an implementation strategy. Among the possibilities are a trial for trucks only that might occur within a state or a collection of states, a system for all vehicles that might occur at a metropolitan scale, and a system for all vehicles that might occur at a state or multistate scale. The trials would be designed as experiments for learning what works and what does not, how the public reacts, what systems would cost, and how designs could be improved.

The Financing Commission was not explicit about research design but emphasized the importance of technical demonstrations and policy research. The commission did have suggestions about the organization of the research, which are discussed in the next section. The Policy and Revenue Study Commission was also not specific about study design but did have recommendations about organization.

Whitty and Svadlenak envisioned an aggressive pace for conducting the research they identify and for conducting a series of large-scale demonstrations. They envisioned a program with two technical teams (one for passenger vehicles and one for motor carriers) that would be interdisciplinary and would consult with interested parties. The teams would have a short time (12 months) to prepare a Phase I report to Congress on

- Feasibility of implementation
  - Identification of potential collection mechanisms
  - Capital costs
  - System operations costs
  - System risk and redundancy
  - Integration with other tax collection systems
  - Seamlessness of transition
  - Technological reliability and security and mitigation of component failures
  - Retrofitting vehicles
- Evasion and avoidance risks
- Collection and enforcement effectiveness
- Privacy protection and audit ability
- Ease of use by the motoring public
- Breadth of payer base
- Transparency and ability to send a price signal
- Adaptability for congestion pricing
- Adaptability for environmental pricing and recovery of externalities, including acting as a carbon tax surrogate
- Potential for inclusion of an option for adoption by local government jurisdictions
- Benefit/cost analysis of mileage charging system alternatives, including comparisons of alternatives that are integrated with existing state, local and

private sector operating systems, all within the context of likely vehicle market acceptance factors, likely policy choices and public acceptability
- Optimum system architecture
- Equipment specifications
- Integration with VII
- Possible phase-in schedule. (Whitty and Svadlenak 2009, 126–127)

Within 18 months, Whitty and Svadlenak envision a Phase II report that would

> provide a determination of the feasibility of transitioning to a mileage-based charging system. This report would:
>
> - Make policy recommendations on the key pivot issues that determine system design and public acceptance;
> - Define an evolutionary system. . . . ;
> - Determine a likely rate structure. . . . ;
> - Address the specific research needs identified [in Chapters 5 through 8 of the Whitty and Svadlenak paper]; and
> - Finalize recommendations on system architecture for permanent, introductory, and interim systems, as needed. (Whitty and Svadlenak 2009, 127)

Whitty and Svadlenak also envision a series of concurrently conducted large-scale demonstration programs:

> As part of Phase Three, the policy oversight body should direct several technology tests and pilot programs that prepare the nation for implementation of the preferred mileage-based charging system, and perhaps an interim system as well.
>
> ***Potential pilot programs.*** The Federal government should identify several states willing to conduct pilot programs to advance specific aspects of the research agenda. In order to assure timely completion, USDOT should grant appropriate relief from administrative regulations for research efforts under these pilot programs. The authors suggest the following specific pilot studies:
>
> - Technology Refinement Pilot Program for the Closed System Pay-at-the-pump Model. This study would select and commercially refine the optimum technologies for the pay-at-the-pump model and include integration of equipment in vehicle manufacturing and fueling station processes and anti-tampering strategies. This study would develop a timeline for commencement of deployment through full implementation and complete capital and operating costs estimates.
> - Central Billing Pilot Program. This study would complete system development for the central billing approach and test the central billing system

operationally. This study would develop a timeline for commencement of deployment through full implementation and complete capital and operating costs estimates.

- Open System Pilot Program for the Integrated Approach. This study would integrate the pay-at-the-pump model with elements of the central billing model under an open system that is cryptographically secure with aftermarket on-vehicle devices, addressing privacy, enforcement, and auditing issues. This study would test voluntary adoption of this mileage charging system. This study would develop a timeline for commencement of deployment through full implementation and complete capital and operating costs estimates.
- Electronic Toll Road Integration Pilot Program. This study would examine and test integration of mileage charging systems with modern electronic tolling technology and toll roads.
- VMT Estimate Pilot Program. This study would complete development and prove implementation viability for this interim mileage charging collection system. [The system proposed by Donath et al. (2009) should also be tested.]
- Electronic Weight–Distance Tax Pilot Program for Heavy Commercial Vehicles. This study would identify and deploy the technology and systems necessary for imposition of an electronic weight–distance tax for the motor carrier fleet applied either in one state or in several contiguous states. This study would develop a timeline for commencement of deployment through full implementation and complete capital and operating costs estimates.
- Multi-state Contiguous Broad Scale Pilot Program. In preparation for commencement of implementation of a mileage charging system nationally, it will be necessary to conduct a multi-state pilot program for contiguous states that tests on a broad-scale the preferred mileage charging collection system identified by the policy oversight body. This study will test the preferred system, including its interstate data and charge collection and distribution elements. Such a test might be conducted by contiguous member states of the I-95 Corridor Coalition or the West Coast Corridor Coalition.

These pilot programs should be conducted by states currently taking concrete steps toward electronic mileage charging system development such as Massachusetts, Minnesota, Oregon and Texas. Consideration should also be given to other states showing interest such as Florida, New York, Pennsylvania, Ohio, California, Washington, Nevada and Colorado. (Whitty and Svadlenak 2009, 128–129)

Within 42 months of the issuance of the Phase II report (within 5 years of enactment of the authorizing legislation), a Phase III report would be delivered to Congress that summarizes the results of the demonstrations and related research:

- Statewide pilot programs for testing, public outreach and Congressional education
- A broad scale pilot program in preparation for ultimate adoption, building from the statewide pilot program research efforts
- Refinement of system technology to commercial viability, including setting final technology component specifications and database requirements
- Identification of transition issues and required steps
- Development of a full implementation timeline
- Development of data to enable congressional staff to advance statements of fiscal impact for directly related legislation in 2015 (Whitty and Svadlenak 2009, 128)

Whitty and Svadlenak suggest that the next authorization period, which is scheduled to begin in October 2009 but may be delayed by 18 months, be devoted to research and testing, and that the following authorization be devoted to consensus building, so that a full-scale system could be implemented beginning in 2021. They also suggest that a simple interim system might be implemented at a much earlier date.

Although the topics Whitty and Svadlenak identify have merit, a 6-year research, development, and testing cycle may be too accelerated for a new system that has as much interagency and cross-governmental-level complexity as mileage charging. Furthermore, the subject involves controversial topics, particularly privacy, that could result in public misunderstanding and rejection if they are not handled carefully. Consensus concerning an appropriate mileage charging system may be achievable within 10 to 12 years of beginning an R&D, outreach, and public discernment process in a nation as large and diverse as the United States. It would be impractical and possibly counterproductive, however, to try to force the R&D to be done too quickly. An accelerated schedule could lead to poorly designed projects, waste, and failed demonstrations.

Cost

Only Whitty and Svadlenak provided cost estimates for conducting the recommended research. On the basis of Oregon's experience in running its pay-at-the-pump demonstration, they estimate $70 million to $80 million in R&D costs as follows: Phase I, $5 million; Phase II, $7 million; and Phase III, $60 million.

This estimate may be too low. If the research is organized as Whitty and Svadlenak recommend, establishing a new commission and staffing it with senior professionals capable of managing, say, a 12-year research and demonstration program could easily cost $5 million annually, or $60 million over the 12 years.[3] If the demonstrations themselves only cost $5 million apiece, which seems low, their total cost would be $35 million. To this a cost of $1 million each for each of the seven areas of research recommended by Whitty and Svadlenak must be added, which totals $7 million. These figures add up to $102 million. Thus, in round terms it is probably most realistic to think of a large-scale demonstration of at least $100 million (about $8.3 million per year over a 12-year period).

Organization

Special Report 285 did not address research organization. The Financing Commission recommended that the research program be overseen by a

> multi-modal body within USDOT that combines technology, policy, tax administration, and systems expertise, similar to the agency created on a much smaller scale by the state of Oregon for its road pricing pilot project. Coordination will be required among several modal administrations. . . . An example of such a multi-modal coordinating body within USDOT can be found in the Intelligent Transportation System (ITS) Joint Program Office for ITS Research. (National Surface Transportation Infrastructure Financing Commission 2009, 218).

The Financing Commission notes that the work of this group should be overseen by an independent advisory committee with appropriate representation that would include organizations focused on civil liberties and privacy.

The Policy and Revenue Study Commission called for Phases I and II of its recommended study to be led by the National Academy of Sciences

[3] This assumes a staff of 22 people (administrators, senior and junior technical professionals, secretaries, accountants, and procurement staff) with full salaries, overhead, and general and administrative expenses.

(NAS) in coordination with the Federal Highway Administration, the Internal Revenue Service, the U.S. Department of the Treasury, state highway and revenue agencies, and affected stakeholders.

Whitty and Svadlenak emphasize the need for the work of the research teams to be guided by an independent policy body charged with following the policy direction set by Congress. They suggest a national commission model for this oversight body, with membership representing states, metropolitan planning organizations, federal agencies, nongovernmental organizations, NAS, the American Association of State Highway and Transportation Officials, and others. The work of the teams would also receive high-level policy oversight by the Secretary of Transportation.

The Financing Commission, the Policy and Revenue Study Commission, and Whitty and Svadlenak recognize the importance of having the research guided by an independent group involving the many stakeholders who would need to be represented. They differ with regard to how the research would be administered. The Financing Commission suggests that it be carried out by USDOT staff, the Revenue and Policy Study Commission recommends that it be carried out by NAS, and Whitty and Svadlenak recommend that it be carried out by an independent commission with high-level oversight from USDOT.

CONCLUSIONS

Mileage charging is technically feasible, but many design and implementation details need to be worked out. Combining mileage charging for raising revenues with policies to mitigate GHGs and conserve energy appears feasible but requires further analysis and demonstration programs to confirm that technologies work as expected and that they would be acceptable to the public. An R&D program to test such concepts would have several elements: large-scale demonstrations of various approaches, parallel research on a variety of topics (administrative costs, privacy, security, ability to audit, etc.), and outreach and education as a central component of the program. A 10- to 12-year program would probably cost on the order of $70 million to $100 million. Because of interagency, intergovernmental, public–private (motor carriers) issues and public concerns about privacy, the work should be guided by an independent group of stakeholders whose members are balanced in terms of perspectives. The group would necessarily include representatives of federal agencies, states, metropolitan areas, cities, and motor carriers; civil liberties and privacy advocates; academicians; and prominent citizens.

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Abbreviation

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APPENDIX B

Data Gaps

As Burbank (2009) points out, transportation data needed to support policies or programs that would be designed to affect travel behavior have major deficiencies. The Center for Clean Air Policy (2009) identified the difficulties that the poor data at the state and local levels would cause in measuring the effects of strategies to reduce travel. The group calls for substantial improvements in data collection and in the models that use these data to help make progress in reducing transportation's greenhouse gas (GHG) emissions.

PASSENGERS

Current information about passenger travel depends to a great extent on the episodic conduct of the National Household Travel Survey (NHTS), which is intended to be a nationally representative, cross-sectional survey of household vehicle ownership, trip-making behavior, and travel distances with considerable demographic and household information. Many compromises have been made in this survey over the years to deal with uncertain administrative support and inadequate resources. The NHTS is itself a combination of the former Nationwide Personal Transportation Survey and the American Travel Survey; the latter was the only survey of long-distance (intercity) trip making. The NHTS has had a checkered history in terms of funding. Conduct of the survey has been postponed in previous cycles because of lack of funding. In 2008, the Bureau of Transportation Statistics (BTS) concluded that it would be unable to support the 2009–2010 NHTS; the Federal Highway Administration assumed responsibility for conducting the survey despite lack of authorized funds to pay for it (other U.S. Department of Transportation administrations, including BTS, contribute to the survey cost).

Many metropolitan planning organizations (MPOs) and states supplement the survey by paying for expanded sampling in their regions. Even these data, however, have gaps. The survey is conducted irregularly, is only cross-sectional, does not provide state- or metropolitan-level detail for jurisdictions that cannot afford to participate, and suffers from the low response rates that characterize such travel surveys. Detailed information about work trips has been provided historically by the decennial census. That source has shifted to the American Community Survey, a rolling survey. To protect privacy, the American Community Survey will not provide the level of geographic detail that regional travel models demand. The consensus study on travel data described in Chapter 3 would provide guidance on what data should be collected to meet the needs of federal, state, regional, and local policy makers.

If legislation that requires reductions in vehicle miles of travel and implementation of strategies to change travel behavior is enacted, much more extensive data collection will be required. States and regions would need a much better baseline estimate of total travel than is currently available. Such information also would be helpful in analyzing the options available to them for achieving the goals of the legislation.

FREIGHT

Information about the movement of cargo by rail and water is available from the Association of American Railroads and the U.S. Army Corps of Engineers, respectively. However, information about freight movement by truck is sorely lacking because of its proprietary nature. Trucks are critical to origin-to-destination trips for almost all freight movement, and a substantial share of ton-miles is moved by truck only. Therefore, the lack of information is a serious gap for public-sector officials trying to determine whether to invest in other modes to divert truck traffic.

Most publicly available information about commodity movements depends on the Commodity Flow Survey (CFS), a survey of domestic shippers conducted by the Census Bureau and funded by BTS. This irregularly conducted survey has suffered from inadequate funding, which in turn has resulted in declining sample sizes that have compromised analysis at levels of geography below the nation as a whole (TRB 2003a; TRB 2003b). Thus, states and regions trying to understand current and future truck movements have great difficulty in analyzing options and forecasting demand in their jurisdictions. Furthermore, the CFS does not provide information about imported commodities or agricultural goods (a large share of total shipments), and it does not indicate the routes taken from origin to destination. Route information must be imputed on the basis of estimates that rely on other data sources. States obviously need route-specific information when they make long-range investments in freight capacity. *Special Report 276* (TRB 2003a) provides one broad-based strategy to collect and provide information about freight movements. The consensus study on travel data described in Chapter 3 would provide guidance on the collection of data that would be helpful in meeting the needs of federal, state, regional, and local policy makers.

COST

Burbank (2009) estimates an annual cost of about $300 million to collect data to inform decisions about the best mitigation policies for federal, state, and regional authorities to implement. The major part of this cost is based on a "bottoms up" estimate of what some MPOs currently spend to collect household travel data for metropolitan area travel models. Much better data and models than in common use would be required to develop MPOs' capabilities to analyze alternatives to meet GHG emission reduction goals and measure progress toward meeting those goals (TRB 2007). Data costs for MPOs with better-than-average data collection and modeling programs are roughly $0.70 to $0.75 per capita per year, for a total of $210 million to $225 million (Burbank 2009). To this cost need to be added (*a*) the cost to states and regions of conducting surveys of transit users and freight movements on roads and highways and (*b*) the cost of national-level surveys of households, shippers, and owners of transportation vehicles. These costs could easily add up to another $0.25 per capita per year, resulting in Burbank's estimate of $1 per capita or, in round figures, about $300 million per year.

Winkelman (2009a; 2009b), building on the work of the Center for Clean Air Policy, estimates that the necessary data collection, model improvements, implementation of model improvements at metropolitan planning agencies, research, and evaluation could cost as much as $1 billion per year over the next authorization. According to his "top down" estimate, to make an overall investment of $500 billion in infrastructure, as recommended in the 2009 surface transportation reauthorization proposal of the House Transportation and Infrastructure Committee, the nation ought to be willing to invest 1 percent of that amount in ensuring that the investments are appropriate in moving toward national and regional transportation and environmental goals.

Winkelman's estimate includes more costs than Burbank's, because his estimate incorporates research and evaluation along with data collection, whereas Burbank's is only for data collection. If one nets out of Winkelman's $1 billion estimate the current cost of highway and transit research programs—on the order of $730 million (TRB 2008, Table 2-2)—$270 million is left for data collection, which is roughly comparable with Burbank's $300 million estimate.

The travel data needed for improved modeling and analysis to meet goals to reduce transportation GHG emissions and conserve energy would be useful for other applications at the federal, state, and local levels. In particular, the data would be helpful for general state and regional transportation planning purposes and for establishing compliance with Clean Air Act mandates in regional and state transportation capital plans. Whereas climate change imperatives might provide the impetus for collecting such data, a portion of the extra cost of data collection should be attributed to these other applications.

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Study Committee Biographical Information

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Emil H. Frankel is the Director of Transportation Policy for the Bipartisan Policy Center in Washington, D.C., and an independent consultant on transportation policy and public management issues. He was Assistant Secretary for Transportation Policy of the U.S. Department of Transportation from 2002 to 2005, where he played a key role in the coordination and development of the administration's proposal to reauthorize the federal highway, transit, and highway safety programs and provided policy leadership in such areas as intermodal freight transportation, reform of the nation's intercity passenger rail system, transportation project financing, and the application of information technologies to transportation systems operations. Mr. Frankel was Commissioner of the Connecticut Department of Transportation from 1991 to 1995, responsible for managing an agency with more than 4,000 employees and an annual budget exceeding $1 billion. Previously, Mr. Frankel served as Special Assistant to the Under Secretary of the U.S. Department of Housing and Urban Development and as a Legislative Assistant to U.S. Senator Jacob K. Javits of New York. Mr. Frankel received his bachelor's degree from Wesleyan University and his LLB from Harvard Law School, and he was a Fulbright Scholar at Manchester University in the United Kingdom. From 1981 to 1997 he was a Trustee of Wesleyan University, where he is now a Trustee Emeritus.

Edward A. "Ned" Helme is President and founder of the Center for Clean Air Policy (CCAP). As an expert on climate and air policy, he advises members of Congress, state governments, the European Commission, and developing countries on these issues. Mr. Helme is the author of more than 50 key studies on climate change, air quality, electricity regulation, and transportation policy. With more than 25 years' experience in climate and air policy, he is an expert in cap-and-trade programs and other market and nonmarket approaches to addressing climate change. Mr. Helme played an instrumental role in the development and passage of the Clean Air Act Amendments in 1990, which established the first national emissions trading program in the United States. He also led the expert team that developed the original design of the European Union's Emissions Trading Scheme. Before starting CCAP, he directed the Natural Resources Division of the National Governors Association and was a legislative director to a U.S. Congressman. He holds an MPP from the Goldman School of Public Policy, University of California at Berkeley, and a BA in political science and psychology from Haverford College.

Adib K. Kanafani is the Edward G. Cahill and John R. Cahill Professor of Civil Engineering at the University of California at Berkeley. His research interests are transportation planning, transportation systems analysis, and air transportation, and he has authored or coauthored numerous papers on these topics, including several papers dealing with the full costing of transportation and analysis of direct and indirect subsidies in various modes. He is a member of the National Academy of Engineering, is currently Chair of the TRB Executive Committee, and has served on several TRB policy study committees. Dr. Kanafani has won several awards, including the James Laurie Prize, the Robert Horonjeff Award, and the Walter L. Huber Civil Engineering Research Prize of the American Society of Civil Engineers. He received a PhD and an MS in civil engineering from the University of California at Berkeley and a BE from the American University of Beirut.

Debra L. Miller is the Secretary of Transportation for Kansas. Earlier, she was director of the Division of Planning and Development of the Kansas Department of Transportation. She was a member of the committee that produced the 2006 TRB policy study report *The Fuel Tax and Alternatives for Transportation Funding* and was a member of the TRB study committee that produced the 1996 report *Paying Our Way: Estimating Marginal Social Costs of Freight Transportation.* Ms. Miller is a member of the TRB Executive Committee and chairs the Standing Committee on Planning of the American Association of State Highway and Transportation Officials. She received a bachelor's degree from Kansas State University.

Michael R. Morris is Director of Transportation at the North Central Texas Council of Governments, which he joined as a Transportation Analyst in 1979. As Transportation Director for the metropolitan planning organization for Dallas–Fort Worth, he is responsible for analysis of the region's long-range transportation plan and transportation improvement program to determine travel and air quality emission impacts of proposed capital and operational investments and public policies. Mr. Morris is a registered engineer in the state of Texas. He is a member of the Association of Metropolitan Planning Organizations, the Institute of Transportation Engineers, the American Society of Civil Engineers, and the Travel Model Improvement Program Review Panel of the Federal Highway Administration. Mr. Morris has served on the NRC Committee to Review EPA's Mobile Source Emissions Factor Model, the Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program of TRB and the Board on Environmental Studies and Toxicology, and the Committee on Air Quality Management in the United States. He is Vice Chair of the TRB Executive Committee. He holds a BA in environmental design and planning and an MS in civil engineering from the State University of New York, Buffalo.