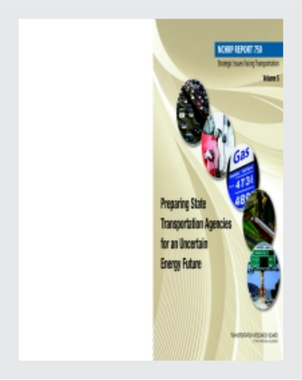

Strategic Issues Facing Transportation, Volume 5: Preparing State Transportation Agencies for an Uncertain Energy Future

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 750

Strategic Issues Facing Transportation

Volume 5: Preparing State Transportation Agencies for an Uncertain Energy Future

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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FOREWORD

By Lori L. Sundstrom
Staff Officer
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This report examines how the mandate, role, funding, and operations of state departments of transportation (DOTs) will likely be affected by changes in energy supply and demand in the next 30 to 50 years, and identifies potential strategies and actions that DOTs can employ to plan and prepare for these effects. The report describes how robust decision-making techniques can be used to help navigate the potential risks and rewards of different policy and management responses under differing surface transportation energy supply-and-demand scenarios. The report will be useful to senior policy analysts and long-range planning officials who want to more effectively understand and manage energy uncertainty as part of policy development and long-range planning activities.

Major trends affecting the future of the United States and the world will dramatically reshape transportation priorities and needs. The American Association of State Highway and Transportation Officials established the NCHRP Project 20-83 research series to examine global and domestic long-range strategic issues and their implications for departments of transportation (DOTs) to help prepare the DOTs for the challenges and benefits created by these trends. *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 5: Preparing State Transportation Agencies for an Uncertain Energy Future* is the fifth report in this series.

Growth in global energy consumption, especially within the transportation sector, is expected to increase demand for oil. Given that the entire transportation sector accounted for more than 90% of all liquid fuel consumption in 2006, it is clear that changes in energy infrastructure and energy sources will affect transportation activities. Because fossil fuel emissions and greenhouse gases from all sources are expected to continue to increase, contributing to air pollution and climate change, the push to move toward energy efficiency and alternative fuels in the transportation sector is expected to continue.

World population growth and energy demand are inextricably linked, but the fossil-based energy supply is finite. Alternative technologies are emerging in the marketplace, and these could prompt enormous changes over time in how DOTs operate. Implementation of alternative fuels will also necessitate a change in highway funding strategies. Most of the revenue that DOTs currently use for the construction, operation, and maintenance of the highway system comes from federal and individual state gas taxes assessed on traditional motor vehicle fuels. The ability to finance future transportation programs has already been negatively affected by various technological, economic, and social changes, and these affects will be magnified over time.

Under NCHRP Project 20-83(04), The RAND Corporation was asked to identify short- and long-range actions and strategies that state DOTs can use to plan, respond to, and otherwise manage under a broad range of plausible future energy scenarios, and to assess the likely consequences associated with potential policy responses and management strategies. The research (1) identified driving forces, leading indicators, critical interdependencies, and their relative importance to future energy use and alternative fuel scenarios; (2) developed representative scenarios regarding the future use of energy and alternative fuels that may result from the driving forces; and (3) analyzed how the mandate, role, funding, and operations of state DOTs may be affected by various plausible future energy supply-and-demand scenarios.

NCHRP Report 750, Volume 5 contains a significant compilation of information from a variety of industry and public sources that may be used to inform long-range transportation planning processes. The scenario planning conducted as part of the research should also be of interest to transportation planners and policy analysts—both for the information generated from the scenarios and for the way in which scenario planning was used. An extended summary of the full report is included that briefly describes the results of the research. A 4-page brochure and a 2-page brochure that further summarize the research results are available for downloading from the project webpage at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2632.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

ACRONYMS AND ABBREVIATIONS

AADT	Annual Average Daily Traffic
AAA	American Automobile Association
AASHTO	American Association of State Highway and Transportation Officials
AB	Assembly bill
ABP	Assumption-based planning
AEO	Annual Energy Outlook
AFV	Alternative-fuel vehicle
ANL	Argonne National Laboratory
AP	Associated Press
API	American Petroleum Institute
APTA	American Public Transit Association
ARRA	American Recovery and Reinvestment Act
ARTBA	American Road and Transportation Builders Association
ATA	American Trucking Association
AVL	Automatic vehicle location
bcm	Billion cubic meters
BD20	Fuel blends including 20% biodiesel
BEA	Bureau of Economic Analysis
BEV	Battery electric vehicle
BLM	Bureau of Land Management
BLS	Bureau of Labor Statistics
BNL	Brookhaven National Laboratory
BP	British Petroleum
BRT	Bus rapid transit
BTS	Bureau of Transportation Statistics
Btu	British thermal unit
CAA	Clean Air Act
CAFE	Corporate average fuel economy
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CBD	Central business district
CBO	Congressional Budget Office
CCS	Carbon capture and sequestration
CEC	California Energy Commission
CEDIGAZ	Centre International d'Information sur le Gaz
CFCP	California Fuel Cell Partnership
CFR	Code of Federal Regulations
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide

CO_2e	Carbon dioxide equivalent
Connecticut DOT	Connecticut Department of Transportation
CPI	Consumer Price Index
CSG	Council of State Governments
CSP	Concentrating solar power
CV	Conventional vehicle
DoD	Department of Defense
DOE	Department of Energy
DOT	(State) Department of Transportation
DSIRE	Database of State Incentives for Renewables and Efficiency
E/EPH/E	Economy/environment and public health/equity
E10	Fuel blends including 10% ethanol
E15	Fuel blends including 15% ethanol
E85	Fuel blends including 85% ethanol
E90	Fuel blends including 90% ethanol
E100	Pure ethanol
EC	European Commission
EEA	Energy and Environmental Analysis, Inc.
EERE	(Office of) Energy Efficiency and Renewable Energy
EGS	Enhanced geothermal systems
EGR	Exhaust gas recirculation
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
ERP	Electronic road pricing
ESA	Economics and Statistics Administration
ETC	Electronic toll collection
ETSAP	Energy Technology System Analysis Program
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
F2F	Freeways to Fuel
FCV	Fuel-cell vehicle
FDA	Formal decision analysis
FFV	Flex-fuel vehicle
FHWA	Federal Highway Administration
Florida DOT	Florida Department of Transportation
FMO	Office of Freight Management and Operations
FT	Fischer-Tropsch
GAO	Government Accountability Office
GDI	Gasoline direct injection
GDP	Gross domestic product
gge	Gallon of gasoline equivalent
GHG	Greenhouse gas
GI	Government Issue
GM	General Motors
GPS	Global positioning system
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GVW	Gross vehicle weight

HCCI	Homogeneous charge compression ignition
HEV	Hybrid-electric vehicle
HFCV	Hydrogen fuel-cell vehicle
HOT	High-occupancy/toll
HOV	High-occupancy vehicle
HSR	High-speed rail
HTF	Highway Trust Fund
ICE	Internal combustion engine
ICM	Integrated corridor management
IEA	International Energy Agency
IMEX	Intermodal Move Exchange
INL	Idaho National Laboratories
ITS	Intelligent transportation system
kbd	Thousand barrels per day
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt hour
LACMTA	Los Angeles County Metropolitan Transportation Authority
LCFS	Low-carbon fuel standard
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
LNG	Liquid natural gas
LPG	Liquid petroleum gas
LTPA	Long-term policy analysis
MAP-21	Moving Ahead for Progress in the 21st Century Act of 2012
Maryland DOT	Maryland Department of Transportation
Massachusetts DOT	Massachusetts Department of Transportation
mbd	Million barrels per day
MBUF	Mileage-based user fee
MHDV	Medium- and heavy-duty vehicles
MIT	Massachusetts Institute of Technology
mpg	Miles per gallon
mpgge	Miles per gallon of gasoline equivalent
mpkg	Miles per kilogram
MPO	Metropolitan planning organization
MSA	Metropolitan Statistical Area
MTBE	Methyl-tertiary butylether
NAE	National Academy of Engineering
NAHB	National Association of Home Builders
NBI	New Building Institute
NCSL	National Conference of State Legislatures
NEMS	National Energy Modeling System
NESCCAF	Northeast States Center for a Clean Air Future
NETL	National Energy Technology Laboratory
NEV	Neighborhood electric vehicle
New Jersey DOT	New Jersey Department of Transportation
NG	Natural gas
NGVA	Natural Gas Vehicle America
NHTSA	National Highway Traffic Safety Administration
North Carolina DOT	North Carolina Department of Transportation

NO_x	Nitrogen oxides
NPC	National Petroleum Council
NRC	National Research Council
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NSTIFC	National Surface Transportation Infrastructure Financing Commission
NSTPRSC	National Surface Transportation Policy and Revenue Study Commission
ODA	Oregon Department of Agriculture
OECD	Organization for Economic Co-operation and Development
OEM	Original equipment manufacturer
OFE	Office of Fossil Energy
OHPI	Office of Highway Policy Information
OPEC	Organization of Petroleum Exporting Countries
Oregon DOT	Oregon Department of Transportation
ORNL	Oak Ridge National Laboratory
OTAQ	Office of Transportation and Air Quality
P3	Public–private partnership (also known as PPP)
PAYD	Pay as you drive
PCGCC	Pew Center on Global Climate Change
PEM	Proton exchange membrane
PGC	Potential Gas Committee
PG&E	Pacific Gas and Electric
PHEV	Plug-in hybrid-electric vehicle
PM10	Particulate matter, 10 microns
PM2.5	Particulate matter, 2.5 microns
POLB	Port of Long Beach
ppm	Parts per million
PPP	Public–private partnership (also known as P3)
psi	Pounds per square inch
PTC	Positive train control
PV	Photovoltaic
R&D	Research and development
RDM	Robust decision making
RFS	Renewable fuel standard
RFS2	(The current federal) renewable fuel standard
RIN	Renewable identification number
RITA	Research and Innovative Technology Administration
ROW	Right-of-way
RPS	Renewable portfolio standard
RVO	Renewable volume obligation
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SB	Senate Bill
SBP	Scenario-based planning
SCOTUS	Supreme Court of the United States
S-GDI	Stoichiometric gasoline direct injection
SO_2	Sulfur dioxide

SO_x	Sulfur oxides
SR	State route
SUV	Sport utility vehicle
SVM	Small-volume manufacturer
tcm	Trillion cubic meters
TCPA	Texas Comptroller of Public Accounts
TDM	Transportation demand management
TfL	Transport for London
TIF	Tax increment financing
TIFIA	Transportation Infrastructure Finance and Innovation Act
TMA	Transportation management association
TSG	Transport Studies Group
TSM&O	Transportation system management and operations
TTI	Texas Transportation Institute
TWh	Terawatt hour
UCS	Union of Concerned Scientists
UDDS	Urban Dynamometer Driving Schedule
ULSD	Ultra-low-sulfur diesel
U.S.C.	United States Code
USDA	U.S. Department of Agriculture
U.S. DOT	U.S. Department of Transportation
U.S. NRC	U.S. Nuclear Regulatory Commission
V-I	Vehicle-to-infrastructure
V-V	Vehicle-to-vehicle
VII	Vehicle-Infrastructure Integration
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle miles of travel
VOCs	Volatile organic compounds
VPPP	Value Pricing Pilot Program
VTrans	Vermont Agency of Transportation
W	Watt
Washington State DOT	Washington State Department of Transportation
WCGH	West Coast Green Highway
WGA	Western Governors Association
Wh	Watt hour
ZEV	Zero emissions vehicle

AUTHOR ACKNOWLEDGMENTS

The research team would first like to acknowledge its gratitude to the AASHTO for funding this study as part of a series of research projects on long-range strategic issues that will confront the transportation industry in the coming decades. The decision to support transportation decision makers in their ability to develop more informed and effective long-range plans is likely to be a sound investment that pays dividends for many years to come.

Next, the research team would like to thank the project panel for their continuing support, attention, and helpful feedback throughout all stages of the project. Members of the panel reviewed countless pages of material—not all of it well-polished—in a series of interim and draft project reports, and their thoughtful comments and attention to detail helped improve the final product immensely.

In the early stages of the work, the research team conducted a series of interviews with experts in the areas of transportation fuels and vehicle propulsion technologies; trends in economy, population growth, and land use; and federal policies involving energy, climate, and transportation funding. The team appreciates the generosity of these experts in sharing their time and thoughtful insights, which proved very helpful in developing plausible transportation energy futures. The experts interviewed included Doug Arent of the National Renewable Energy Laboratory; Allison Premo Black of the American Road and Transportation Builders Association; Larry Burns of the University of Michigan, formerly of General Motors; Robert Cervero of the University of California, Berkeley; Mark Delucchi of the University of California, Davis; Reid Ewing of the University of Utah; Emil Frankel of the Bipartisan Policy Center; David Friedman of the Union of Concerned Scientists; David Greene of Oak Ridge National Laboratory; W. Michael Griffin of Carnegie Mellon University; Jim Harger of Clean Energy; Scott Hassell of CB Richard Ellis; John Heywood of the Massachusetts Institute of Technology; John Horsley of the American Association of State Highway and Transportation Officials; Paulina Jaramillo of Carnegie Mellon University; John Juriga of Hyundai/Kia American Technical Center; Richard Karp of Chevron; W. Ross Morrow of Iowa State University; Arthur Nelson of the University of Utah; Steven Plotkin of Argonne National Laboratory; Randall Pozdena of ECONorthwest; Mike Ramage, formerly of Exxon; David Raney, formerly of Honda North America; Lee Schipper, formerly of Stanford University; Dan Sperling of the University of California, Davis; Brian Taylor of the University of California, Los Angeles; Luke Tonachel of the Natural Resources Defense Council; Michael Wang of Argonne National Laboratory; and James Whitty of the Oregon Department of Transportation. The team also acknowledges the early technical contributions from Andrew Burke and Marshall Miller from the UC Davis Institute of Transportation Studies.

In later stages of the research, the team engaged in a series of interviews, followed by a workshop, with representatives of state departments of transportation from across the country. The interviews and workshop provided for a greater understanding of how the plausible transportation energy futures developed for the project might affect state departments of transportation and what types of strategies states would consider in response. They also yielded helpful feedback on the utility of robust decision making as a framework for assisting states to develop robust long-term plans. The team is quite grateful to all of the state department of transportation staff, several of whom later joined the project panel, who contributed their time and energy to participate in the initial interviews or subsequent workshop. These included Kristen Keener Busby from Arizona; Austin Hicks, Mahmoud Mahdavi, and Vahid Nowshiravan from California; Robert Romig from Florida; Tom McQueen from Georgia; Steve Massey and Susan Stitt from Illinois; Clinton Bench, Ned Codd, and Jeffrey Mullan from Massachusetts; Niles Annelin, Denise Jackson, and Polly Kent from Michigan; Jean Wallace from Minnesota; Jackie Duckworth and Melinda McGrath from Mississippi; James Barna and Jennifer Townley from Ohio; Barbara Fraser from Oregon; Natasha Fackler and Toby Fauver from Pennsylvania; James Bass from Texas; Todd Harrison, Kathy Leotta, Brian Smith, Seth Stark, and Megan White from Washington; Eric Crawford, Robert Pennington, Tim Sedosky, and Rob Watson from West Virginia; and John Davis, Martin Kidner, and Mark Wingate from Wyoming.

SUMMARY

This summary outlines the results of NCHRP Project 20-83(04), "Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation." The study is part of a series of reports funded by the American Association of State Highway and Transportation Officials (AASHTO) to examine strategic issues facing the transportation industry and inform long-range planning efforts by state departments of transportation (DOTs).

As specified in the initial call for proposals, the objectives of this research were "(1) to determine how the mandate, role, funding, and operations of DOTs will likely be affected by future changes in long-term energy supply and demand and (2) to identify strategies and actions that can be used by the DOTs to plan and prepare for these effects." Perhaps most obviously, with the traditional reliance of state DOTs on federal and state motor-fuel taxes to fund highway construction and maintenance activities, any significant shift in transportation energy use could adversely affect DOT revenue. Yet changes in fuel sources, prices, and usage patterns could also positively or negatively affect many other issues of concern to state DOTs, such as the cost of construction inputs, aggregate travel demand, choice among modes for passenger travel and good movement, local air quality, and greenhouse gas emissions.

S.1 Study Approach and Scope

The research team, led by the RAND Corporation with assistance from Cambridge Systematics and the Institute of Transportation Studies at the University of California, Davis, pursued an approach to the study consisting of three main steps: developing a broad range of plausible future transportation energy scenarios in the 2040 to 2060 time frame; examining how the future scenarios might adversely affect state DOTs given their current and evolving roles, mandates, funding, and operations; and employing the principles of robust decision making (RDM), a method for effective long-term policy analysis in the context of an uncertain future, to evaluate and identify promising strategies for states and state DOTs to respond to the potential impacts.

Most traditional planning approaches seek to identify one or more futures viewed as highly likely and then develop a set of strategies tailored for the envisioned futures, potentially leading to inferior results should the future evolve in an unexpected direction. In contrast, RDM considers a much broader array of potential future outcomes and then facilitates the development of plans that should perform at least reasonably well regardless of how the future unfolds. This robust quality of RDM planning is enabled in part through the use of adaptive strategies that can be triggered or modified as new information about the future becomes available.

Two additional notes on the scope of the study are merited. First, potential changes in fuels and vehicle propulsion technologies are not the only uncertainty confronting transportation policy makers. Many other factors—such as the rise of social networking and improved telecommunications, changing attitudes toward transportation among younger generations, and the potential advent of autonomous vehicles in future years—could also affect future travel choices in profound ways. These are beyond the main scope of this study, however, and thus are considered only in passing. As an additional note, solutions to some of the energy-related challenges likely to confront state DOTs, such as reduced fuel-tax revenue, do not fall within the authority of a typical DOT. For this reason, with concurrence from the project panel, the study considered strategies that might require state legislation, a governor's executive order, or collaboration with peer agencies along with strategies that DOTs could pursue on their own initiative.

S.2 Evolving State DOT Roles, Mandates, Funding, and Operations

As a backdrop for the results and analysis that follow, it is first helpful to review current and evolving roles, mandates, funding, and operations for state DOTs. While the structure and responsibilities of a DOT can vary considerably from one state to the next, it is still possible to distill several generally applicable characteristics and trends. State DOTs have traditionally focused much of their efforts on planning, constructing, and maintaining highways and other state roads, devoting considerable attention to such concerns as engineering standards, state of repair, and safe operations. Much of the funding for roads has derived from user fees such as federal and state fuel taxes and vehicle sales taxes and registration fees.

Like other aspects of society, though, state DOTs continue to evolve. Three emerging trends have proven especially important in recent decades. First, while highway travel remains a central concern for DOTs, many have also taken on greater roles in planning, funding, or oversight for other modes of travel such as transit, rail, aviation, and marine transport. Second, state DOTs are increasingly asked to address a broader range of policy objectives in their planning efforts. Areas of emphasis vary by state but may include economic development, equity, local air quality, greenhouse gas emissions, quality of life, and heightened attention to traffic safety. Third, following the initial boom in Interstate highway construction, federal and most state fuel-tax rates—typically levied on a cents-per-gallon basis—have not been increased enough to keep pace with inflation and improved fuel economy. With available revenue lagging the rapid growth in vehicle travel, many DOTs have found it necessary to focus much more attention on transportation demand management and operational efficiency as an alternative to significant additional capacity expansion.

S.3 Future Transportation Energy Scenarios

The future transportation energy scenarios developed for the project are intended to reflect a range of plausible outcomes relating to energy and travel that could pose challenges for DOTs given their roles, mandates, funding, and operations. As indicated in Table S.1, key elements of the scenarios can be clustered into three categories.

Table S.1. Elements of the future transportation energy scenarios.

Energy Futures	Travel Futures	Federal Policy Futures
• Price of oil • Vehicle fuel economy • Mix of transportation fuels • Vehicle cost • Energy cost of travel	• Passenger vehicle travel • Trucking • Transit demand	• Climate and energy policy • Transportation funding policy

To develop plausible futures for the scenario elements listed in the table, the team first reviewed the literature on future prospects for petroleum-fueled vehicles along with alternatives such as natural gas, biofuels, electricity, and hydrogen. The team also examined past trends and future projections for other factors likely to influence travel demand and mode choice in the coming decades, including population growth, economic growth, and land use. Finally, the team reviewed ongoing challenges and policy debates relating to energy, climate, and transportation funding. Findings from the literature were supplemented with insights from a series of interviews with experts from across these disciplines. Drawing on this research, the team established plausible future outcomes for each of the energy, travel, and federal policy elements listed in the table. While there is a degree of correlation among certain elements of the scenarios—for example, higher vehicle fuel economy will generally lead to lower energy cost of travel—the team opted to present the scenarios in disaggregate fashion. This provided greater flexibility for assessing how certain scenario elements, either alone or in combination with other elements, might affect state DOTs.

Future energy scenarios. Future oil prices are uncertain, with plausible futures for the 2050 time frame ranging from $70 to $230 or more per barrel (2011 dollars). With recent advances in drilling and extraction technologies to access petroleum from conventional and unconventional sources, however, the lower end of this range appears more likely. More-stringent federal corporate average fuel economy (CAFE) standards have now been specified through 2025, suggesting that vehicle fuel economy should at least double by 2050 and could even quadruple. With greater access to petroleum, mandates for major gains in fuel economy in the coming years, and mature industries for fuel distribution and automotive engineering, parts supply, and maintenance, many of the experts interviewed expected petroleum to remain dominant for decades to come. Technical innovation is difficult to predict, though, so the team also considered futures in which one or more of the competing fuels—natural gas, biofuels, electricity, or hydrogen—emerges to claim a significant share of the market by 2050. Success for any of these alternatives would almost certainly require significant technology advances along with major investments in distribution and refueling infrastructure.

Vehicles appear likely to be more expensive in future years. For conventionally fueled vehicles, the advanced technology required to meet more-stringent CAFE standards is expected to add a couple thousand dollars to the price of a vehicle; for alternatives such as hydrogen or electric, the additional premium could approach $10,000. On the other hand, the energy cost of travel could be much lower in 2050. The study entertains the possibility that oil prices could increase more rapidly than vehicle fuel economy, which would actually lead to a slight rise in per-mile energy costs. If the price of oil stabilizes or declines while vehicles achieve higher fuel economy, however, or if alternatives such as hydrogen, natural gas, or electricity achieve market success, per-mile fuel costs could easily decline to a half or even a third of what they are today.

Future travel scenarios. Expected growth in the U.S. economy and population appear likely to spur continued growth in automobile and truck travel, with the possibility that auto travel could increase by as much as 80% and truck travel could rise by as much as 200% by 2050. At the opposite end of the spectrum, the study also considers the possibility that auto and truck travel could remain flat or even decline modestly, though this possibility would be most plausible in specific states resulting from potential population declines. Transit presently accounts for around 2% of passenger travel for the nation as a whole, and there is little reason to assume that it would shrink to less than this share. The report also considers the possibility that transit mode share could rise to as much as 10% on average; though not unprecedented in historic terms, this would likely require major policy intervention along with other factors motivating greater use of non-automotive travel options.

Federal policy scenarios. Current federal energy and climate policies can be viewed as an ad-hoc mix of subsidies and regulations aimed at the not entirely compatible goals of maintaining low energy costs, increasing energy security, and reducing greenhouse gas emissions. The scenarios for this study include one future in which the current mix of federal policies is maintained in the coming decades; one in which greater emphasis shifts to the goal of reducing energy costs, leading in turn to expanded federal support for increased domestic fossil-fuel production; and one in which the goal of climate mitigation emerges as paramount, resulting in stronger policies—such as carbon pricing—to reduce the use of petroleum, coal, and other high-carbon fuels.

Shifting to transportation funding, failure to increase federal fuel taxes to keep pace with inflation and fuel economy gains over the past two decades has led to growing shortfalls in the federal Highway Trust Fund. The report considers one possible future in which federal fuel taxes continue to stagnate, leading to increasing devolution of funding responsibility to state and local governments; one in which federal fuel taxes are increased or indexed to provide more stable federal transportation funding; and one in which the federal government transitions from fuel taxes to support for direct user charges—some combination of facility tolls, mileage fees, weight-distance truck tolls, and congestion tolls—to raise revenue and promote greater system efficiency.

S.4 Potential Impacts on State DOTs

After developing the future transportation energy scenarios, the team conducted a series of interviews with groups of knowledgeable senior DOT staff from 10 states to solicit insights on how any of the various futures might affect DOTs in the coming decades. Based on the comments received during the interviews along with additional supporting research, the team distilled seven potential impacts of concern.

Declining fuel-tax revenue. More-stringent CAFE standards threaten to undermine the revenue from federal and state fuel taxes, which in combination provide a significant share of highway funding. Assuming continued reliance on some mix of petroleum and liquid biofuels, this problem could be addressed by increasing or indexing fuel taxes to keep pace with inflation and improved fuel economy. Should natural gas, electricity, or hydrogen—any of which might potentially allow for home refueling—achieve market success, then the current system of fuel taxes may no longer suffice.

Higher construction costs. In addition to its role as a fuel, petroleum also serves as a key input for road construction activities and materials, such as the production of asphalt. Any significant increase in the price of oil could therefore translate into much higher costs for road construction and maintenance.

Increasing traffic congestion. Should aggregate auto and truck travel continue to rise due to growth in population and the economy along with a potential reduction in the energy cost of travel, traffic congestion could worsen considerably, with negative implications for both quality of life and the efficiency and reliability of goods movement. The effects would be most pronounced in states with large metropolitan areas and major trade corridors, whereas more rural states could be largely unaffected.

Increasing crashes and fatalities. Increased auto and truck travel could also result in more total crashes and fatalities, which tend to scale with vehicle travel. Yet this impact is highly uncertain; recent federal and state initiatives have already improved safety outcomes, and the possible emergence of autonomous vehicles—though beyond the scope of this report—could lead to dramatic safety improvements in future years.

Difficulty meeting air quality standards. Greater challenges in meeting air quality standards could also arise in some futures. Contributing factors might include a continued reliance on petroleum, a shift to certain alternative fuels such as coal-generated electricity, growth in passenger and truck travel, and the possible further tightening of air quality standards by the U.S. Environmental Protection Agency.

Increasing pressure to mitigate greenhouse gas (GHG) emissions. While public opinion on climate change is currently polarized, any increase in extreme weather events could plausibly galvanize public opinion on the utility of concerted policy intervention. If total auto and truck travel continue to grow, if the transportation sector continues to rely on petroleum or other relatively carbon-intensive alternative fuels, and if the federal government has not enacted a national framework to address climate change, then state DOTs might be called upon to play an increasing role in reducing GHG emissions from the transportation sector.

Greater demand for alternative travel modes. Higher demand for transit and other non-automotive travel options might occur in association with higher vehicle costs or energy costs for travel. Alternatively, significant growth in auto and truck travel could lead to worsening congestion, in turn creating a demand for alternative modes as a means to avoid sitting in traffic. Many, of course, view increased demand for transit, walking, and biking as a positive outcome; from the perspective of most DOTs, with their traditional focus on highways, the main challenge would lie in determining an appropriate and effective role in helping to plan and fund significant expansion for alternative modes to serve this evolving demand.

S.5 Developing Robust Long-Range Plans to Address Impacts

After identifying potential impacts of concern to state DOTs, the next step was to evaluate strategies that states might find helpful in addressing the impacts. Each strategy, as defined in this study, includes multiple policy options with generally similar goals and approaches that a state might pursue. For example, the congestion pricing strategy encompasses the more specific policy options of high-occupancy/toll (HOT) lanes, express lanes, priced facilities, and cordon congestion tolls. In total, the team examined 23 strategies aimed at such objectives as raising revenue, reducing DOT costs, improving automobile and truck travel, improving transit and other alternative travel modes, and promoting energy efficiency or lower-carbon alternative fuels. Drawing on available evidence, the evaluation of each strategy considered expected effectiveness in mitigating the potential impacts listed previously; broader effects on the economy, environment and public health, and equity; barriers relating to financial cost, public acceptance, technical risk, required legislation, or the need for institutional restructuring; required lead time for strategy implementation and results; and caveats regarding applicability in different state contexts (e.g., rural versus urban).

Based on the strategy assessments and through qualitative application of RDM principles, the team then outlined a framework to assist state DOTs in developing robust long-term plans for addressing the potentially significant but also uncertain impacts associated with the range of plausible future transportation energy scenarios. Development of the framework included (a) categorizing strategies based on the appropriate time frame for action and the degree of risk associated with taking action, and (b) rating the relative merits of different strategies within each category.

Time frame for action and degree of risk. In considering whether and when to pursue strategies aimed at a given objective, the application of RDM principles leads to four possible outcomes, as follows:

- **Robust strategies for near-term action.** Impacts that appear likely across all futures can be addressed in the near term with little chance of regret. Given that federal and state fuel taxes are not generally indexed for fuel economy improvements, and with much more stringent CAFE standards scheduled through 2025, declining fuel-tax revenue can be viewed as highly probable, and any shift to alternative fuels would further erode fuel-tax receipts. While increased construction costs stemming from higher oil prices are less certain, efforts to decrease DOT costs through increased efficiency should be beneficial as well. Thus, actions to stabilize or enhance revenue and to reduce DOT costs can be viewed as robust strategies for near-term action.

- **Deferred adaptive strategies to address uncertain impacts.** One of the important conceptual contributions of RDM is that the robustness of a plan can be enhanced by deferring strategies intended to address uncertain impacts until more information about how the future is unfolding becomes available. Specifically, RDM makes use of signposts—leading indicators about future trends—to trigger the initiation or adjustment of adaptive strategies. For this study, the impacts of increased traffic congestion, adverse safety outcomes, air quality challenges, pressure to reduce greenhouse gas emissions, and greater demand for alternative travel modes only occur in some futures and are thus candidates for deferred adaptive strategies.
- **Near-term hedging strategies to address uncertain impacts.** To safely defer action on a mitigation strategy until relevant signposts appear, the lead time required to implement the strategy and achieve intended effects must be less than the amount of advanced warning provided by the signposts. For strategies requiring longer lead times, decision makers may wish to pursue near-term implementation to ensure that the benefits of the strategies are available if needed. Such hedging actions, however, carry the risk of wasted investment should the impacts fail to emerge. In considering whether to pursue hedging strategies, decision makers will therefore need to weigh the benefits of having implemented the strategies should they be needed against the costs of the strategies should they prove unnecessary.
- **Near-term shaping strategies to influence future transportation energy outcomes.** The preceding discussion focuses on strategies to mitigate the potential impacts of alternate plausible energy futures. Rather than simply considering how to respond to whatever future emerges, some states may wish to proactively pursue actions intended to influence or shape future transportation energy outcomes with the goals of promoting energy security, reduced emissions, or more stable energy costs. Like hedging strategies, however, shaping strategies also carry a degree of risk. First, the actions of an individual state may exert comparatively little influence in the context of much broader global energy and technology trends. Second, if a state's efforts do prove helpful in accelerating a transition away from petroleum, it will need to develop alternate funding mechanisms that much sooner (though this challenge may be preferable to the risk of severe climate change).

Rating strategies to address specific objectives. For any of the potential mitigation or shaping objectives considered in the study, there are multiple strategies that could offer some degree of benefit. To assist states in selecting among the options, the team rated strategies in each category, taking into consideration their anticipated effectiveness in addressing the objective in question; their broader effects on economy, environment and public health, and equity; and barriers relating to financial cost, public acceptance, technical risk, required legislation, and possible need for institutional restructuring. Based on these factors, strategies for each objective were designated as most promising, optional high impact, or optional low impact. Strategies rated as most promising offer strong performance and present a generally favorable relationship between benefits and barriers. Strategies in the latter two groupings, in contrast, combine either high benefits with high barriers or low benefits with low barriers and are thus framed as optional.

Summary of strategy timing, risk, and ratings. Table S.2 summarizes appropriate timing, degree of risk, and strategy ratings for the various mitigation and shaping objectives included in the study. Strategies entailing higher degrees of risk—either hedging or shaping strategies—are shown in italicized text.

Table S.2. Framework for strategies to address an uncertain energy future.

Objective	Most Promising	Optional High Impact	Optional Low Impact
Near-term strategies to address highly probable impacts			
Revenue and DOT costs	• Fuel taxes • Tolling or MBUFs • Registration fees • Beneficiary fees • DOT efficiency • Land use	• Carbon pricing • Congestion pricing	• Private capital • Agency energy use
Deferred adaptive strategies and *near-term hedging strategies* to address uncertain impacts			
Traffic congestion	• Congestion pricing • *Goods movement* • TDM • Public transportation	• *ITSs*	• TSM&O
Safety	• Traffic safety • *ITSs* • *Goods movement* • TSM&O		
Air quality or greenhouse gas emissions	• Feebates • Carbon pricing • *Goods movement* • TDM • *Land use*	• Fuel mandates and programs • Public transportation	• Fuel production and distribution • Agency energy use
Demand for alternative travel modes	• Public transportation • TDM • *Land use* • Traffic safety	• Congestion pricing • *ITSs*	• TSM&O
Shaping strategies to influence future transportation energy outcomes			
Shaping future transportation energy outcomes	• *Feebates* • *Fuel taxes* • *Land use*	• *Carbon pricing* • *Fuel mandates and programs* • *Public transportation*	• *Fuel production and distribution* • *Agency energy use*

Note: Strategies entailing higher degrees of risk are shown in italicized text. ITSs = intelligent transportation systems, MBUFs = mileage-based user fees, TDM = transportation demand management, TSM&O = transportation system management and operations.

Because revenue is the most immediate challenge confronting DOTs, it may be helpful to provide additional commentary on the first four strategies listed as most promising. Increasing fuel-tax rates—ideally indexing them to account for both inflation and fuel economy gains—is a promising near-term option that should work well as long as most vehicles rely on petroleum or liquid biofuels. If other alternative fuels gain significant market share, however, then tolls or mileage-based user fees (MBUFs) would provide more stable revenue, allocating costs fairly and promoting more efficient use of the system. Increasing registration fees would be an even simpler option for raising revenue from alternative-fuel vehicles, though it does not offer the same policy advantages as tolling or MBUFs. Finally, beneficiary fees levied on developers or property owners, who also benefit from transportation investments, could further broaden the revenue base in an equitable manner.

S.6 Tailoring Strategic Plans for State Context

States exhibit considerable variation in terms of such factors as size, population density, economic structure, travel patterns, and policy priorities. With that variation in mind, this report closes by suggesting various ways in which states, beginning with the framework outlined previously, can tailor plans to meet their own contextual needs. Opportunities for customizing plans to meet specific state needs include:

- Choosing among strategies rated as most promising for any given objective based on contextual characteristics such as the degree of urbanization, expected population growth, and presence of major goods-movement facilities or corridors.
- Choosing whether to pursue optional high-impact and optional low-impact strategies based on policy priorities and ability to overcome associated barriers.
- Determining the signposts that will be used to trigger deferred adaptive strategies. (The report suggests a number of possibilities, but states may vary in terms of what new information would be viewed as sufficient to precipitate action.)
- Choosing to implement some adaptive strategies in the near term, rather than waiting for future signposts, to address problems that a state may already be facing.
- Choosing whether to implement strategies with long lead times in the near term to hedge against certain plausible futures and the resulting impacts on state DOTs, recognizing the possibility that those futures may fail to emerge.
- Choosing whether to pursue near-term shaping strategies intended to promote future transportation energy outcomes viewed as more desirable, recognizing that such efforts are not guaranteed to succeed.

CHAPTER 1

Introduction

This chapter briefly summarizes the motivation for the study, provides commentary on the approach and scope, and outlines the organization of the remaining chapters and appendices.

1.1 Motivation

The American Association of State Highway and Transportation Officials (AASHTO) funded a series of NCHRP projects to examine long-range strategic issues that state departments of transportation (DOTs) and other transportation agencies are likely to confront in the coming decades. This document presents the results of one of these: NCHRP Project 20-83(04), "Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation." The objectives of the project, as set forth in the call for proposals, were "(1) to determine how the mandate, role, funding, and operations of DOTs will likely be affected by future changes in long-term energy supply and demand and (2) to identify strategies and actions that can be used by the DOTs to plan and prepare for these effects."

Over the past century, the nation's transportation systems have depended largely on petroleum-based liquid fuels, most notably gasoline and diesel. Several factors suggest that this could shift considerably in the coming decades. Increasing global demand for oil has contributed to higher prices and greater price volatility, boosting the relative appeal of petroleum alternatives. Concerns related to energy independence and climate change have provided further motivation for federal and state policies to promote the development and adoption of alternative fuels and vehicle propulsion technologies. Finally, considerable public and private research investment has already been devoted to the exploration and development of alternative-fuel vehicle technologies, including plug-in hybrid-electric vehicles, battery electric vehicles, natural-gas–fueled vehicles, bio-fueled vehicles, and hydrogen fuel-cell vehicles. Some of these are now available on the market, and others are expected to be introduced within just a few years.

While alternative fuels offer great promise, they also face significant obstacles based on such factors as cost, technical maturity, and refueling infrastructure requirements. At the same time, improved drilling and extraction technologies have vastly expanded the supply of economically recoverable petroleum from conventional and unconventional sources, and the federal government recently adopted much more stringent vehicle fuel economy standards through 2025. With more available petroleum, the ability of cars and trucks to travel much farther on a gallon of gasoline or diesel, and a mature fuel distribution network already in place, many experts expect that petroleum—barring major technical breakthroughs for any of the potential competitors—will remain the dominant source of transportation fuel for at least several more decades.

Regardless of whether petroleum remains dominant or is gradually displaced by one or more alternative fuels, state DOTs may be still be affected. One of the major concerns involves state DOT revenue, a substantial share of which derives from federal and state excise taxes on gasoline and diesel. Because such taxes are typically levied on a cents-per-gallon basis, inflation and vehicle fuel economy gains threaten to undermine total inflation-adjusted fuel-tax revenue in relation to total vehicle travel. While this could be addressed by periodically increasing fuel-tax rates or indexing them to keep pace with inflation and average fleet fuel economy, pursuing such action appears to have become more politically challenging for federal and state elected officials in recent decades. Should any of the alternative fuels gain significant market share, the stability of fuel-tax revenue could be further eroded. Other issues that could be affected by changes in fuels and vehicle technologies and prices, posing either challenges or opportunities for state DOTs, include aggregate demand for passenger travel and goods movement, demand for different modes of travel, effects on air quality, and implications for greenhouse gas emissions.

1.2 Approach

The research team, led by the RAND Corporation with assistance from Cambridge Systematics and the Institute of Transportation Studies at the University of California, Davis, pursued an approach to the study consisting of three main steps:

- Develop a broad range of plausible future transportation energy scenarios in the 2040 to 2060 time frame.
- Examine how the future scenarios might challenge state DOTs given their current and evolving roles, mandates, funding, and operations.
- Employ the principles of robust decision making (RDM), a method for effective long-term policy analysis in the context of an uncertain future, to evaluate and identify promising strategies for states to respond to the potential impacts.

Many traditional planning approaches seek to identify one or more futures viewed as likely and then develop a set of strategies tailored for the envisioned futures. While this approach can work quite well for near-term plans resting on a relatively stable set of assumptions, the predict-then-act planning paradigm can prove more problematic when applied to longer-term horizons with greater degrees of uncertainty. Should the future evolve in an unexpected direction, the plan considered optimal may in fact prove to be grossly inferior. In contrast to traditional planning approaches, RDM considers a much broader array of potential future outcomes and then facilitates the development of plans that should perform at least reasonably well regardless of how the future unfolds. The robust quality of RDM planning is enabled in part through the use of adaptive strategies that can be triggered or modified as new information about the future becomes available (Lempert, Popper, and Bankes 2003).

1.3 Scope

As further context for the material and findings contained in this report, it may be helpful to offer several additional comments about the scope of the study as understood and executed by the research team.

Focus on fuels and vehicle propulsion technologies. The explicit focus of this study was on potential future trends and outcomes in transportation fuels and vehicle propulsion technologies and their respective prices and performance. These are not, however, the only uncertainties confronting transportation policy makers. Other emerging issues—such as evolving attitudes toward transportation among younger generations, social networking and improved telecommunications, and the possible advent of autonomous vehicles in the coming years—could likewise affect future travel patterns in profound ways. Though important and worthy of research in their own right, such issues and uncertainties are viewed as beyond the main scope of this study and thus are mentioned or considered only in passing. The final chapter in the report suggests several additional lines of research that could complement the findings from this study.

Focus on highways, transit, and rail. Among the various available modes of transport, this report focuses mainly on passenger vehicle travel and trucking, and to a lesser degree on public transit and passenger and freight rail as competitors to cars and trucks. The traditional role of the state DOT has been to fund, plan, construct, operate, and maintain highways and other state roads. While DOTs have become more involved with other modes over time, their roles in other modes are often limited to oversight or planning functions; in terms of both staffing and funding allocations, highway travel remains the primary focus for most state DOTs. As of 2009, for example, 64% of all state and local transportation expenditures were devoted to roads, with another 24% allocated to transit [Bureau of Transportation Statistics (BTS) 2012c].

Additionally, passenger vehicle travel and trucking account for significant shares of both total travel and transportation energy consumption. Automobiles carried about 87% of all passenger miles in the United States in 2010 (BTS 2012a), while trucks were responsible for about 31% of the ton-miles of U.S. freight in the same year (BTS 2012b). Cars and trucks together accounted for about 71% of all energy consumption in the transportation sector as of 2010 [Oak Ridge National Laboratory (ORNL) 2012, Table 2.6]. Any significant changes in transportation fuels or prices are thus likely to exert their most dominant effects on passenger vehicles and trucks—aligning with the main focus on roads and highways for most state DOTs—with additional implications for such competing modes as transit, passenger rail, and freight rail.

Focus on state-level policies. This report identifies a number of ways in which plausible transportation energy futures might create challenges for state DOTs, such as declining fuel-tax revenue, increased traffic congestion, and greater difficulties meeting federal air quality standards. Among the range of potential policy responses to these challenges, some are reserved for federal-level action, others could be appropriate for state-level implementation, and still others fall principally in the domain of local governments. This report—with its primary audience of state transportation decision makers—focuses on the subset of policies that could either be implemented or influenced through state-level action. The analysis also recognizes that many of the potential policy responses to challenges discussed in the report—for example, increasing fuel-tax rates or introducing alternate revenue mechanisms—lie beyond the authority of most state DOTs. With concurrence from the project panel, the report therefore considers policy actions that a state DOT could pursue on its own initiative, along with actions that might require state legislation, a governor's executive order, or collaboration with other state agencies.

1.4 Organization of the Report

Figure 1.1 shows the logical flow of the analysis for this study, which in turn shapes the organization of the report. To understand how evolving fuel sources, vehicle technologies, and prices might affect state DOTs, it was useful to consider current DOT roles, mandates, funding, and operations, as well as how they are evolving over time. In parallel, the team also investigated trends and future prospects for a range of technical, socio-demographic, and policy variables likely to influence future transportation energy outcomes. Based on this research, and with additional input from a series of interviews with subject matter experts, it was possible to construct a set of future transportation energy scenarios for the 2040 to 2060 time frame. In essence, the scenarios represent plausible ranges or outcomes for various factors of interest—such as the price of oil, the mix of fuels used to propel the vehicle fleet, growth in passenger vehicle travel, and future federal energy policies.

After developing the scenarios, the team conducted a second set of interviews, this time with state DOT staff, to consider how some of the plausible futures might affect DOTs, along with appropriate policy responses. Beginning with state DOT staff suggestions as a starting point, the next steps were to outline a more comprehensive set of strategies that states might find helpful in mitigating certain impacts and to carefully assess the strengths and limitations of each. Finally, the team employed the principles of RDM to construct a framework for assisting state DOTs to develop effective long-range plans for addressing uncertain but potentially significant changes in future transportation energy sources, technologies, and prices, which was further refined in a follow-on workshop with state DOT staff. In essence, the framework offers a logic for selecting, combining, and timing the pursuit of certain strategies, with the aim of minimizing the chances of regret—that is, minimizing the chances of either investing in a strategy that proves unnecessary given how the future unfolds or failing to have implemented a strategy that would have been useful.

The organization of the report follows the logical flow shown in Figure 1.1. Following this introduction, Chapter 2 discusses current and evolving roles, mandates, funding, and operations for state DOTs. Providing this information at the outset offers helpful insights into some of the ways that evolving transportation energy supplies might affect state DOTs and also suggests useful factors to include within the future transportation energy scenarios developed for the study.

Next, Chapters 3 and 4 summarize background research used to help develop the range of plausible transportation energy futures. Chapter 3 discusses the current status along with future opportunities and barriers for some of the more promising fuel and vehicle technologies available. These include anticipated advances for conventional vehicles along with prospects for natural gas, biofuels, electric vehicles, and hydrogen fuel-cell vehicles, both in the light-duty fleet (cars and light trucks) and medium- and heavy-duty vehicle applications. Chapter 4 considers broader socio-demographic and policy factors that may also play a role in determining future travel demand and mode choice, and in turn aggregate transportation energy consumption. These include trends in population, economy, and land use, along with current policy debates in the areas of energy, climate, and transportation funding.

Drawing on this background research, Chapter 5 presents the plausible transportation energy scenarios developed for the study, which consist of a series of elements divided into three categories: energy, travel, and federal policy. Energy-related elements, such as the future price of oil and the mix of fuel types in use within the on-road fleet, describe possible evolutions

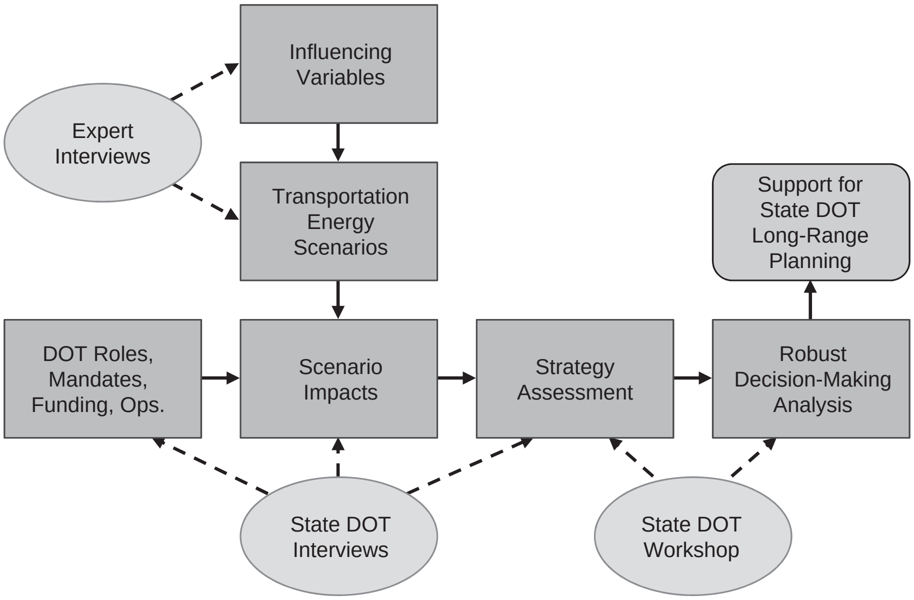


Figure 1.1. Logical flow of the analysis.

in energy use and technologies, and in some cases these may affect state DOTs in a direct way. For example, a significant shift away from petroleum-based fuel would lead to a steep decline in fuel-tax revenue. Next, travel-related elements, such as the growth in automotive or truck travel, are likely to be heavily influenced by evolving energy trends and technologies and will often affect DOTs in a more direct manner. Cheaper per-mile driving costs associated with electric vehicles, for example, could stimulate additional growth in vehicle travel, presenting state DOTs with the challenge of greater traffic congestion. Finally, elements related to federal policies in the areas of energy, climate, and transportation funding are likely to influence both energy and travel trends, and they may also expand or constrain the set of policy choices available to state DOTs in future decades. If the federal government were to allow broader application of tolling on the Interstate system, for instance, a state might gradually replace fuel-tax revenue with greater reliance on toll collection.

Chapter 6 identifies the potential impacts of greatest concern for state DOTs. Determined after the future scenarios were constructed and input was obtained through the state DOT interviews, these include reduced revenue, increased costs, greater traffic congestion, increased crashes and fatalities, mounting pressure to reduce greenhouse gas (GHG) emissions, difficulty in meeting air quality goals, and greater demand for more affordable, non-automotive travel options.

Next, Chapters 7, 8, and 9 focus on the policy analysis conducted for the study. Chapter 7, also drawing on insights from the state DOT interviews, compiles a set of strategies, or coordinated policy actions, that states may wish to consider, either to mitigate the negative impacts associated with certain plausible futures or to enhance the prospects for achieving a more sustainable energy future. The chapter also offers a summary of the relative strengths and limitations for each of the strategies considered. Building on this assessment, Chapter 8 employs RDM principles to create a framework intended to assist state DOTs in the development of robust long-range plans for addressing an uncertain energy future. The framework distinguishes between strategies appropriate for near-term action and strategies that can be safely deferred until more information about the future becomes available, as well as between strategies entailing either lower or higher degrees of risk. Chapter 9 then explores possible ways in which individual states can tailor elements of the robust decision-making framework to meet their own contextual challenges. For example, the set of strategies selected to mitigate a given challenge might vary depending on whether a state has a large metropolitan population or is instead largely rural. Chapter 10, which concludes the main body of the report, offers some suggestions for additional research that could complement the findings from this study.

The report then includes a series of appendices that provide more details about certain facets of the analysis. First, Appendices A, B, C, D, and E contain detailed discussions of the potential fuels and vehicle technologies likely to compete for market share within the light-duty fleet (passenger cars and light-duty trucks) in the coming decades. These include conventional petroleum-fueled vehicles, natural gas, biofuels, electric vehicles, and hydrogen. Appendix F then discusses the promise of some of these fuels and technologies in the context of medium- and heavy-duty vehicle applications. The summary discussion of fuels and vehicle technologies in Chapter 3 draws on the data and analysis presented in these six appendices.

Next, Appendices G and H provide additional discussion of some of the broader socio-demographic and policy factors that could influence future energy and travel outcomes. Appendix G focuses on trends in population, economy, and land use, while Appendix H considers ongoing debates and future prospects for federal policies relating to energy, climate, and transportation funding. The summary material in Chapter 4 draws on the findings from these two appendices.

Finally, Appendices I, J, K, L, and M present and assess strategies that state DOTs might find helpful in responding to or, alternatively, seeking to influence, an uncertain energy future. Appendix I considers strategies aimed at stabilizing or enhancing transportation funding, while Appendix J examines strategies tailored to help reduce DOT costs. Next, Appendix K encompasses strategies to improve auto and truck travel—for example, to reduce congestion or to improve traffic safety, while Appendix L considers strategies to enhance other modes of travel. Appendix M then examines strategies that states might employ to foster greater energy efficiency or increased use of alternative fuels.

References

BTS. 2012a. Table 1-40: U.S. Passenger Miles. *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_40.html (accessed March 14, 2013).

BTS. 2012b. Table 1-50: U.S. Ton-Miles of Freight (BTS Special Tabulation). *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_50.html (accessed March 14, 2013).

BTS. 2012c. Table 6-8: Transportation Expenditures by State and Local Governments: 2009. *State Transportation Statistics 2011.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/state_transportation_statistics/state_transportation_statistics_2011/html/table_06_08.html (accessed March 14, 2013).

Lempert, R. J., S. W. Popper, and S. C. Bankes. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Policy Analysis.* RAND Pardee Center, Santa Monica.

ORNL. 2012. *Transportation Energy Data Book*, Edition 31. U.S. Department of Energy.

CHAPTER 2

State DOT Roles, Mandates, Funding, and Operations

Under any plausible energy future, including continued reliance on petroleum, state DOTs will likely undergo institutional, financial, and structural change to adapt to evolving conditions, demands, and constraints. The nature of these changes and the resulting long-term impacts on decision making remain uncertain and will most likely vary from one state to the next.

To better understand how changes in transportation fuels and vehicle propulsion technologies and prices could affect state DOTs in the coming decades, this chapter surveys current DOT roles, mandates, funding, and operations and considers their evolution over time. This exercise is fundamental to the research effort, providing the context for identifying potential impacts of alternate energy futures and suggesting the utility of including certain elements within the plausible future scenarios developed later in the report. For example, understanding that most DOTs rely on fuel taxes for a significant share of their highway revenue, and that such taxes are commonly levied on a cents-per-gallon basis, indicates that it would be helpful for the scenarios to consider potential changes in vehicle fuel economy in the coming decades.

The information presented in this chapter draws on a review of state DOT publications, national datasets, and current literature. This includes the 2008 report prepared by ICF International, *Long Range Strategic Issues Facing the Transportation Industry: Final Research Plan Framework*, which identified pressing future issues to be investigated as part of the NCHRP Project 20-83 research series. The material in this chapter was further refined through a series of interviews with state DOTs and national thought leaders.

While this chapter aims to provide an overview of state DOTs, it should be stressed from the outset that each state DOT is unique. The current organization and responsibilities in each state DOT are products of the historical development, economy, constitutional structure, infrastructure and assets, and travel patterns and demands on the transportation system within that state. As a result, it can be challenging to accurately characterize the roles, mandates, funding, and operations of state DOTs as a group. The approach in this chapter is to offer high-level summary information relevant to state DOTs in general, while occasionally highlighting developments in certain states to illustrate specific themes, issues, or variations.

To provide additional context for the study, this chapter opens with a brief historical review of how energy trends and developments have affected or influenced state DOTs in previous decades. Next, the chapter presents a detailed review of current state DOT roles, mandates, funding, and operations and considers how these have shifted and changed over time. The chapter then closes by highlighting several broader themes relating to the evolution of state DOTs in recent decades and the challenges to be confronted in coming decades.

2.1 Historical Effects of Energy Trends on State DOTs

As public institutions, state DOTs must evolve and adapt to changing travel demand, emerging technologies, current policy priorities, and shifting external economic and development patterns. Relative to other state agencies, DOTs also tend to be more visible and must be more responsive to the traveling public.

DOTs have been asked to address energy issues, including potential shifts in energy supplies, at various junctures over the last few decades. Current public debates over energy concerns and the appropriate roles and actions for DOTs center on such issues as energy security, the economic effects of fuel prices on growth and prosperity, and the threat of climate change from the combustion of fossil fuels. State DOTs must also be internally responsive to energy issues since variations in fuel and construction material prices can affect budgets for maintenance, operations, and capital programs. These are largely long-term issues reflecting supply and demand trends and the dominance of petroleum-based motor fuels. This report considers future energy scenarios in which petroleum remains dominant, along with scenarios in which other alternative fuels and vehicle propulsion technologies achieve significant market share. To consider how the roles, mandates, finances, and operations of DOTs might change in the future given significant shifts in energy supplies, it is instructive to consider past examples.

In the 1970s, energy figured prominently in the national debate, driven by concerns over fuel prices and availability after supply disruptions during the 1973 oil embargo. The political focus on energy issues prompted federal policy innovations and state DOT responses that continue to shape transportation today. In 1974 and 1975, in response to oil price shocks, several important pieces of federal legislation were introduced. These included a trial period of year-round daylight savings time, a national 55-mph speed limit, adoption of corporate average fuel economy (CAFE) standards, the National Mass Transportation Assistance Act, and Highway Fuel Economy Test standards and vehicle emissions rating programs. Some state-level actions were taken as well. In 1973, for example, the governor of Florida introduced proposals to further reduce the speed limit on state government cars to 50 mph and to stagger work hours for state employees to help offset the effects of energy prices on state coffers [Associated Press (AP) 1973]. Also in 1973, the State of California adopted legislation enabling the creation of "special lanes for buses in metropolitan areas" as incentives for commuters to reduce energy consumption by shifting to transit (The Daily Union Democrat 1973). And in 1974, the State of Washington's Energy Policy Council recommended creating an integrated state department of transportation to better address future energy issues (Spokane Daily Chronicle 1974).

Some of these approaches lasted only as long as fuel shortages persisted, while others have become fundamental components of today's transportation regulation and policy framework. Transportation energy concerns eased through the 1980s and 1990s as fuel prices stabilized, with most state action centering instead on fuel-tax rates and declining revenues. Over the past decade, fuel prices have surged and become volatile once again, prompting sharp cutbacks in driving reflected in unprecedented declines in national vehicle miles traveled during 2007 and 2008. Federal and state responses to energy challenges in recent years have been more tempered than those that occurred 30 years earlier. This may be because many immediately feasible demand management and operations-based responses have already been instituted. More technically, financially, or socially challenging solutions—such as the development and adoption of alternative fuels to mitigate fuel price volatility, significant expansion of transit capacity to offer more alternatives to driving, or the use of greenhouse gas emissions pricing schemes to promote lower-carbon fuels—face much longer adoption time frames.

Over the 30-to-50 year horizon considered in this report, it is not certain that changes in energy supplies or prices will be as abrupt as those of the 1970s. That period in history does demonstrate, however, the strong and ongoing connection between state DOTs and transportation energy and highlights the fact that energy issues can bring about long-term institutional change in the roles, responsibilities, and operations of state DOTs. The remainder of this chapter provides a summary overview of state DOT roles, mandates, funding, and operations, highlighting the energy context where relevant.

2.2 State DOT Roles

State DOTs have historically been responsible for planning, constructing, and maintaining state highways and bridges and providing oversight of local roads and multimodal systems. Over time they have evolved from highway-centric departments primarily focused on engineering and construction to more integrated transportation agencies with increasing responsibilities across modes, activities, and functions.

2.2.1 Historical Evolution of State DOTs

State agencies with the power to construct or regulate roads, bridges, canals, railways, and private transit providers emerged in the early decades of the 20th century. These agencies focused mainly on the provision of state highways and bridges, with most roads remaining under local jurisdiction. Over the next half century, these agencies assumed greater responsibilities, often merging with other mode-specific departments and taking on greater involvement in safety, commerce, and urban development. Through the 1960s and into the 1970s, many state highway departments were officially renamed state transportation agencies, reflecting the evolution of intermodal mandates and responsibilities. Today, state DOTs generally have expansive responsibilities to operate, or at least oversee, intrastate transportation systems, including highways, rail, aviation, waterborne transportation systems, and transit infrastructure. In addition, DOT activities have evolved beyond engineering and construction to include roles in financing, planning, safety, freight, economic development, environmental protection, archeology, and other emphasis areas. For many state DOTs, however, the primary focus, measured in budgetary terms, remains on highways.

DOT roles have changed over time in response to emerging issues, changes in federal and state mandates, technological advancements, and the evolving expectations and demands of their customers—the users of a state's transportation systems. In some cases, agency responsibilities have expanded. For example, the Colorado High Performance Transportation Enterprise Board was created within the DOT to leverage new innovative finance mechanisms. Washington State DOT created new interagency offices and funded staff positions through its Sustainable Transportation and Climate Change program to further that state's commitment to sustainability goals. And the Minnesota DOT has in recent years become increasingly active in freight and passenger rail planning efforts and initiatives. In other cases, fiscal pressures and changing workforce dynamics have led DOTs to scale down direct involvement in engineering and construction activities and adopt more oversight roles through expanded reliance on contractors (Warne 2003). Many state agencies such as the Ohio DOT are outsourcing more services traditionally provided by the state, such as rest area operation and maintenance, aerial surveying, and traffic data collection.

State DOTs have traditionally focused on activities related to roadways and vehicles. Planning and construction of the Interstate highway system dominated DOT attention through the 1950s and 1960s. Not until the 1970s and 1980s did state DOTs begin to significantly expand their roles in other transportation modes. Deregulation of the airline industry in the late 1970s, accompanied by an increase in federal funding for aviation planning, necessitated that state DOTs support local airport authorities and help provide service to smaller communities. In the same time period, restructuring in the railroad industry resulted in state DOTs assuming responsibility for abandoned lines and even acquiring small short-line railroads. With declines in federal funding for urban transit through the 1980s, many state DOTs became more involved in planning, funding, and providing technical assistance to urban and rural mass transit providers (Goetz et al. 2004). Other states, such as Alaska, Washington, and Florida, have long had roles in the operation of public ferries or other water transportation systems.

State roles in intermodal transportation have increased, particularly since the passage of the 1991 Intermodal Surface Transportation Efficiency Act, and continue to expand today. Relative to the amount of staff, resources, and activities that DOTs dedicate to highways and bridges, however, the responsibilities for other transportation modes are of a much smaller scale. As of 2011, just eight states had full-time employees whose primary function was transit, 15 states had employees dedicated to aviation, and 19 states had employees dedicated to water transportation (U.S. Census Bureau 2012a). These employees may or may not be included within the state DOT, but the data provide some light on the relative involvement of state DOTs in other modes.

Additionally, while states do play an important role in financing public transit services, just 6% of all state government transportation-related expenditures in 2010 were dedicated to transit (U.S. Census Bureau 2012b). Highways are likely to continue to be the focus of many states, given the volume of vehicle travel and relative financial needs of these systems.

DOT roles and responsibilities will no doubt continue to evolve as transportation needs and service models change. The DOT of the future will likely look and act more like a private-sector business, with a greater focus on the customer, performance, and financial sustainability (Lockwood 2006).

2.2.2 Today's DOT

The exact organizational structure, service model, authority, mandated responsibilities, and scope of activities of DOTs varies considerably from state to state. In an effort to catalog the variety of DOT roles and responsibilities across the nation, the research team reviewed the organizational structures, divisional responsibilities, and major activities of a selection of state DOTs, including Alaska, California, Colorado, Delaware, Florida, Idaho, Kentucky, Louisiana, Maryland, New York, North Carolina, Ohio, Texas, and Washington. The review was structured to include both large and small agencies and states with diverse multimodal systems, along with states that are mainly dominated by highway transportation. The review also included state DOTs that have recently reorganized or that have relatively distinct organizational structures. Descriptions of key roles and responsibilities, based on organizational structure, were synthesized. While the nomenclature, organization, and management of state DOTs vary widely, core roles and functions (listed in Table 2.1) are generally consistent.

Table 2.1 organizes DOT core functions and illustrates the roles of a generic state agency. DOTs generally have significant responsibilities for the development and operation of transportation systems. Development roles may include coordination or oversight of activities across modes, policy development, planning activities, and a range of pre-construction responsibilities (e.g., review, permitting, programming, and development). Operations roles include research and development for materials and design standards, engineering and construction oversight and supply, and ongoing maintenance and operations activities. Agencies also perform various administrative roles, both internal to the organization, such as management and human resources, and external, such as contracting and communications. Finally, in most states, there are shared organizational roles, or at least close relationships, between the DOT departments or divisions responsible for traffic safety and law enforcement and for driver licensing and vehicle registration.

2.3 Federal and State Mandates on State DOTs

Construction and maintenance of the National Highway System, inland water navigation facilities, aviation facilities, and other federally regulated interstate commerce or transportation systems have been largely delegated to the states, with financial support and technical assistance provided through the U.S. Department of Transportation and other

Table 2.1. Catalog of generalized state DOT roles and functional areas.

Systems Development	*Systems Operations*
• Policy and planning • Intermodal systems • Environment and permitting • Programming • Finance • Right-of-way • Information management	• Design • Materials • Engineering • Construction • Maintenance • Facilities and equipment • Management and operations • Tolling
Agency Administration	***Agency Affiliates***
• Budget and finance • Public relations • Human resources • Information technology • Executive management	• Safety and enforcement • Motor carrier services • Motor vehicle and driver licensing

federal agencies. At the state level, DOTs have the primary responsibility for constructing, operating, and maintaining intrastate highway and transportation systems and providing for the administration and oversight of regional and local transportation facilities. In carrying out these responsibilities, state DOTs are subject to conditions, restrictions, and duties imposed by both federal and state laws. These mandates are typically intended to further national or state goals in the areas of civil rights, education, environmental protection, public safety and security, economic development, and others. Federal mandates can affect state DOT decision making in many ways, such as requirements or funding incentives to follow prescribed planning processes for transportation investments or environmental protection or to comply with certain standards or targets, as with the national drinking age limit and certain highway safety provisions. State mandates may direct state DOTs to adhere to additional state planning processes, to support state environmental or energy conservation goals, or to meet certain performance and level-of-service standards.

2.3.1 Federal Mandates in State Transportation Decision Making

Federal transportation policies and regulations are promulgated through requirements included within major public laws, presidential executive orders, or agency rulemaking. The Congressional Budget Office (CBO) defines a federal mandate as any provision in legislation, statute, or regulation that imposes an enforceable duty on state or local governments (CBO 2010). Some federal mandates carry the force of law, while others are imposed as a condition of the receipt of federal funds. Transportation-related mandates are interpreted and implemented—that is, applied to state and local agencies subject to the mandates—by the U.S. Department of Transportation and other federal agencies.

The Federal Highway Administration's Policy and Guidance Center has established a framework for federal transportation mandates along a spectrum of enforceability that spans legislation, regulation, policy, guidance, and information. Legislation (e.g., the National Environmental Policy Act) involves an act of law that creates enforceable mandates. In some cases the mandates may be enforced for any state DOT projects or activities, while in others they may be enforced only as a condition for the receipt of federal aid. Regulations are administrative or agency statements with the full force of law that are typically intended to implement legislation; examples include executive orders or rules codified in the Code of Federal Regulations (CFRs). Policies are agency statements, such as FHWA's Value Engineering Policy Directive, that establish a course of action or procedure on regulatory or technical issues with the expectation that states will adhere without deviation. Guidance includes agency statements providing advice or assistance on regulatory or technical issues intended to influence decisions and actions to achieve an expected program outcome. The implied agency expectation is that guidance will be considered in decision making. Information is provided purely for educational purposes without implied or explicit agency expectations (FHWA 2012).

Examples of enforceable federal mandates are the Clean Air Act of 1963 and the Americans with Disabilities Act of 1990, both of which include requirements for state regulation of public and private transportation facilities regardless of the contribution of federal funds to a project. Other federal regulations, such as the National Historic Preservation Act of 1966 and the National Environmental Policy Act of 1969, are conditional on the use of federal-aid highway funds and may be enforced through the withholding of those funds for noncompliance. For example, the National Maximum Speed Law passed in 1974 (repealed in 1995) required states to reduce speed limits to or enact them at 55 miles per hour on major arterial roads. This was enforced as a condition of receipt of the federal-aid highway funds. In 1986, Nevada ignored this mandate and posted a 70 mph speed limit on a stretch of Interstate 80. The FHWA promptly informed the state that it could no longer approve projects and was withholding funds until the state was in compliance [Supreme Court of the United States (SCOTUS) 1989]. While the conflict was quickly resolved, this incident does demonstrate the power of the federal government in mandating certain state actions, in the sense that any state choosing to forgo federal funding would face significant difficulties in raising sufficient transportation revenue on its own.

With the exception of certain major laws concerning civil rights or the environment, the federal government primarily sets policy and influences decision making at the state level for highways, safety, and transit through the funding mechanisms of surface transportation authorization acts, such as the Moving Ahead for Progress in the 21st Century Act of 2012 (MAP-21). States are subject to the regulations and requirements of funding authorizations and other federal acts governing environmental review, air quality non-attainment, waterborne commerce, freight common carriers, intercity bus and rail service, aviation safety and security, and highway safety, among many others. It would require significant effort to catalog each regulation, policy, or program within MAP-21 and prior transportation authorization acts along with any other federal regulations, policies, or directives that impose requirements on state DOTs. For the sake of this discussion it is assumed that most states participate in most significant federal transportation programs and, therefore, choose to comply with most federal guidelines.

Mandates embedded in federal surface transportation policy have influenced the organizational models, roles and responsibilities, and operations of state DOTs. Indeed, the organization of DOTs often reflects the major federal mandates and requirements that they must address, with offices or coordinator positions focused on such issues as intermodal planning and policy functions, performance measurement, environment, historical preservation, bicycle and pedestrian planning, road maintenance and bridge inspections, and motor vehicle and commercial carrier safety, enforcement, and licensing. Federal mandates may also influence programming and financing decisions through dedicated funding for certain programs, such as the Transportation Alternatives or Congestion Mitigation and Air Quality Improvement Program, or through prohibitions on certain finance options, such as restrictions on the tolling of existing capacity on federal-aid highways. Rules and regulations may also dictate performance standards for certain state DOT operations, including conformity standards for regional intelligent transportation systems architecture or work-zone safety programs. Table 2.2 provides examples of major legislation, codified regulations, agency policy directives, and agency guidance pertaining to major issue areas (FHWA 2012).

2.3.2 State Mandates in Transportation Decision Making

Mandates adopted by state legislatures confer exact and enforceable requirements on state DOTs that include planning requirements, financing authority, modal or regional responsibility, and program requirements. Legislative mandates vary considerably from state to state, given the scope of authority granted to the DOT and the range of activities undertaken by an agency. States may also exert authority over DOTs through legislative committees or executive appointment of agency directors and executives, as well as through formal state transportation commissions.

State mandates may restrict or enable the funding mechanisms available to the DOT, the ability of the DOT to enter into public–private partnerships, or the ability to govern the disposition of transportation funds. Other laws may impose project prioritization or performance standards on the DOT in terms of the state of good of repair of bridges and highways. For example, in 1994 the Washington State legislature passed statutes that directed the DOT to implement a priority project prioritization system, based on factual needs and life-cycle costs and benefits (Revised Codes of Washington 47.05.010). State laws may also codify additional requirements beyond federal mandates, for example requiring that state goals or planning factors be reflected in federally required state transportation plans. In 2011, Vermont revised its statutes governing transportation planning such that “complete streets” principles would be integral to the transportation policy of the state (Vermont House Bill 198). In some cases, states may also mandate that a DOT pursue a certain infrastructure project or invest state funds in priority or intermodal projects. In 2003, the Florida legislature created the Strategic Intermodal System requiring certain annual allocation of state transportation funds to priority investments across all modes (Florida Statutes XXVI.339.61). State legislative actions impose any number of mandates on DOTs, from seemingly small and detailed requirements to significant infrastructure investment projects, studies, or programs.

The following is a summary of recent energy and environmental mandates adopted by states that directly affect the decision making of DOTs. The examples highlighted

Table 2.2. Examples of federal mandates and implementing regulations.

Issue Area	Legislation	Regulation	U.S. DOT Policy	U.S. DOT Guidance
Air quality	Clean Air Act of 1963, Section 176(c) as amended by SAFETEA-LU.	Conformity of Transportation Plans, Programs, and Projects Developed, Funded or Approved Under Title 23 United States Code (U.S.C.) or the Federal Transit Laws	U.S. Environmental Protection Agency (EPA) Area Designations for the Revised 24-Hour Fine Particle National Ambient Air Quality Standard	Guidance for Quantifying and Using Emissions Reductions from Best Workplaces for Commuter Programs in State Implementation Plans and Transportation Conformity Determinations, 2007
Environment	The National Environmental Policy Act of 1969	Executive Order 13274: Environmental Stewardship and Transportation Infrastructure Project Reviews	Policy Statement on Bicycle and Pedestrian Accommodation Regulations and Recommendations, 2010	Environment and Planning Linkage Processes Legal Guidance, 2005
Pavement and materials	N/A	N/A	Final Policy Statement: Life-Cycle Cost Analysis, 1996	Pavement Preservation Definitions, 2005
Planning	SAFETEA-LU Section 1927	Title 23, CFR Part 450: Subpart C - Metropolitan Planning	U.S. DOT, Accommodating Bicycle and Pedestrian Travel: A Recommended Approach , 2008	Recreational Trails Program Compliance Memorandum, 2009
Safety	Title 23, U.S.C. Section 148: Highway Safety Improvement Program	Title 23, CFR Part 1208: National Minimum Drinking Age	U.S. DOT, Formal Speed Policy and Implementation Strategy, 1997	Guidance Regarding Use of Funding Flexibility in Highway Safety Improvement Program, 2006

here focus on mandates for which the state DOT has direct implementation responsibility and that are directly related to energy concerns.

Alternative fuel and vehicle infrastructure. Nearly every state provides consumer or producer incentives, such as rebates or access to high-occupancy vehicle (HOV) lanes, to promote the adoption of alternative fuel and vehicle technologies [Office of Energy Efficiency and Renewable Energy (EERE) 2012]. Several states promote changes in fleets by investing in necessary infrastructure such as refueling and charging stations or fuel distribution networks. The following examples highlight a range of state mandates in relation to alternative fuels and vehicle technologies:

- In 2009, Washington State passed legislation requiring the DOT to install charging outlets for electric vehicles in areas such as rest stops and maintenance facilities (Second Substitute House Bill 1481) as part of the state's participation in the West Coast Green Highway Initiative. This partnership involving Washington, Oregon, California, and British Columbia is intended to speed adoption and use of electric vehicles by providing a network of public-access recharging locations along the I-5 corridor.
- In 2009, Connecticut passed legislation requiring its DOT to develop a plan for implementing a zero-emission bus fleet, including the technological, facility, and financial arrangements necessary for converting bus fleets and locating hydrogen refueling stations along state highways (Public Act No. 09-186).
- In 2008, Pennsylvania passed legislation requiring its DOT to certify the availability of on-road diesel infrastructure to successfully handle, store, blend, and distribute biodiesel-blended fuels (Act 78). In response, the DOT conducts infrastructure assessment surveys of pipeline fuel terminal operators and the commonwealth offers grant programs for necessary upgrades.

- In 2004, by executive order, California committed to support hydrogen as a potential fuel source for transportation through a variety of actions (Executive Order S-7-04). Specific actions included the designation of the California Hydrogen Highway Network and the deployment of a network of hydrogen fueling stations.

Energy efficiency of public agencies. Many states pursue policies in the spirit of leading by example through the introduction of energy efficiency technologies and practices in state operations, facilities, and fleets. All but five states have now instituted energy conservation targets for state agencies. As of 2010, 19 of these states had enacted definitive energy efficiency standards or requirements for state-owned vehicle fleets (Molina et al. 2010). The following examples provide a selection of significant energy-efficiency policies with direct implications for DOTs.

- In 2009, Washington State passed legislation requiring state agencies to satisfy 100% of fuel needs for all state fleet vessels, vehicles, and construction equipment from electricity or biofuels by 2015. In 2008, the Washington State DOT completed a pilot program studying the feasibility of biodiesel for use by the state ferry system, which consumes 18 million gallons of traditional diesel each year (Washington State University et al. 2009).
- In 2007, Utah passed legislation requiring state agencies to actively manage their vehicle fleets for energy efficiency objectives [House Bill 110, Statute 63A-9-401.5(3)]. Implementation includes plans and programs to decrease the overall volume of fuel used, increase fleet fuel economy, and improve vehicle maintenance practices.
- In 2007, by executive order, New Mexico established a statewide goal of reducing energy consumption per capita 20% by 2020 (Executive Order 053). The order requires executive branch agencies, including the DOT, to achieve a 20% reduction below 2005 levels in state fleet and transportation-related activities by 2015, based on the average transportation-related energy usage per state employee.
- In 2005, by executive order, Minnesota required state agencies to reduce the petroleum consumption of fleet vehicles 50% by 2015 (Executive Order 04-10). The same order mandated that 75% of new purchases of state-owned vehicles be powered by biodiesel, ethanol, or hydrogen.

Energy intensity of the transportation sector. Relatively few states have instituted mandates that explicitly address energy use across the broader transportation system, though many DOT policies seek to influence this issue indirectly. The goal of reducing energy intensity is often targeted through the measurement of and reduction in greenhouse gas emissions levels. As of 2008, nine states were considering greenhouse gas emissions in transportation planning and programming (ICF 2008). As of 2012, four states had adopted targets for the reduction of vehicle miles of travel (C2ES 2012), while 19 states had instituted comprehensive growth management policies to link land use and transportation planning as of 2010 (Bhatt, Peppard, and Potts 2010). The following examples identify states with definitive regulations or requirements for DOTs relating to energy intensity and emissions from the entire transportation sector.

- In 2008, Washington State passed legislation requiring its DOT to develop strategies for achieving an 18% reduction in annual per-capita vehicle miles traveled by 2020, a 35% reduction by 2035, and a 50% reduction by 2050 (Engrossed Second Substitute House Bill 2815).
- In 2008, Massachusetts approved legislation setting an economy-wide greenhouse gas emissions reduction target of 80% by 2050 (Senate Bill No. 2540). The act requires state agencies to formulate plans to achieve targeted reductions through specific strategies. In response, the Massachusetts DOT adopted the GreenDOT Initiative in 2010, which includes policies for incorporating sustainability in DOT activities and strategies for reducing GHG emissions in the transportation sector by 7.3% below 1990 emission levels by 2020 and by 12.3% by 2050 (Massachusetts DOT 2010).
- In 2008, California passed the Sustainable Communities and Climate Protection Act, often referred to as SB (Senate Bill) 375, an innovative measure to link regional land use and transportation planning with the express goal of reducing GHG emissions from passenger vehicles. SB 375 requires metropolitan planning organizations (MPOs), working with the state Air Resources Board and local communities, to set emission reduction targets and identify implementation strategies in adopted sustainable communities strategy documents.

Efficiency of transportation system operations. State legislation mandating that DOTs implement programs or actions aimed at improving transportation system efficiency and operations has been relatively uncommon in the past. Increasingly, though, states are directing agencies to examine or implement programs such as congestion tolling, mileage-based user fees (MBUFs), and other user fees intended to mitigate congestion and promote more efficient use of the system. By increasing the marginal price for using a facility to more closely align with the marginal costs imposed by that use, including the cost of providing and maintaining the infrastructure as well additional costs such as congestion delays or harmful emissions, such fees create an incentive for travelers to ration their least-valued trips, in turn helping to reduce congestion and improve the economic efficiency of the system (Wachs 2003).

Currently there are at least 22 operationalized congestion pricing projects in 11 states, with more than a dozen studies underway [Value Pricing Pilot Program (VPPP) 2012]. The National Conference of State Legislatures (NCSL) reports that MBUF trials led by states, regions, and universities have been conducted in 18 states to date, and at least 11 states have now considered legislation to study or implement MBUFs (Shinkle, Rall, and Wheet 2012), often with the aim of collecting user fees from alternative-fuel vehicles (AFVs). Sorensen, Ecola, and Wachs (2012) review a variety of potential implementation approaches that are being explored in Oregon, Minnesota, Colorado, Nevada, Texas, and Washington. Other policies considered by states in recent years to promote more efficient system use, and in some cases to raise revenue, include increased registration fees for vehicles in urban areas, increased registration fees for heavier vehicles, weight-distance truck tolls, regional congestion-relief document fees, and state approval for pay-as-you-drive (PAYD) insurance policies (NCSL 2012). The following examples highlight recent state legislative action in this area.

- In 2011, legislation in Hawaii was introduced authorizing the DOT to establish an MBUF pilot program to evaluate the use of mileage fees as an alternative to the existing state and county fuel-tax system (Senate Bill 819.201). Legislation is pending in committee. In 2009, Colorado authorized a similar mileage-fee study, and in 2001, Oregon authorized its Road User Fee Task Force to examine alternative revenue mechanisms, including mileage fees.
- In 2009, Maine passed legislation directing its DOT to study transportation policies and develop recommendations for reducing energy use and promoting efficient operations in major transportation corridors (HP 582, LD 846). Recommendations must meet the state objective of saving energy by maintaining arterial functions, improving system efficiency, facilitating transit development, and using other land use and transportation strategies designed to reduce growth in vehicle miles traveled.
- In 2009, Oregon passed legislation requiring its DOT to implement one or more congestion pricing pilot programs in the Portland metropolitan area (Chapter 865, Section 3, Jobs and Transportation Act). Approaches currently under consideration include time-of-day tolls, on-ramp tolls, and citywide parking management proposals.
- In 2008, California passed legislation allowing for a high-occupancy/toll (HOT) lanes value pricing program to be administered and operated on State Highway Route 110 and Interstate 10 in Los Angeles County (SB 1422).

Energy and climate planning. As of 2010, only one state, Vermont (VTrans 2008), had produced a DOT-specific climate action plan, though other DOTs have been involved in developing the transportation elements of broader state climate action plans (AASHTO, undated). In 2007, Washington State DOT completed an agency greenhouse gas emissions inventory that examined energy usage of DOT fleets and facilities (Landsberg 2009). More than 10 state DOTs have climate adaptation activities underway to identify vulnerable transportation facilities and needs for protecting or retrofitting transportation facilities, an emerging responsibility for states. State and regional agencies are also beginning to develop capabilities to model energy consumption and greenhouse gas emissions or to coordinate climate change planning with other state agencies, MPOs, and regional and local governments (AASHTO, undated). These activities add to DOT roles and responsibilities and may constrain agency decision making or investment prioritization.

2.4 State Transportation Funding

While states raise and expend revenue to support various modes of transportation, the majority of funds have historically been invested in highway programs. As of 2008 (the last year for which complete data are available), for example, roughly 70% of state and local transportation expenditures—$178 billion out of $255 billion—was directed to highway investment. Another 20% was allocated to transit, with the remainder divided mostly between aviation and water transport (BTS 2012). Given this focus, much of the discussion in this section centers on highway revenue and expenditures.

Motor-fuel and vehicle taxes and fees are the mainstay of federal and state highway programs and a major contributor to transit funding, and will likely continue to be for the foreseeable future. Fuel and vehicle taxes account for all revenues dedicated to the federal Highway Trust Fund (HTF) along with a major share of state highway revenue [Office of Highway Policy Information (OHPI) 2012a]. Both the HTF and state fuel-tax funding, however, face serious near-term challenges. The value of fuel-tax revenues—measured in real revenue per vehicle mile of travel—is eroding because the cents-per-gallon rate structure does not automatically keep pace with inflation or improved vehicle fuel economy, and elected officials have found it increasingly challenging to raise fuel-tax rates to offset these factors. Coupled with construction and operating cost escalations above the rate of general inflation, the purchasing power of DOT fuel-tax revenue has been steadily declining.

The estimated costs to maintain the nation's existing infrastructure and transportation assets and to make needed investments in new capacity, operations, and infrastructure upgrades far exceed current revenue forecasts (Cambridge Systematics et al. 2006). Recent calculations suggest that the shortfall in combined federal, state, and local funding needed to simply maintain the nation's transportation networks falls in the range of $57 billion to $118 billion per year, while the shortfall in funding needed to improve the nation's transportation networks falls in the range of $113 billion to $185 billion per year [National Surface Transportation Infrastructure Financing Commission (NSTIFC) 2009].

States wishing to adequately maintain and improve their transportation systems will need to adopt revenue strategies to close this growing gap between available revenues and funding needs. Increasing fuel-tax rates and surcharges would appear to offer the most straightforward, if politically challenging, near-term solution for raising highway revenue, but higher federal fuel economy standards in future years combined with a potential shift to alternative fuels suggest that continued reliance on conventional fuel taxes may prove increasingly challenging. Maximizing other current revenue sources, including vehicle registration fees, tolls, value capture strategies, and general levies, may also generate some additional revenue, though perhaps not at the scale necessary to offset fuel-tax declines. Tolling schemes, public–private partnerships, and innovative finance methods are being employed in a number of states to enable construction of new capacity, but these are often used to fund specific projects rather than a broader capital program. Over the longer term, states may choose to adopt more innovative funding mechanisms such as mileage-based user fees.

Future revenue and investment strategies have been looked at extensively in recent years, and there is a substantial body of current literature dedicated to this topic [see, for example, Cambridge Systematics et al. 2006, National Surface Transportation Policy and Revenue Study Commission (NSTPRSC) 2007, NSTIFC 2009, and Government Accountability Office (GAO) 2012]. In the text that follows, summary information on the current sources and allocations of state transportation revenues is presented, including information on variations from state to state.

2.4.1 State Transportation Revenue Sources

State DOTs rely on a diverse set of federal, state, and (to a more limited degree) local revenue sources to fund transportation systems across different modes. Focusing on highway programs, common revenue mechanisms can be grouped in several categories:

- **Direct user fees.** This category includes fees that are based on actual use of the system. Examples are facility tolls, congestion tolls, weight-distance truck tolls, and possibly mileage-based user fees at some point in the future.
- **Indirect marginal-cost user fees.** The fees in this category are indirectly related to use of the system and, like direct user fees, increase in proportion to the amount of travel. Examples are taxes on motor fuels, tires, and lubricants.
- **Indirect fixed-cost user fees.** This category includes fixed fees that are indirectly related to travel but do not vary in proportion to system use. Some of the revenue sources in this category, such as sales taxes on the purchase of new cars, trucks, or trailers, are levied on a one-time basis. Others, such as annual registration and licensing fees or heavy vehicle use taxes, are levied on a recurring basis.
- **Beneficiary fees and value capture.** Revenue mechanisms in this category are intended to apportion some of the cost for building and maintaining transportation facilities to other parties who benefit from the investments, such as land owners or developers. Examples include special assessment districts, developer impact fees, and tax increment financing.
- **General revenue sources.** States also draw on a variety of transportation funding sources that are largely unrelated to the transportation system. Common examples are general fund transfers or specifically earmarked portions of income or sales taxes. Others are visitor taxes, document stamp taxes, and leases, concessions, or other revenue derived from private use of state assets.

Note that states may also issue bonds to raise funds to help pay for infrastructure projects. Such bonds, however, will ultimately need to be repaid based on revenue from one or more of the mechanisms outlined. General obligation bonds, for example, are repaid from a state's general fund.

States exhibit considerable variation in terms of the mechanisms they employ to raise highway revenue as well as in the share of funding that they receive from the federal government and, in a few cases, from transfers from local jurisdictions. While state-by-state data are not available for all of the specific revenue mechanisms listed previously, the FHWA's Highway Statistics series (OHPI 2012a) does provide useful information for categorizing the main sources of highway funding used by states.

In 2010, state DOTs expended more than $150 billion on highways. Table 2.3 presents data for the share of this funding that states received in transfers from the federal government (primarily from the HTF), that states raised on their own, and that states received in transfers from local governments. It also considers the total share of state highway funding derived from the combination of federal and state user fees (specifically, HTF funds plus state fuel taxes, vehicle and motor-carrier taxes, and tolls). To provide some indication of the variation among states, the table lists the national average for each of these measures, along with three or four states with the highest percentage scores. (In cases where two states were tied for fourth place, only three states are listed.)

Table 2.4 examines the degree to which states relied on different revenue mechanisms as a share of highway revenue raised at the state level in 2010. Specifically, it presents the

Table 2.3. Federal, state, and local share of state highway funds, 2010.

Federal Transfers as a Share of Total State Highway Funding		State Revenue as a Share of Total State Highway Funding		Local Transfers as a Share of Total State Highway Funding		Federal and State User Fees as a Share of Total State Highway Funding	
National Avg.	26%	National Avg.	72%	National Avg.	2%	National Avg.	63%
Top States		*Top States*		*Top States*		*Top States*	
Montana	66%	New Jersey	90%	Nebraska	37%	Hawaii	95%
Wyoming	62%	Massachusetts	84%	Minnesota	9%	Maine	94%
Alaska	60%	Washington	84%	Mississippi	9%	Tennessee	93%
South Dakota	60%	Maryland	83%			West Virginia	93%

Source: Author computations based on data from OHPI (2012a).

share of state-raised highway funds provided by motor-fuel taxes, motor-vehicle and motor-carrier taxes, tolls, and other sources generally unrelated to use of the system (including appropriations from general funds, other state imposts, and miscellaneous sources). Here again the table lists the national average along with three or four states with the highest percentage scores for each of the categories. Note that the percentage computations do not include bond proceeds because these can vary considerably from one year to the next and must ultimately be backed by other revenue sources.

In response to the growing gap between available revenue and investment needs, states are seeking to increase funding from current sources and to develop new, alternative revenue sources. Examples of recent state activity to address revenue shortfalls include:

- **Increasing revenue from primary sources.** State efforts to increase revenue from existing sources, typically by raising rates, have been relatively common in recent years. Based on recent reviews of major state transportation legislation from the National Conference of State Legislatures (Hobbs 2009; Wheet and Rall 2011; Wheet, Rall, and Workman 2012; and Durkay and Rall 2013), for example, there were at least 12 states that considered legislation to increase fuel-tax rates in 2009, at least seven in 2010, at least eight in 2011, and at least five in 2012. Such efforts remain politically challenging; only Oregon, Rhode Island, Vermont (in 2009) and Connecticut (in 2011) were successful in their efforts to increase fuel-tax rates. (Several other states eliminated certain fuel-related tax subsidies or exemptions, for example on ethanol blends.) State legislatures have also sought, with some success, to increase revenue from other sources, such as vehicle registration fees or tolls.
- **Increasing revenue from alternative sources.** While not likely to be significant sources, other alternative revenue streams such as advertising are being pursued. The Georgia DOT covers annual operating costs of $2 million for its Highway Emergency Response Operator and 511 Traffic Information programs through corporate sponsorship. The Pennsylvania DOT is seeking federal permission to sell advertising on electronic highways signs, with revenues valued at $150 million annually.

Table 2.4. Sources of state-raised highway revenue, 2010.

Motor-Fuel Taxes as a Share of State-Raised Highway Revenue		Vehicle Fees and Motor-Carrier Taxes as a Share of State-Raised Highway Revenue		Tolls as a Share of State-Raised Highway Revenue		Other Sources as a Share of State-Raised Highway Revenue	
National Avg.	36%	National Avg.	27%	National Avg.	10%	National Avg.	27%
Top States		*Top States*		*Top States*		*Top States*	
South Carolina	72%	Colorado	62%	New Jersey	49%	Dist. of Col.	96%
Alabama	66%	Vermont	54%	Delaware	43%	Wyoming	73%
Tennessee	66%	Oregon	53%	Maine	29%	Rhode Island	70%
		Hawaii	50%	Maryland	25%	Massachusetts	63%

Source: Author computations based on data from OHPI (2012a).

- **Pursuing innovative financing mechanisms.** States are actively pursuing new project financing techniques such as public–private partnerships and bonding authorization for transportation purposes, although neither of these options should be viewed as revenue streams. Public–private partnerships are a project delivery vehicle that sometimes involves financing by the private sector (ultimately paid by the public sector), and bonds are simply cash-flow management techniques.
- **Adopting new revenue mechanisms.** As discussed earlier, congestion pricing is receiving increasing attention for its potential role in managing traffic congestion and, to a lesser extent, raising revenue. Applications of congestion pricing, most commonly in the form of HOT lanes or express lanes, have been gaining rapid momentum in the United States over the past decade. States are also examining, via studies or pilot tests, new funding mechanisms with much greater revenue potential, including truck-only toll lanes, weight-distance truck tolls (Kentucky, New Mexico, New York, and Oregon already levy such fees, but other states do not), expanded use of tolling on existing infrastructure, and mileage-based user fees.

The robust decision-making framework developed for this study considers a series of strategies to mitigate the potential revenue impacts associated with substantial shifts in fuel economy or fuel type, including direct user fees, indirect marginal-cost user fees, indirect fixed-cost user fees, beneficiary fees, general revenue sources, and private capital. Though these all could be effective in increasing available revenue, they differ considerably in terms of other policy advantages and shortcomings. These trade-offs are explored more in subsequent chapters and appendices.

2.4.2 State Transportation Expenditures

Changes in future energy prices and sources are likely to affect the costs of delivering infrastructure and services, potentially leading DOTs to re-prioritize their investment decisions. Many DOTs are already limited in their ability to maintain existing assets and foresee shifting greater resources to maintenance expenditures, with little remaining for new capacity or operational improvements. All DOTs are facing pressure to scale back total expenditures and to be more strategic and more focused on priority investments. Current agency interest in asset management, performance measurement, and transportation system management and operations approaches reflects these realities. However, states may reach a point where pared-down capital budgets and operational efficiencies alone will not free enough resources to meet investment needs. It is useful to consider that at some point, DOTs might have to defund accessory support functions and agency roles or devolve responsibility for certain assets to local governments.

Given the vast scope of federal mandates and the range of critical functions and support activities that DOTs provide, opportunities to significantly cut expenditures in absolute terms are not clear. Of the $104.6 billion that states expended on highways in 2010, 64% was devoted to capital outlays for right-of-way, construction, and system preservation and maintenance. Remaining expenditures included 9% for highway traffic services, operations, snow removal, and other services; 8% for research, planning, and administration; and 8% for safety and enforcement (OHPI 2012b). These represent national averages, and the expenditure shares may differ considerably from one state to the next.

Given state and federal performance requirements governing physical maintenance and system preservation of bridges and roadways, along with other required activities such as safety and enforcement services, nearly one-half of the average DOT budget could be described loosely as nondiscretionary. The remaining budget allocations, including construction, transportation enhancement programs, planning, and research, represent areas of current emphasis that could theoretically decline in the future absent sufficient funding. DOT leadership currently see a clear trend in focusing greater federal resources on maintenance and preservation of the current asset base, with proportionally less emphasis on capacity expansion. Already, excluding federal funds, growth in state expenditures for highway maintenance and operations has outpaced spending on capital outlays. In 2004, state and local spending (excluding federal funds) for operations and maintenance totaled $58.5 billion, greater than the $40.6 billion spent on capital expenditures (CBO 2007).

2.5 State DOT Operations

DOT operations are generally viewed as including any programs and efforts aimed at optimizing the performance, reliability, safety, and security of existing infrastructure. Operational approaches often cut across agency roles and responsibilities and include a wide variety of programs able to address multiple state goals or intended performance outcomes. Operations strategies are increasingly being implemented by state DOTs to address the impacts of growing congestion and to adjust to changing travel demands. Advanced data and management systems are also being pursued in recognition of the shift toward greater performance-based planning of systems and agencies. This current emphasis is likely to continue under plausible future energy scenarios that result in increased congestion, greater urban travel demand, or reduced state revenues.

While operations strategies may be implemented in different areas or corridors for different specific reasons, they generally serve to further state and national goals in the broader areas of performance, reliability, safety, and security. Operations strategies, by their nature, tend to involve integration, collaboration, proactivity, a strong systems orientation, and a focus on performance. Table 2.5 offers a synthetic, high-level overview of common operations approaches, along with the broad goals that they can support. The FHWA's Office of Operations identifies more than 20 distinct program areas (FHWA Office of Operations 2011), and other national coalitions, research institutions, and state and regional transportation officials use a variety of wording to describe the full range of specific operations strategies in existence. In the table are listed 20 common and broad categories of operations approaches. This is not intended to be an exhaustive list, but rather to demonstrate the breadth of operations strategies and their general ability to address multiple goals together.

Many operations approaches are also closely tied to the energy conservation goals of state DOTs. Strategies such as transportation demand management, signal coordination, ramp metering, intelligent transportation system (ITS) deployments, and freight demand management may be undertaken with the intended outcome, among others, of reducing transportation-related energy use. As energy conditions change, potentially increasing the relative prioritization of DOTs for mitigating congestion, addressing revenue shortfalls, and improving highway safety, operational strategies could assume an increasingly important role.

While operations solutions have been applied successfully in a wide variety of contexts across the nation, DOTs do face some challenges in adopting ever-more sophisticated strategies. Operational improvements often represent significant near-term investments, such as complex management software tools or the upgrading of facilities to enable advanced

Table 2.5. Common operations strategies and policy goals.

Operations Strategies	*Policy Goals*			
	Performance	Reliability	Safety	Security
Road Network Management				
Active freeway lane management	●	●	●	
Arterial and corridor traffic management	●			
Traffic signal coordination	●	●		
Electronic toll payment collection	●	●		
Work-zone management			●	
Traffic incident management		●	●	
Emergency and natural hazard response systems		●	●	●
Intelligent transportation systems deployment	●	●	●	
Travel Information and Demand Management				
Transportation demand management	●	●		
Real-time traveler information services	●		●	●
Road and weather information services		●	●	
Transit Management Practices				
Transit priority integration	●	●		
Active transit fleet management and dispatching		●		
Freight Management Practices				
Commercial vehicle programs		●	●	
Vehicle permitting and inspection		●	●	●
Freight demand management	●	●		
Truck-only toll lanes or facilities	●		●	
Agency Management Practices				
Maintenance management systems	●	●	●	
Performance measurement and reporting	●			
Asset management systems	●	●	●	

ITS implementation. While costly in the near-term, investments in operational strategies can provide long-term savings—such as by reducing traffic congestion and improving safety outcomes, in turn reducing or delaying the need for costly capacity enhancements or expansions. An agency may also need to expand its technical expertise and capacity to deliver services such as electronic payment collection systems, information management and technology services, or advanced communication and data transfer networks. Full adoption of some approaches may also require that DOTs reengineer business processes, change internal culture, or undergo organizational restructuring.

2.6 The Changing State DOT

It is still unclear to what degree alternative fuels and advanced vehicle technologies will be adopted and what the broader direction of transportation systems and services in the 21st century will be. What is more certain is that state DOTs as public institutions will continue to adapt and confront shifting trends, resolve challenges, and provide solutions.

The material presented in this chapter has offered a detailed look at current state DOT roles, mandates, funding, and operations and how they have changed over time. Before continuing on to examine potential impacts of evolving fuel sources and technologies in subsequent components of the analysis, it may be helpful to distill several broader themes that have characterized the recent evolution of DOTs and that may continue to unfold in the coming years. Additionally, in a study intended to develop insights and findings to inform the long-range planning efforts of individual state DOTs, it is useful to consider the significant variations in contextual factors that exist for different states across the country. Such variations will likely influence the manner in which different state DOTs are affected by shifts in fuel sources and vehicle propulsion technologies and play a role in determining the most appropriate and feasible responses.

2.6.1 Broader Themes in the Evolution of State DOTs

Looking back over the past few decades, one can discern several major trends in the evolution of state DOTs, as follows.

Greater involvement in additional modes of transportation. Expanding on their early focus on highway travel, many DOTs have become more involved with other transportation modes, such as transit, rail, aviation, marine, and multimodal goods movement. In contrast to their central responsibility for building, operating, and maintaining highways, state DOTs often assume a more collaborative support role for other modes, assisting with such functions as planning, oversight, and funding. It is possible, though, that the roles and responsibilities of DOTs for other modes could continue to expand.

Broader array of policy concerns. The spectrum of policy goals that state DOTs have been asked or required to address has broadened over time as well. A primary focus for DOTs in earlier decades was to plan, fund, construct, and operate well-engineered roads to serve the public's rapidly expanding needs for automobility and efficient goods movement via trucks. The goal of safety has also been a motivating factor in the development of certain design and engineering standards. In more recent decades, however, the negative side effects of automobile dependency and automobile-centric development patterns have become increasingly apparent—neighborhoods divided and degraded by freeway construction, extreme traffic congestion, harmful air pollution, reduced physical activity, dependence on oil from foreign nations, and the threat of climate changed posed by the combustion of fossil fuels. In turn, many DOTs have been asked to incorporate related policy goals in their decision making, including such issues as economic development, equity, local air quality, greenhouse gas emissions, and livability. Additionally, DOTs are now further bolstering their efforts to promote safer travel.

Greater emphasis on operating the system efficiently. Most DOTs face major funding shortfalls that shape and constrain their options for accommodating the increases in travel stemming from growth in population and the economy, among other factors. During the height of the Interstate construction era in the late 1950s, 1960s, and early 1970s, drawing on adequate state revenue streams along with a generous federal match from the HTF, states were often able to provide new freeway capacity in anticipation of future travel demand. Over the last several decades, however, federal and state fuel taxes have been allowed to stagnate, while construction costs have risen more rapidly than the general rate of inflation. This has resulted in greater transportation funding shortfalls for many states, making it more difficult to adequately maintain existing facilities, let alone to provide new capacity. In turn, growth in travel has far outpaced increases in system capacity in recent decades, contributing to significantly worse traffic congestion in cities and suburbs across the nation. Faced with tight funding constraints, DOTs have devoted much greater attention to other means for addressing growth in traffic, such as transportation demand management measures and strategies for operating the system at higher levels of efficiency. In other words, a core emphasis for state DOTs has shifted—in large part due to funding challenges—from seeking to expand the system to meet unrestrained demand to actively managing demand and pursuing operating strategies aimed at greater efficiency. Note that parallels to this shift can be observed in other economic sectors as well, such as the trend among electric utilities of promoting energy efficiency as a cost-effective strategy for reducing the need for new generating capacity.

Exploration of innovating funding mechanisms. Finally, growing budget shortfalls, deteriorating traffic conditions, and rapid advances in enabling technologies have in recent years stimulated increasing experimentation among states with a range of innovative user-fee funding mechanisms capable of both raising revenue and promoting greater system efficiency. Examples include electronic tolling, congestion tolls, automated weight-distance truck tolls, and mileage-based user fees. Some of these innovations, such as variably priced HOT or express lanes, appear to be gaining momentum rapidly. Others, such as mileage-based user fees, are still in the early experimentation stages, and it is too early to determine whether they will prove to be cost-effective and acceptable to the public. If such innovative strategies prove successful and are adopted on a widespread basis in future decades, however, it could have a profoundly positive effect on DOT funding as well as operational efficiency.

2.6.2 Contextual Variations Among States

As shifting energy technologies place increasing or new pressures on DOTs, agencies will continue to change and adopt new approaches. Some of these strategies may be improvements over existing ideas, while others may represent entirely new ways of rethinking how transportation services are delivered, how the transportation system is managed, and how transportation agencies are organized. The robust decision-making framework introduced in subsequent chapters is intended to provide state leadership with decision support tools and clear strategic directions to use to consider future changes and robust responses to a shifting but deeply uncertain transportation energy future.

In developing such guidance, however, the research team recognized that there are important contextual variations among states that may affect the degree to which DOTs are affected by certain trends and influences or that constrain suitable policy responses. To illustrate, states vary in terms of their size, geography, population, economic structure, prevailing political preferences, and many other characteristics. Based on the analysis conducted in this study, three specific factors appeared to be most important:

1. **Urban versus rural.** Some of the potential impacts associated with certain plausible futures, such as continued growth in travel and worsening traffic congestion, are likely to be much more problematic for states with significant urban populations than for largely rural states. Correspondingly, some strategies, such as congestion pricing or investment in significant transit improvements, would be less relevant for largely rural states.
2. **Population growth.** States with rapidly growing populations are more likely to face certain potential future impacts, such as worsening traffic congestion. At the same time, population growth translates to increased development activity, so states experiencing significant growth pressures may have more opportunity to make use of some of the strategies considered in this study, such as more integrated land use and transportation planning, than states with stagnant or declining populations.
3. **Major goods-movement facilities and corridors.** Some of the potential impacts and strategies considered in this report relate to the goods movement system. These will be most relevant for states that are home to major goods-movement facilities, such as ports, distribution hubs, border crossings, and major trucking corridors.

Finally, it is worth noting that some of the strategies considered in this study, such as congestion pricing, promise significant benefits but also face major barriers in terms of public acceptance and other factors. Others, such as expanded deployment of more traditional travel demand measures, offer more modest benefits at the margins but face lower barriers. While prevailing political attitudes within a state—in particular, the relative receptiveness to fees, taxes, or regulations—have little bearing on the potential utility of certain strategies, such attitudes most definitely affect their political viability. Accordingly, the study considers multiple strategies for addressing any given policy objective that states might consider based on their needs, preferences, and constraints.

References

AASHTO. Undated. State/Local/MPO Activities. AASHTO Transportation and Climate Change Resource Center. http://climatechange.transportation.org/state_local_mpo/ (accessed September 27, 2012).

AP. 1973 (November 16). “Senate Rejects Rationing Requirement.” *Daytona Beach Morning Journal.*

Bhatt, N., C. Peppard, and S. Potts. 2010. *Getting Back on Track: Aligning State Transportation Policy with Climate Change Goals.* Natural Resources Defense Council and Smart Growth America, New York.

BTS. 2012. Table 3-35 – Transportation Expenditures by Mode and Level of Government from Own Funds, Fiscal Year. *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_03_35.html (accessed March 11, 2013).

Cambridge Systematics, Mercator Advisors, A. E. Pisarski, and M. Wachs. 2006. *NCHRP Web-Only Document 102: Future Financing Options to Meet Highway and Transit Needs.* Transportation Research Board of the National Academies, Washington, D.C.

CBO. 2007. *Trends in Public Spending on Transportation and Water Infrastructure, 1956 to 2004.*

CBO. 2010. *A Review of CBO’s Activities in 2009 Under the Unfunded Mandates Reform Act of 1995.*

C2ES. 2012. VMT-Related Policies and Incentives. Arlington, VA. http://www.c2es.org/us-states-regions/policy-maps/vehicle-miles-traveled (accessed March 12, 2013).

The Daily Union Democrat. 1973 (December 24). "Crisis Session: Lawmakers Focus on Energy Shortage."

Durkay, J. and J. Rall. 2013. *Major State Transportation Legislation, 2012.* National Conference of State Legislatures, Washington, D.C.

EERE. 2012. Federal and State Laws and Incentives. Alternative Fuels Data Center. http://www.afdc.energy.gov/laws/ (accessed September 27, 2012).

FHWA. 2012. PGC [Policy and Guidance Center] Category Definitions. The Federal-aid Highway Program Policy & Guidance Center. http://www.fhwa.dot.gov/pgc/definitions.cfm (accessed March 13, 2013).

FHWA Office of Operations. 2011. Strategies and Program Areas. http://ops.fhwa.dot.gov/program_areas/programareas.htm (accessed September 28, 2012).

GAO. 2012. *Highway Trust Fund: Pilot Program Could Help Determine the Viability of Mileage Fees for Certain Vehicles.* GAO-13-77.

Goetz, A. R., J. S. Szyliowicz, T. M. Vowles, and G. S. Taylor. 2004. *Assessing Intermodal Transportation Planning at State Departments of Transportation.* National Center for Intermodal Transportation, University of Denver.

Hobbs, J. 2009. *Major State Transportation Legislation, 2009.* National Conference of State Legislatures, Washington, D.C.

ICF. 2008. *Integrating Climate Change into the Transportation Planning Process.* Federal Highway Administration.

ICF International. 2008. *Long Range Strategic Issues Facing the Transportation Industry: Final Research Plan Framework.* NCHRP Project 20-80(2), Transportation Research Board of the National Academies.

Landsberg, K. 2009. *2007 WSDOT Greenhouse Gas Emissions Inventory.* Washington State Department of Transportation.

Lockwood, S. 2006. Changes in Roles and Partnerships: Towards the 21st Century State DOT. Presented at Advancing Practice in State DOTs from Good to Great, University of Minnesota, Minneapolis, September 24–26.

Massachusetts DOT. 2010. *GreenDOT Policy Directive.*

Molina, M., M. Neubauer, M. Sciortino, S. Nowak, S. Vaidyanathan, N. Kaufman, and A. Chittum. 2010. *The 2010 State Energy Efficiency Scorecard.* American Council for an Energy-Efficient Economy, Washington, D.C.

NCSL. 2012. *Transportation Funding Legislation Database.* Washington, D.C. http://www.ncsl.org/issues-research/transport/ncsl-transportation-funding-legislation-database.aspx (accessed September 27, 2012).

NSTIFC. 2009. *Paying Our Way: A New Framework for Transportation Finance.*

NSTPRSC. 2007. *Transportation for Tomorrow: Report of the National Surface Transportation Policy and Revenue Study Commission.*

OHPI. 2012a. Table SF-1: Revenues Used By State for Highways. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/sf1.cfm (accessed March 12, 2013).

OHPI. 2012b. Table SF-4C. Disbursements for State-Administered Highways – 2010. Classified by Function. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/sf4c.cfm (accessed March 18, 2013).

SCOTUS. 1989. *State of Nevada, Petitioner V. Samuel K. Skinner, Secretary of Transportation, et al.*, No. 89-696.

Shinkle, D., J. Rall, and A. Wheet. 2012. *On the Move: State Strategies for 21st Century Transportation Solutions.* National Conference of State Legislatures, Washington, D.C.

Sorensen, P., L. Ecola, and M. Wachs. 2012. *Mileage-Based User Fees for Transportation Funding: A Primer for State and Local Decisionmakers.* RAND Corporation, Santa Monica.

Spokane Daily Chronicle. 1974 (November 25). "Conservation Best Way."

U.S. Census Bureau. 2012a. State Government Employment and Payroll Data by State and by Function: March 2011. 2011 Annual Survey of Public Employment and Payroll. http://www.census.gov/govs/apes/ (accessed March 18, 2013).

U.S. Census Bureau. 2012b. Table 1. State and Local Government Finances by Level of Government and by State: 2009-10. 2010 Annual Survey of State and Local Government Finance. http://www.census.gov/govs/estimate/ (accessed March 18, 2013).

VPPP. 2012. Value Pricing Pilot Program Projects Report. http://ops.fhwa.dot.gov/tolling_pricing/value_pricing/projects/index.htm (accessed September 27, 2012).

VTrans. 2008. *VTrans Climate Change Action Plan.*

Wachs, M. 2003. *Improving Efficiency and Equity in Transportation Finance.* The Brookings Institution, Washington, D.C.

Warne, T. 2003. *NCHRP Synthesis of Highway Practice 313: State DOT Outsourcing and Private Sector Utilization.* Transportation Research Board of the National Academies, Washington, D.C.

Washington State University, University of Idaho, The Glosten Associates, and Imperium Renewables. 2009. *Washington State Ferry Biodiesel Research & Demonstration Project: Final Report.* Washington State Department of Transportation.

Wheet, A. and J. Rall. 2011. *Major State Transportation Legislation, 2010.* National Conference of State Legislatures, Washington, D.C.

Wheet, A., J. Rall, and S. Workman. 2012. *Major State Transportation Legislation, 2011.* National Conference of State Legislatures, Washington, D.C.

CHAPTER 3

Emerging Fuels and Vehicle Technologies

The central aim of this study is to consider how changes in transportation fuels and vehicle technologies might affect state departments of transportation in the coming decades. As a basis for developing plausible transportation energy use futures, the research team reviewed the current status and future prospects for both conventional and alternative fuels and vehicle technologies, including gasoline and diesel, natural gas, biofuels, electricity, and hydrogen. While much of the effort focused on fuels and vehicle technologies in the context of the light-duty fleet—including passenger cars, pickup trucks, vans, and sport utility vehicles—the analysis also considered medium- and heavy-duty vehicle applications.

This chapter summarizes the examination of relevant fuels and vehicle technologies. Detailed discussions of the prospects and challenges for conventional fuels, natural gas, biofuels, electricity, and hydrogen within the light-duty fleet appear in Appendices A, B, C, D, and E, respectively, while Appendix F examines the potential utility of various alternative fuels and vehicle technologies for different medium- and heavy-duty vehicle applications, such as garbage trucks, transit buses, and long-haul freight trucks.

This chapter begins by reviewing each of the fueling alternatives for light-duty vehicles in turn and discusses issues such as fuel production, distribution, refueling infrastructure, relevant vehicle technologies, cost and performance issues, and key challenges or barriers likely to influence future adoption. The chapter then offers a side-by-side comparison of the major strengths and limitations or challenges for the various fuels and vehicle technologies for light-duty applications. Finally, the chapter closes with a brief overview of the potential for alternative fuels and advanced vehicle technologies for medium- and heavy-duty uses.

3.1 Conventional Fuels

Petroleum-based fuels—gasoline and diesel—power nearly all vehicles on the road today, and many experts anticipate that petroleum will remain dominant for decades to come [see, for example, projections in the Energy Information Administration's (EIA) most recent *Annual Energy Outlook* (EIA 2013b)]. To begin with, recent advances in extraction technologies have led to upward revisions in global reserve estimates [International Energy Agency (IEA) 2012], which may help to moderate the growth in oil prices. At the same time, more-stringent federal fuel economy standards through 2025 will enable vehicles to travel many more miles per gallon, effectively reducing per-mile energy costs for gasoline and diesel. Yet the global demand for oil continues to rise, leading to concerns about future prices and price volatility, and continued reliance on gasoline and diesel is also problematic with respect to greenhouse gas emissions and local air quality. Such issues have stimulated increased investment into a range of alternative fuels and vehicle technologies that, if successful, could begin to compete with and ultimately displace petroleum fuels.

3.1.1 Petroleum Production, Distribution, and Refueling

The distribution and refueling networks for petroleum-based fuels are well established and mature. As an illustration, the American Petroleum Institute (API) reports that there are more than 150,000 gasoline and diesel stations across the country (API 2013). Estimated global oil reserves, as noted previously, have increased due to improved extraction technologies. Recent analysis from the IEA (2012) estimated that global proven reserves of oil, defined as the amount of petroleum that could be produced at current prices with existing technology, totaled about 1.7 trillion barrels in 2011. This provides a reserves-to-production ratio (the period that petroleum could be produced at current rates) of around 55 years. IEA also estimated that global technically recoverable reserves, or the amount of oil that could be produced with current technology irrespective of price, stood at around 5.9 trillion barrels in 2011, an amount that could support current rates of production for almost 200 years.

The United States has been a major beneficiary of the improved fossil-fuel extraction technologies. With the ability to develop significant tight oil and shale gas reserves, U.S. oil and gas production have increased significantly in the past few years, and forecasts suggest that the United States could be a net fossil-fuel exporter by 2030 (IEA 2012). U.S. consumers, however, are still subject to global oil prices and shocks despite increasing domestic production (CBO 2012).

The proven and technically recoverable reserve estimates from IEA (2012) include enhanced oil production from existing wells, oil production from harder-to-reach locations such as ultra-deepwater and Arctic wells, oil from currently producing unconventional sources such as oil sands and light tight oil, and oil from undeveloped oil shale; the estimates do not, in contrast, include synthetic petroleum from coal-to-liquid and gas-to-liquid technologies, which could further bolster supplies. Many of these sources, however, are expected to be more expensive to exploit than current wells, and some pose major environmental concerns. Absent carbon capture and sequestration (CCS), for example, coal-to-liquid technology would produce far more GHG emissions than gasoline (Mashayekh et al. 2012). Given uncertainties about future demand and costs, EIA's most recent oil cost projections for 2040 range from $71 to $228 per barrel for imported crude (EIA 2013b).

Any significant shift away from petroleum, then, is unlikely to be caused by running out of oil. Rather, it would more likely be due to some combination of escalating oil prices and the emergence of cost-competitive alternative fuels, perhaps supported by environmental regulations that favor less carbon-intensive fuels and technologies.

3.1.2 Conventional Vehicle Technologies

Conventional vehicles reliant on internal combustion engines (ICEs)—including spark ignition for gasoline and compression ignition for diesel—are technologically mature. Still, there are notable opportunities for additional gains in efficiency, including improved aerodynamics, lightweight materials, advanced direct injection engines and transmission improvements, and widespread application of hybrid-electric drivetrains to capture and recycle power through regenerative braking (Kobayashi, Plotkin, and Ribeiro 2009; NRC 2013b).

From the late 1980s to the early 2000s, federal CAFE standards remained rather stagnant, and oil prices were relatively low. As a result, auto manufacturers found it more profitable to apply efficiency gains to increased vehicle size and power versus improved fuel economy (Knittel 2011). In just the past few years, however, the Obama administration has issued a series of far more stringent CAFE standards and harmonized GHG emissions standards for future years, resulting in a required average fuel economy of 35.5 miles per gallon (mpg) by 2016 and an average of 54.5 mpg by 2025 [U.S. Environmental Protection Agency (EPA) and U.S. National Highway Traffic Safety Administration (NHTSA) 2012]. To meet these more aggressive targets, auto manufacturers will likely need to apply many of the advanced technologies just mentioned.

3.1.3 Conventional Vehicle Cost and Performance

As the long-standing incumbent technology, conventional petroleum-fueled vehicles provide the benchmark against which the cost and performance of competing fuels and vehicle technologies are judged. Conventional vehicles are generally viewed as providing acceptable size, range, and power and reasonably affordable vehicle and fuel costs (except, perhaps, during oil price spikes). On the other hand, their emissions of greenhouse gases and local air pollutants—including non-methane volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), and sulfur oxides (SO_x)—are viewed as problematic.

Looking forward, the recent revisions to CAFE standards, by inducing the adoption of more advanced vehicle technologies, are likely to increase the average cost of new vehicles. The incremental increase, however, is expected to be more than offset from fuel-cost savings over the life of the vehicle (EPA and NHTSA 2012). The higher fuel economy standards should also result in significant reductions in greenhouse gases and air pollutants. On the whole, even with the modest increase in vehicle prices, more-stringent CAFE standards are likely to make it more difficult for alternative fuels and vehicle technologies to compete effectively with petroleum. Still, some of the competing alternatives, such as natural gas and electricity, already offer the potential for significant fuel-cost savings, and it is also possible that increases in the price of oil could outpace vehicle fuel economy gains. The continued dominance of petroleum is thus not a certainty.

3.1.4 Future Market Prospects for Conventional Vehicles

Absent the emergence of cost-competitive alternatives, petroleum-fueled vehicles—though almost certainly with much higher fuel economy than what is offered by most models today—are likely to remain dominant in the market for the foreseeable future. However, should a cost-competitive alternative emerge—especially one that offers some combination of reduced fuel costs and substantial environmental benefits—it is also plausible that petroleum could be largely displaced as a transportation fuel by the middle of the century. Key factors likely to influence petroleum's market share through 2050 include the future trajectory of oil prices, progress and potential breakthroughs in competing fuel and vehicle technologies, and future regulations relating to climate and local air quality.

3.2 Natural Gas

Two other fossil-based fuels considered for transportation applications are natural gas (NG) and liquid petroleum gas (LPG, also referred to as propane or autogas). Interest in natural gas and LPG as transportation fuels—especially in the context of vehicle fleets that could share centrally installed refueling infrastructure—gained momentum in the United States in the 1990s and early 2000s but then entered a brief period of decline. The recent advent of horizontal drilling and hydraulic fracturing (or fracking), however, has greatly expanded domestic reserves of economically recoverable natural gas and triggered sharp reductions in prices, stimulating renewed interest in natural gas as a transportation fuel.

With a cheap and abundant domestic supply, natural gas offers the prospects of reduced energy costs for travel and greater energy independence. Additionally, natural gas appears to offer moderate GHG emission reduction benefits [Argonne National Laboratory (ANL) 2012], although the climate mitigation advantages could be undermined by even modest leakage of methane in the natural gas supply chain (Alvarez et al. 2012). To store natural gas in a vehicle, it can either be compressed (CNG) or chilled and liquefied (LNG). Light- and medium-duty vehicles generally rely on CNG, whereas heavy-duty vehicles can use natural gas in either form (Yacobucci 2005). Converting natural gas into methanol to power flex-fuel vehicles has also received attention. Research at the Massachusetts Institute of Technology (MIT 2011) indicates that the energy equivalent of a gallon of gasoline in methanol can be produced for about $2.00 when natural gas costs $8 per million British thermal units, and the current price is well below that figure. Here, though, the focus is on CNG.

3.2.1 Natural Gas Production, Distribution, and Refueling

Natural gas has many uses—as a feedstock for electric power generation, as a fuel for many industrial processes, as a raw input for some products, as a source of power and heat for commercial and residential applications, and as a transportation fuel. As such, the pipeline distribution network for natural gas in the United States is already quite extensive. With the success of fracking, U.S. reserves and production have been on the rise in recent years (IEA 2012). Between 2000 and 2010, according to EIA (2012), proven natural gas reserves in the United States rose by 71%. While concerns over the environmental effects of fracking remain, the United States should have access to an abundant and low-cost supply of natural gas if these concerns can be satisfactorily resolved.

From the fuel-supply side, then, the main limitations for natural gas lie less with available supply and long-range distribution, but rather stem from a lack of refueling stations. As of September 2013, there were just over 1,250 natural-gas stations across the country (EERE 2012b), and more than half of these were dedicated to fleet vehicles and were not publicly accessible. Expanding the network of refueling stations would require considerable investment. The National Petroleum Council (NPC) estimated that a dedicated CNG station costs about $1.5 million, while a modular CNG station connected to an existing gasoline station costs around $400,000 (NPC 2012). The cost of a home refueling appliance for natural gas is around $3,500, with another $1,000 to $2,000 for installation [Western Governors Association (WGA) 2008].

3.2.2 CNG Vehicle Technology

As of 2011, there were approximately 234 million light-duty vehicles in the U.S. fleet. Of these, about 66,000 relied on CNG, and most of these were fleet vehicles (EERE 2012b). The modest market penetration to date is mirrored by a paucity of available models. First offered by original equipment manufacturers (OEMs) in the early 1990s, the number of light-duty CNG offerings peaked at 18 OEM models in 2002 and then entered a period of decline. In the latter part of the first decade of the 2000s, Honda, with its Civic GX, was the only auto manufacturer still offering a light-duty CNG. Spurred by the lower prices and increased supply of natural gas enabled by fracking, however, interest in CNG vehicles on the part of OEMs is once again on the rise. As of 2012, Chevrolet, Ford, GMC, Honda, and the Vehicle Production Group all offer light-duty CNG vehicles, and Ford also offers a bi-fueled truck capable of running on natural gas (EERE 2012b).

CNG engines typically rely on spark ignition and are in many ways quite similar to a gasoline ICE. Configuring a vehicle for CNG thus requires only modest changes to the fuel lines and electronic control system. The most significant difference is the fuel tank, which must hold highly pressurized gas (Yacobucci 2008). Given the relatively minor differences, it is fairly straightforward to convert a gasoline-fueled vehicle to run on natural gas, and a number of conversion kits for both new and used vehicles are available on the market [Natural Gas Vehicle America (NGVA) 2011].

3.2.3 CNG Vehicle Cost and Performance

The current cost difference between a CNG vehicle and an otherwise similar conventionally fueled vehicle is significant, on the order of at least several thousand dollars. For example, the suggested retail price for Honda's base-model 2013 Civic sedan starts at $18,165, while the Civic natural gas model from 2012 begins at $26,305 (Honda 2013). The cost of converting a conventional vehicle to run on natural gas is even higher, falling in the range of $12,000 to $18,000 per estimates from NGVA (2011). The high cost of CNG vehicles stems in part from low production volume, but also from the expense associated with high-pressure fuel tanks.

Once purchased, though, CNG vehicles offer the potential for significant fuel-cost savings. On an energy-equivalent basis, CNG vehicles offer roughly the same fuel economy as a gasoline-fueled ICE, yet CNG is currently much less expensive. As of July 2013, for example, the average U.S. retail price for gasoline was $3.65 per gallon, while the average retail price for CNG was $2.14 per gallon of gasoline equivalent (EERE 2013c). Looking forward, the most recent reference-case projections from EIA (2013b) anticipate that the cost of CNG will increase slightly faster than the cost of gasoline through 2040, but not by enough to offset the differential cost advantage of CNG. Thus natural gas should remain relatively attractive as a transportation fuel.

Additional benefits of CNG include a modest reduction in per-mile emissions of greenhouse gases and some local air pollutants. Compared to gasoline vehicles of comparable fuel efficiency, for example, CNG vehicles appear to offer about a 14% reduction in well-to-wheel carbon dioxide emissions (ANL 2012). A major unresolved concern, however, is that natural gas vehicles or upstream distribution infrastructure could leak methane, itself a greenhouse gas. Methane has a 34-times greater climate-warming impact than carbon dioxide, so even modest levels of leakage in the natural gas supply chain could undermine the life-cycle GHG benefits of CNG in comparison to petroleum (Alvarez et al. 2012). Another limitation for natural gas as a transportation fuel, beyond the obvious issue of vehicle cost, is that CNG engines tend to generate less power for the same size engine in comparison to a gasoline ICE. This has the effect of limiting acceleration and hill-climbing power. Additionally, the energy density of CNG is less than that of gasoline, resulting in relatively limited driving range (200 miles or less) for many CNG vehicles (Yacobucci 2008).

3.2.4 Future Market Prospects for CNG

If natural gas retains its current cost advantage in relation to petroleum and the premium cost of CNG vehicles can be reduced, the future for natural gas as a transportation fuel could be promising. Renewed effort on the part of auto manufacturers to offer CNG models would seem to reflect this possibility. On the other hand, there are significant challenges that would need to be overcome in order for natural gas to gain significant market share as a transportation fuel. Some of the critical issues likely to influence the market success for compressed natural gas are unresolved environmental concerns associated with fracking, the potential for methane leakage in the natural gas supply chain, low availability of publicly accessible refueling infrastructure, cost and availability of light-duty CNG models, performance and range of CNG vehicles, and perceived safety concerns (WGA 2008) associated with natural gas. CNG as a transportation fuel will also need to compete with other potential uses for natural gas, such as power generation, industrial processes, and home heating.

3.3 Biofuels

The displacement of petroleum with liquid fuels produced from biomass, commonly referred to as biofuels, promises several potential advantages. Estimates indicate that domestically produced biofuels could further the objective of energy security by meeting roughly a third of U.S. transportation fuel needs (Parker et al. 2011). Also, depending on their feedstocks and production methods, biofuels could help reduce greenhouse gas emissions from the transportation sector.

Biofuels can be classified by their technological and economic maturity. Widely used first-generation biofuels include ethanol from the fermentation of corn, sugar cane, and other sugary or starchy food crops along with biodiesel derived from oil seeds such as soy and canola through a chemical process known as transesterification. (Waste fats and recycled cooking oil can also be used to produce biodiesel, but these feedstocks are more limited in quantity.) Unlike other alternative fuels such as natural gas and hydrogen, ethanol and biodiesel are not commonly used in their pure form but rather are blended with petroleum-based gasoline or diesel. Ethanol is routinely blended with gasoline in mixes of up to 10% ethanol (E10) in the United States, and can be used in blends of up to 85% (E85) in specially modified flex-fuel vehicles (FFVs). Biodiesel is typically blended in mixes of up to 20% (BD20).

There are a variety of potential feedstocks and production pathways, most still in the earlier stages of research and development, for advanced second-generation biofuels (NRC 2009, NPC 2012, NRC 2013b). One option is to produce cellulosic ethanol or butanol through biochemical processes using wood, grasses, or crop wastes (e.g., corn stover) as feedstocks. Alternatively, thermochemical processes—such as gasification followed by Fischer-Tropsch catalytic processing, gasification to produce methanol followed by the conversion of methanol to gasoline, or pyrolysis followed by hydroprocessing—can be used with biomass feedstocks to create drop-in gasoline and diesel replacements (often referred to as green gasoline and green or renewable diesel) that work well with existing vehicles and distribution infrastructure without the need for blending. Algae, which offers the advantage of requiring less land and water to produce, is also being explored as a potential feedstock for biofuels.

The remainder of this section briefly highlights recent developments and future prospects for liquid biofuels; more detailed discussion is available in Appendix C.

3.3.1 Biofuel Production, Distribution, and Refueling

Ethanol has benefited from a long history of federal subsidies. Additionally, the more recent federal renewable fuel standard (RFS2), along with similar regulations in some states, mandates increasing production and sale of several types of biofuels. As a result of these federal and state incentives and mandates, the production and consumption of biofuels in this country have accelerated rapidly in recent decades. Between 2000 and 2012, annual consumption of ethanol in the United States rose from about 1.7 billion gallons to about 12.9 billion gallons (EIA 2013c), with the vast majority vended as E10 rather than E85. As of 2011, ethanol supplied about 10% by volume of total demand for gasoline in the United States (NRC 2013b). Most ethanol consumed in the United States is currently derived from corn, a rather inefficient feedstock that yields only modest greenhouse gas reduction benefits at best (Mullins, Griffin, and Mathews 2010; ANL 2012).

A possible near-term alternative to corn-based ethanol is cellulosic ethanol, which is made from breaking down the woody fibers in trees, grasses, and crop wastes. Several technical challenges have slowed the ability to produce cellulosic ethanol at commercial scales. If these can be overcome, however, the technology promises cheaper biofuels with more substantial reductions in life-cycle GHG emissions in comparison to corn-based ethanol. Over the longer term, the production of drop-in gasoline and diesel replacements via thermochemical processes could offer the environmental benefits of cellulosic ethanol without the need for blending, dedicated pipelines, or specialized vehicle technology (NPC 2012, NRC 2013b). Researchers are also examining the use of algae as a feedstock for biofuel production over the longer term that would require less land and water to produce (Williams et al. 2009, Parker et al. 2011).

Once refined, biofuels must be transported to local distribution centers. As a general rule, liquid fuels can be transported most efficiently by pipelines. Ethanol distribution by pipeline, however, poses some challenges with respect to the absorption of water and other impurities, which can then damage engines and degrade performance. For this reason, the vast majority of ethanol is transported instead by rail, truck, or barge. Moving biodiesel via pipeline is also problematic because it can stick to pipeline walls and then contaminate other fuels that flow through the pipeline subsequently (NPC 2012). In contrast, drop-in green gasoline and diesel, if successful, could rely on the same transport pipelines as their petroleum-based counterparts.

In terms of refueling, all stations can dispense ethanol in blends up to E10 or E15, but separate storage and dispensers are needed for E85. The usage of E85 is currently concentrated in the Midwest, where the majority of American corn is produced. The availability of E85 fueling stations in the United States remains limited to date, with about 2,300 stations that are predominately concentrated in the Midwest (EERE 2013d). For E85 to be used in much greater volume, the availability of E85 stations will need to be greatly expanded.

3.3.2 Biofuel Vehicle Technologies

Ethanol can be efficiently combusted in older conventional vehicles at blends of up to E10 and, for newer vehicles, up to E15. FFVs sold in the United States, in contrast, are able to use blends that range from 100% gasoline to 85% ethanol (EERE 2013a); blends above E85 are not used because higher ethanol concentrations can make it difficult for vehicles to start in cold weather. FFVs include a sensor that automatically detects the amount of ethanol in the fuel, and the vehicle computer then modifies the fuel injection and spark timing as needed. The incremental vehicle cost is modest, and automakers often offer FFVs at the same prices as comparable conventional vehicles.

U.S. sales of FFVs to date have been impressive, though this may reflect the concerted marketing efforts of auto manufacturers motivated by the opportunity to gain credits under the CAFE mandate rather than a response to strong consumer demand for the ability to fuel with E85. Between 1998 and 2009, the number of FFVs in the United States increased from a very small number to nearly 10 million (EIA 2013b). However, available estimates indicate that only about 860,000 of these are fueled primarily with E85 (EIA 2013a).

3.3.3 Biofuel Vehicle Cost and Performance

In comparison to other alternative fuels, an important advantage of biofuels is that the additional vehicle costs are either minimal or non-existent. The additional production cost for an FFV is on the order of $100 in most cases (Corts 2010), while drop-in gasoline or diesel can be combusted in conventional vehicles without modification. Looking forward, both FFVs and conventional vehicles will be equipped with advanced technologies to meet more-stringent CAFE standards, so vehicle costs could rise by a few thousand dollars. Yet this would also translate to reduced fuel costs based on greater fuel economy.

Though the premium cost for FFVs is negligible, current biofuels are generally more expensive than their petroleum-based counterparts on a gallon of gasoline equivalent (gge) basis. In October of 2010, for example, the national average price of gasoline was $2.78 per gallon, while E85 sold for $3.45

per gge (EERE 2010). In January of 2012, the average cost of gasoline had risen to $3.76 per gallon, while E85 was selling for $4.96 per gge (EERE 2012a). Biodiesel also tends to be more expensive than conventional diesel, although the margin is much smaller than for E85 and gasoline. In January of 2012, the national average price of diesel was $3.86, while BD20 sold for $4.02 per gallon of diesel equivalent (EERE 2012a).

An important performance-related challenge for ethanol is that it contains about a third less energy on a per-gallon basis than gasoline, and this has the effect of reducing the range between refueling stops for an FFV operating on E85 rather than gasoline. Lower range, higher fuel costs, and limited availability of E85 stations have all contributed to tepid demand for E85 to date.

In comparison to gasoline, biofuels may offer potentially significant benefits for reducing greenhouse gas emissions, though the effects depend on the feedstock and production process. For corn-based ethanol, the GHG reductions are modest at best, and the fuel may even perform more poorly than gasoline once direct and indirect land use effects are taken into account. With cellulosic ethanol, in contrast, life-cycle GHG reductions could be reduced by 50% or more in comparison to gasoline, though again there are uncertainties relating to land use effects (Delucchi 2006, Farrell et al. 2006, Searchinger et al. 2008, Williams et al. 2009, ANL 2012). For drop-in gasoline, it may actually be possible to achieve negative life-cycle GHG emissions through the use of carbon capture and sequestration during the production process (NRC 2013b).

With respect to local air pollutants, corn-based ethanol may perform worse than gasoline for volatile organic compounds, nitrogen oxides, and fine particulate matter (ANL 2012). Future reductions in air pollutants from biofuels could be achieved, however, as biofuel feedstocks and production processes are improved and rely on electricity with fewer emissions.

3.3.4 Future Market Prospects for Biofuels

Over the near term at least, despite its relatively higher cost in relation to gasoline, ethanol should continue to gain market share based on the mandates embedded in RFS2 and similar state regulations. In its most recent *Annual Energy Outlook*, for example, EIA (2013b) projects that the consumption of E85 will increase from around 117 million gallons in 2012 to about 2 billion gallons in the 2040 reference case. Over the longer term, however, the production of biofuels may face practical limitations based on the amount of arable land available for planting and harvesting feedstocks. Already there are concerns that the diversion of corn for fuel production is adversely affecting food prices, creating valid equity concerns for poorer nations around the world. Given such constraints, many studies have suggested that biofuels could ultimately displace in the range of 20% to 30% of petroleum-based fuels [see, for example, Perlack et al. 2005, West et al. 2009, U.S. Department of Energy (DOE) 2011].

Critical factors that will influence the penetration of biofuels include available land and effects on food prices; investments in blending and storage capacity, transport capacity, and refueling infrastructure for first-generation biofuels; the pace of technical progress in the development of cellulosic ethanol and drop-in gasoline and diesel products; fuel price volatility; and technical progress on other competing alternative fuels and vehicle technologies.

3.4 Electricity

Electric vehicles (EVs), as defined in this report, can be partially or fully powered by batteries charged from an off-board source of electricity (e.g., grid power). Two possible EV configurations are now beginning to enter the marketplace: battery electric vehicles (BEVs), such as the Nissan Leaf and Tesla Model S, which only operate on electricity; and plug-in hybrid-electric vehicles (PHEVs), such as the Chevy Volt, the Toyota Prius plug-in model, the Ford C-Max Energi and Fusion Energi, and the Honda plug-in Accord, which accommodate a more limited range in all-electric mode but also include a gas tank and an internal combustion engine to power the vehicle or recharge the batteries.

EVs face several steep obstacles, such as higher vehicle prices and, for BEVs especially, relatively limited driving range and long recharging times. Yet they also promise many compelling benefits, including greater energy independence based on domestically produced electricity and much lower energy costs for travel. Depending on how and where the electric power is generated, a significant shift from petroleum to EVs could also provide for considerable reductions in greenhouse gas emissions and much-improved urban air quality.

3.4.1 Electricity Production, Distribution, and Refueling

Annual electric power production in the United States climbed steadily over the past century and through the beginning of this century, peaking at just over 4,000 terawatt hours in 2007 and then declining modestly over the past several years. As of 2012, the most significant source of electric power production, accounting for 38.5% of the nation's total, is coal combustion, though the share of coal-fired power has been declining in recent decades. Other major sources of power are natural gas with 29.2%, nuclear with 19.7%, and large hydroelectric facilities with 7.0%. Other renewable energy sources, such as wind, solar, and geothermal, have been expanding rapidly but still account for just 4.8% of power on the U.S. grid (EIA 2013c).

For a variety of environmental reasons—climate change, air quality, water quality, land degradation, and others—there is considerable interest in shifting away from coal to cleaner sources of power generation, a process that is already underway. For newly installed capacity, a number of alternatives, such as natural gas and several forms of renewable energy, can compete favorably with coal in terms of levelized cost—the cost of producing power accounting for initial capital costs, feedstock costs, expected operational capacity, and operating costs (EIA 2013b). The main reason for coal's continuing cost advantages, setting aside the fact that power producers are not charged for many of the harmful emissions associated with coal, is that there is a large base of existing coal-power production capacity for which the capital investments have already been made.

Looking forward, there are significant opportunities for shifting to greater reliance on less-polluting power sources on the grid, including nuclear, solar, wind, small-scale hydro and wave, geothermal, and biomass. Natural gas is already much cleaner than coal, but carbon capture and sequestration is receiving significant attention as a possible means for capturing the greenhouse gas emissions associated with both of these fossil-fuel options [National Energy Technology Laboratory (NETL) 2013]. All of these possibilities, however, still face one or more hurdles that will need to be overcome in order to accommodate broader adoption (NRC 2010a, Crane et al. 2011). These include limitations in the available resource base (for current geothermal technology or for new conventional hydropower projects), competition for resources with other possible applications (for biomass), intermittency and the related challenges of balancing supply and demand (for wind and solar), safety and security concerns leading to greater public acceptance challenges (for nuclear), and uncertainties regarding the technical and economic feasibility of CCS (for coal and natural gas). Still, the general trajectory is toward greater use of cleaner or renewable power, with the main open questions relating to the timing and specific mix of technologies deployed.

Electricity is distributed across the nation via the electrical grid, which includes long-range transmission lines from power plants to major load centers (e.g., cities) along with local distribution facilities from utilities to industrial, commercial, and residential clients. While existing long-range transition capacity is not viewed as imposing significant constraints on the adoption of EVs, new transmission capacity could be needed to accommodate an increase in renewable energy on the grid given that the necessary resources—such as wind on the Great Plains—are often located far from population centers (Kintner-Meyer, Schneider, and Platt 2007). In contrast, many local distribution networks will require upgrades—particularly for local transformers serving residential households—to accommodate demand patterns imposed by EV charging (May and Johnson 2011).

One convenient advantage of EVs is that they can be charged at home, using either an existing 120-volt outlet (referred to as Level 1 charging) or an electric vehicle charging appliance on a 240-volt circuit (described as Level 2 charging). The main challenge, however, is that recharging the battery pack is slow. With Level 1 charging, it can take 16 hours or more to fully charge the battery pack for a typical BEV; even with Level 2, it can take several hours. While this may be acceptable for charging a vehicle at home or at work, it is not a viable option for recharging during the middle of a long-distance trip or while running a quick errand (EERE 2011). Further compounding this challenge, most current BEV models only accommodate a relatively limited range, on the order of 100 miles or less, between recharging.

The potential need to recharge away from home has led to considerable public and private interest and investment in publicly accessible fast-charging stations for EVs, where "fast" is defined (per EERE 2011) as 30 minutes or fewer. While the need to wait 30 minutes for a battery charge is still likely to deter many prospective EV owners, it is still preferable to a recharge time of several hours. Level 3 charging, which provides an electric load (the product of voltage and amperage) of 14.4 kilowatt (kW) or higher, is currently the main option available for fast recharging. Level 3 stations, which can cost in excess of $50,000 (NPC 2012), typically require commercial or industrial electrical service and may not, based on the load and the capacity of the battery pack to be charged, actually achieve the 30-minute goal (EERE 2011). The concept of swapping a fully charged battery for a depleted battery, a process that can be executed in under two minutes, has also been explored. Battery swapping was developed by a firm that subsequently declared bankruptcy; more recently, Tesla Motors announced a plan to provide battery-swapping services for its EV customers (Tesla 2013).

Owing to considerable public subsidization to date, including stimulus funding from the American Recovery and Reinvestment Act, the network of publicly accessible charging stations in the United States has grown rapidly. As of September 2013, there were a little more than 19,000 charging stations in the United States (EERE 2013b). About 1,500 of these are located in California, some of which are residual from earlier efforts to support the state's zero emissions vehicle (ZEV) mandate in the 1990s and early 2000s.

3.4.2 Electric Vehicle Technology

Following failed efforts to develop and successfully market EVs in the 1990s, the underlying technology has progressed significantly. Several BEV and PHEV models, such as the Tesla Roadster and Model S, the Nissan Leaf, the Chevy Volt, the Toyota Prius plug-in, and the Ford C-Max Energi, have already been released, and many more are anticipated in the near term. Current models still face limitations, including a significant premium cost along with relatively constrained driving range in all-electric mode. Most BEV models that have already been released or are planned for the near future, for example, are limited to around 100 miles between charges.

The high cost associated with BEVs and PHEVs stems in large part from the expense of batteries. Relatively recent battery cost estimates range from $500 to $800 per kilowatt hour (kWh) (NPC 2012, NRC 2013b), though costs continue to decline. For a PHEV with a 16-kWh battery pack, this translates into a premium of $8,000 to $13,000. To compete effectively with conventional vehicle technologies in future years, significant further reductions in battery cost will almost certainly be needed. Other areas for improvement include safety and abuse tolerance, usable energy storage, peak power, and cycle and calendar life. These attributes vary with different potential battery chemistries; to date, lithium-ion batteries appear to offer the best combination of attributes for BEV and PHEV applications, though improved chemistries could emerge.

For PHEVs, the integration of electric power with the internal combustion engine involves additional technical considerations. These include power blending strategies as well as battery charging and discharging modes. One important design choice is how to employ the power generated by the ICE. In the Chevy Volt, power from the ICE is used to charge the battery pack, which in turn powers the drivetrain. The other alternative, essentially an extension of the approach employed in most conventional hybrids, is to blend output from the battery and ICE in powering the drivetrain. The Toyota Prius plug-in provides an example of this latter strategy.

3.4.3 Electric Vehicle Cost and Performance

The high cost of EVs, stemming in turn from the high cost of batteries, stands as a major impediment to broader adoption. To offer a few illustrations, the Prius plug-in has a premium of almost $8,000 over the standard third-generation Prius hybrid-electric vehicle (HEV) (Toyota 2013a, b), the Chevy Volt has a premium of almost $17,000 over the Chevy Cruze (GM, undated a, b), and the Nissan Leaf has a premium of almost $15,000 over the Nissan Versa (Nissan, undated a, b). To help offset the added cost associated with EVs, the federal government currently offers tax credits of up to $7,500, depending on the battery capacity of the model purchased, and some states offer additional subsidies. Given mounting pressure to trim federal and state budgets, however, it is unclear whether the public sector will be able to keep offering such financial support over the longer term. Absent public subsidies, reductions in the cost premium for EVs, largely a reflection of battery costs, will be important for broader adoption of EVs. Many analysts expect, though, that EVs will continue to require at least a moderate premium for the next several decades (Plotkin and Singh 2009, Michalek et al. 2011).

While EVs currently cost much more than conventional vehicles, they also offer outstanding performance in terms of the energy cost of travel. Additionally, because BEVs are mechanically simpler than conventional vehicles, routine maintenance costs may be lower as well. Precise estimates of the fuel-cost benefits of EVs are contingent on the relative price of electricity and gasoline along with the respective fuel economy of EVs and gasoline-fueled vehicles. Currently, though, the per-mile cost of electricity for driving an EV is only about a quarter to a third of the per-mile cost of gasoline for an average conventional vehicle [see, e.g., cost curves from Idaho National Laboratories (INL), undated]. Additionally, the cost of electric power is expected to increase much less than the cost of petroleum over the coming decades (EIA 2013b). As noted by Michalek et al. (2011), however, the cost of gasoline would need to increase to well above $4 per gallon on a sustained basis for the fuel-cost savings of EVs to pay back the vehicle cost premium at current battery prices.

Turning to other performance characteristics, both BEVs and PHEVs offer impressive power and torque. As noted previously, however, BEVs face important limitations in driving range, an issue that is compounded by the relative paucity of public charging stations and the long time required to recharge the battery pack. PHEVs, with their ability to run on gasoline when the battery pack becomes depleted, are not affected by this issue.

For GHG emissions, the benefits of EVs depend on the means of electric power production (for PHEVs, another important factor is the amount of miles powered by electricity versus petroleum). In some regions of the country that depend heavily on coal combustion, GHG emissions for an EV can be worse than for a conventional vehicle fueled by gasoline. For the U.S. grid mix as a whole, however, EVs do produce notably fewer well-to-wheels GHG emissions than a typical ICE vehicle, and the advantage is even more pronounced in states like California that derive a greater than average share of the power from renewables and lower-carbon sources (ANL 2012). Note, however, that battery production is quite carbon-intensive, partially offsetting some of the GHG reduction benefits of EVs (Michalek et al. 2011, Mashayekh et al. 2012). If all electric power could be produced renewably, then the full fuel-cycle emissions for BEVs could be driven close to zero.

As with greenhouse gases, the implications of EVs for local air pollutants likewise depend on the means of power production. With the current mix of power on the grid, EVs perform better for many air pollutants but much worse for particulate matter and sulfur oxides. All of the well-to-wheels emissions for BEVs, and for PHEVs in all-electric mode, however, occur at the power production facility; driving a vehicle in electric mode produces no emissions. Even with the current grid mix, then, EVs could lead to improved air quality in many urban areas, positively affecting human health.

3.4.4 Future Market Prospects for Electric Vehicles

Assuming that battery costs can be reduced and certain performance characteristics improved, then the market potential for EVs within the light-duty fleet is unconstrained. Important factors that are likely to influence the overall commercial success of EVs, the relative market shares for BEVs versus PHEVs, and the social benefits afforded by EVs include vehicle and battery costs, battery life cycle and replacement needs, battery performance and range limitations, availability of publicly accessible fast recharging stations, impacts on the power grid, shifts to more renewable electric power sources, the price of conventional fuels, and the pace of progress for competing alternative fuels and vehicle technologies.

3.5 Hydrogen

While hydrogen has been used for various commercial applications for over a century, serious interest in hydrogen as a transportation fuel began with the first hydrogen fuel-cell bus demonstration by Ballard Power Systems in 1993 [Office of Fossil Energy (OFE) 2000]. Hydrogen can alternatively be combusted in an ICE, either in pure form or mixed with natural gas, but fuel cells provide for more efficient use of the embodied energy in hydrogen. A number of automakers have now developed demonstration hydrogen fuel-cell vehicles (HFCVs, or FCVs), and early commercialization is expected around 2015 (NRC 2013b).

Because there are several methods for producing hydrogen that rely on domestically abundant resources, hydrogen promises important energy-security benefits. It is also likely that FCVs would reduce the energy cost of driving in relation to conventional ICE vehicles. Finally, depending on the hydrogen feedstocks, FCVs could support major reductions in greenhouse gas emissions and local air pollutants (NRC 2013b).

3.5.1 Hydrogen Production, Distribution, and Refueling

While a significant quantity of hydrogen is already produced in the United States each year, most of this is already used for other applications. To support a major shift to hydrogen as a transportation fuel, the current volume of U.S. hydrogen production would need to be expanded by nearly an order of magnitude (Joseck 2012). Near-term options for producing hydrogen include electrochemical conversion processes, such as steam reformation of natural gas or the gasification of coal or biomass, and electrolysis, in which electricity is used to split water molecules into separate streams of hydrogen and oxygen. Looking out even further, clean hydrogen could be generated via thermochemical water splitting with high-temperature heat from nuclear or concentrated solar power, via biological or photoelectrical water splitting, or via biomass pyrolysis, although these technologies face greater economic challenges (Ogden et al. 2011, NPC 2012). Currently, the methods of producing hydrogen involving lower greenhouse gas emissions also tend to be more costly (NRC 2013b).

Both natural gas reformation and electrolysis can be implemented in large central plants or in smaller installations at a refueling site. Large central plants allow for greater economies of scale in the production of hydrogen, while smaller installations obviate the need for transport. For centrally produced hydrogen, options for transporting the fuel to distribution centers or refueling stations include gaseous hydrogen tube trailers, liquid hydrogen tank trailers, and gaseous hydrogen pipelines. Transporting via truck trailers is likely to be the least expensive option in the early stages of adoption, while a pipeline distribution network would be far more cost-efficient for handling higher volumes of hydrogen. Pipelines for hydrogen, however, must rely on alloy steel to avoid embrittlement, along with special seals given the small size of hydrogen molecules, and the estimated costs range from $1 million to $1.5 million per mile in urban settings. One study concluded that transporting hydrogen via pipeline would only become cost-effective once FCVs had achieved a 25% market share among the light-duty fleet (Washington State DOT 2009).

As with electric and natural gas vehicles, home refueling with hydrogen is a realistic possibility at some point. Options might include a tri-generation appliance that uses natural gas to produce some combination of heat, electric power, and hydrogen fuel, or a home electrolysis device. Over the foreseeable future, however, such technology is likely to be priced out of the reach of most households, necessitating the consideration of publicly accessible hydrogen refueling infrastructure to enable a large-scale shift to hydrogen as a transportation fuel (Ogden et al. 2011). Providing such infrastructure will require a major investment. One recent study (NPC 2012) estimated that the cost of building a hydrogen refueling station falls in the range of $1 million to $7 million, depending on size and configuration. Nicholas and Ogden (2006) have calculated that the number of refueling stations required to support large-scale adoption of FCVs falls in the range of 4,500 to 11,000; at present there are fewer than 80 hydrogen stations across the country (Fuel Cells 2000, 2012).

The question of hydrogen refueling infrastructure is often described as a “chicken-and-egg” problem. Without a significant number of FCV owners, fuel providers will be reluctant to invest much in hydrogen refueling infrastructure; at the same time, however, prospective customers will be less willing to purchase FCVs unless the network of refueling stations is sufficiently developed. Many thus envision that some form of public support will be necessary to jump-start a network of hydrogen fueling stations. Mobile refuelers have also been explored as an option for serving early FCV adopters until more extensive refueling infrastructure becomes available [California Energy Commission (CEC) 2004].

3.5.2 Hydrogen Vehicle Technology

The fuel cell in an FCV is used to convert hydrogen into electricity, producing only water as a by-product. The electricity then powers an electric motor, which in turn propels the vehicle. Key vehicle components include the hydrogen storage tank, the fuel-cell stack, the electric motor, the power controller, and batteries for hybrid operation and cold-start support. Among these, hydrogen storage and the fuel cell present the greatest research and development challenges.

Fuel-cell technology has advanced considerably in recent years, providing acceptable size, weight, driving performance, and tolerance for low-temperature operations. There are, though, some remaining challenges—most notably with respect to durability and cost. Current proton exchange membrane (PEM) fuel-cell systems have a lifetime of about 2,500 hours in on-road tests, well short of the 5,000-hour life viewed as a target for commercialization. PEM fuel-cell durability is continuing to increase, however, and laboratory tests have demonstrated lifetimes of more than 7,000 hours (NRC 2013a). The cost of fuel-cell technology, often measured in dollars per kilowatt, is currently quite high, owing in part to low production volumes. The U.S. DOE, however, has estimated that if current fuel-cell configurations were produced at greater scale—on the order of 500,000 units per year—the cost would fall to about $49 per kW (NRC 2013a). This would translate to about $4,000 for an 80-kW system, which is roughly twice the cost of a comparable internal combustion engine. The target set by DOE is $30 per kW, which automakers hope to achieve via improved materials, reduced use of platinum, and increased power density (Ogden et al. 2011). At $30 per kW, fuel cells would still be more expensive than ICEs, but the differential would be more modest.

Determining the most cost-effective way to store enough hydrogen on an FCV to accommodate a 300-mile range is another target for further research and development. The main options include high-pressure cylinder tanks with hydrogen stored at either 5,000 or 10,000 pounds per square inch (psi), super-cooled liquid hydrogen tanks, or the use of metal hydrides or other materials to absorb hydrogen under pressure. Absent breakthroughs in the latter two technologies, most automakers have opted for compressed hydrogen in their demonstration vehicles, which is expected to be the technology of choice for at least the near term. Estimates for the cost of mass-produced compression tanks based on current technology fall in the range of $12 to $19 per kWh. This translates to about $2,800 for a tank able to hold enough hydrogen to provide a compact FCV with a range of 300 miles (NRC 2013a).

3.5.3 Hydrogen Vehicle Cost and Performance

Most FCVs to date have only been produced as demonstration vehicles, making it difficult to estimate their costs. It is safe to assume, however, that the premium cost for an FCV will be significant in the near term but then decline over time with increased production volume. Ogden et al. (2011), for example, provide a series of future FCV cost estimates based on a rapid market adoption scenario as follows: 5,000 FCVs sold by 2014 at a cost of $140,000 per vehicle, over 50,000 sold by 2015 at a cost of $75,000, over 300,000 sold by 2017 at a cost of $50,000, and two million sold by 2020 at a cost of $30,000. In this same projection, the cost premium for an FCV ultimately declines and levels out in the 2025 time frame at about $3,600 more than the cost of a conventional vehicle.

While FCVs may demand a price premium, they are also expected to provide at least moderate fuel-cost savings. The energy content in a gallon of gasoline is about the same as the energy in a kilogram of hydrogen, yet the fuel economy of an FCV, in miles per kilogram, is about twice the fuel economy for a conventional vehicle, and about 35% to 65% higher than for an HEV vehicle. More-stringent CAFE standards will result in greater fuel economy for conventional vehicles, but FCVs are expected to achieve much higher fuel economy in future years as well. An NRC (2013b) study, for example, has estimated that the average on-road fuel economy for a mid-sized passenger FCV in 2050 could fall in the range of about 140 to 170 miles per gallon of gasoline equivalent. Given the proportionally higher fuel economy for FCVs, hydrogen priced in the range of $4 per kilogram—an estimate provided in the NRC study for the 2050 time frame assuming a high level of adoption of FCVs—should be able to compete with gasoline priced at $2 to $3 per gallon. Gasoline prices are already above this level, and many (for example, see EIA 2013b) anticipate that gasoline will become more expensive in future decades. Accordingly, FCVs should compare favorably with conventional vehicles in terms of per-mile fuel costs, and they could allow for significant savings.

Beyond the question of fuel-cell durability mentioned earlier, current demonstration FCVs do not appear to suffer any particular performance challenges. Speed and power are acceptable, and vehicle range—at least with compressed hydrogen storage at 10,000 psi—appears to rival that of conventional vehicles. Refueling time is likewise not an issue.

Turning to environmental performance considerations, the potential for reducing GHG emissions depends on the feedstocks and processes for producing hydrogen. With either natural gas reformation or electrolysis using the current mix of grid power, FCVs could yield GHG reductions on the order of 15% to 25% in comparison to a typical gasoline-fueled ICE (ANL 2012). Looking at the longer term, greater reliance on renewable feedstocks, such as wind or solar power, or the use of carbon capture and sequestration with fossil feedstocks, could support far greater GHG reductions (Ogden et al. 2011, NRC 2013b).

Likewise, the implications of a shift to FCVs for local air pollutants depend on how the hydrogen is produced. In particular, emissions of fine particulate matter appear to be sensitive to the method of hydrogen production (Sun, Ogden, and Delucchi 2010; ANL 2012). Several production pathways, in fact, could lead to greater well-to-wheels particulate matter emissions in comparison to gasoline-fueled vehicles. The increase would be most significant if the hydrogen is produced via electrolysis using the current U.S. grid mix (Ogden et al. 2011) given the degree to which it relies on coal combustion, although increased substitution of natural gas or other generation for coal would lessen this effect. Additionally, many power plants are located away from dense settlements, mitigating the human health impacts to some extent.

3.5.4 Future Market Prospects for Hydrogen

Hydrogen as a transportation fuel offers great promise but also faces steep challenges. Unsurprisingly then, projections for future market share vary considerably. In its base-case projections from the most recent *Annual Energy Outlook*, for example, EIA (2013b) anticipates that cumulative FCV sales will only reach 70,000 by 2040. Greene et al. (2008), in contrast, explore three scenarios in which FCV sales in 2025 range from 500,000 at the low end to 2.5 million at the high end. With a similar degree of optimism, the California Air Resources Board (CARB 2009) has laid out an aspirational vision in which both BEVs and FCVs begin to enter the market in significant numbers by 2020 and together account for virtually all light-duty vehicle sales by 2040. The ultimate success and attendant benefits of a shift to hydrogen fuel are likely to hinge on such issues as hydrogen costs and feedstocks, fuel-cell cost and durability, onboard hydrogen storage cost, availability of refueling infrastructure, and technical progress for competing fuels and vehicle technologies.

3.6 Summary of Prospects for Light-Duty Vehicles

Drawing on the previous discussion as well as the information presented in Appendices A, B, C, D, and E, now is offered a qualitative summary of future prospects, challenges, and potential market share for conventional and alternative fuels and vehicle technologies in the light-duty fleet in future decades. Table 3.1 illustrates vehicle cost, per-mile fuel cost, and the well-to-wheels emissions of GHGs in the 2050 time frame versus a typical gasoline-fueled ICE in today's fleet. Each cell in the table has a series of symbols that consists of two downward arrows followed by a dot followed by two upward arrows. These are intended to reflect the range between a significant decrease with the left-most downward arrow and a significant increase with the right-most upward arrow, with the dot in the center representing the baseline for a current conventionally fueled light-duty vehicle. This setup enables comparison of the potential attributes of future fuels and vehicle technologies to the current fleet of petroleum-fueled light-duty vehicles, as well as to each other, to highlight their prospective strengths and limitations.

Symbols shown in black within each cell designate the range of outcomes judged to be reasonably likely based on the evidence reviewed by the research team, while symbols in light gray are viewed as less plausible. So, for example, the Vehicle Cost column of the first row in the table shows that the future price of a conventional ICE or HEV appears likely to be the same or moderately more, in real terms, than the cost of a conventional vehicle today, due to the inclusion of

Table 3.1. Future vehicle cost, fuel cost, and well-to-wheels emissions prospects.

Fuel and Vehicle Technology	Vehicle Cost	Per-Mile Fuel Cost	GHG Emissions
Petroleum and ICE or HEV	▽▽●▲△	▽▼●▲△	▽▼○△△
Natural gas and CNG vehicle	▽▽○▲△	▼▼○△△	▽▼○△△
Cellulosic E85 and FFV or drop-in biofuels and ICE	▽▽●▲△	▽▼●▲△	▼▽○△△
Electricity and BEV or PHEV	▽▽○▲▲	▼▼○△△	▼▼○△△
Hydrogen and FCV	▽▽○▲▲	▽▼●△△	▼▽○△△

Source: Assessments based on data and analyses presented in Appendices A, B, C, D, and E.

advanced vehicle technologies to meet more-stringent federal fuel economy standards.

Based on the entries in this table, conventional vehicles and FFVs appear likely to entail the lowest vehicle premiums, while natural gas and electricity promise the greatest fuel-cost savings. Biofuels, electricity, and hydrogen offer the greatest potential reductions in GHG emissions.

Table 3.2 summarizes the major obstacles and uncertainties likely to affect future market share and environmental benefits for each of the alternative fuels and vehicle technologies in competition with conventional petroleum-fueled vehicles. Challenges are organized into two columns: the first deals with fuel production and distribution, while the second focuses on supporting vehicle technologies. Factors likely to influence adoption rates are shown in standard text, while issues relating to the environmental benefits of adoption are italicized.

3.7 Medium- and Heavy-Duty Vehicle Applications

In its examination of alternative fuels and advanced vehicle technologies, the research team focused principally on light-duty vehicles, which account for the majority of all fuel use in the transportation sector. Additionally, though, the team explored potential applications of efficiency improvements and alternative fuels for medium- and heavy-duty vehicles (MHDVs). The results of this analysis, presented in greater detail in Appendix F, are summarized here.

3.7.1 Fuels and Vehicle Technologies

Motivated by concerns over energy security, climate change, and economic efficiency, there have been several initiatives and studies in the United States aimed at reducing

Table 3.2. Factors influencing market potential and environmental benefits.

Technology	Production, Distribution, and Refueling	Vehicle Cost and Performance
Natural gas CNG or LNG	• *Environmental concerns with fracking* • *Climate concerns from possible leakage of methane in the supply chain (which could more than offset GHG benefits of natural gas versus petroleum)* • Lack of refueling stations • Competition with other potential uses of natural gas	• High costs for onboard CNG or LNG storage, leading to higher vehicle costs • Perceived safety concerns for CNG • Limited vehicle range for CNG
Cellulosic E85 or drop-in biofuels FFV or ICE	• Insufficient feedstocks to fully displace petroleum and potential competition with food crops • *Uncertain ability of industry to meet RFS2 targets for advanced low-carbon biofuels such as cellulosic ethanol or, eventually, drop-in biofuels* • Limited distribution network, blending and storage capacity, and refueling stations for E85	• Reduced vehicle range with E85 given lower energy content per volume for ethanol versus gasoline
Electricity BEV or PHEV	• *High cost of increasing the share of renewable electricity on the grid* • Cost of upgrading local transformers to support at-home charging • Cost of upgrading residential electrical systems and installing home recharging equipment • Limited availability of fast recharging stations (most critical for BEVs)	• Unresolved battery performance concerns related to safety, longevity, and ability to handle fast recharging • Very high battery costs, leading to very high vehicle costs • Limited all-electric driving range and long required recharging time (most critical for BEVs)
Hydrogen FCV	• *High cost of renewable hydrogen in comparison to hydrogen produced from fossil fuels* • Lack of hydrogen distribution network and refueling stations	• Insufficient durability of fuel cells • High cost of onboard hydrogen storage and very high cost of fuel cells, leading to very high cost of vehicles

Source: Assessments based on data and analyses presented in Appendices A, B, C, D, and E.

fuel consumption and improving the performance of MHDVs. The 21st Century Truck Partnership, for example, is a cooperative research and development partnership among the DOE, the DOT, the U.S. Department of Defense (DoD), the EPA, and 15 industry partners. Its goal is to increase the ability of trucks to move freight while reducing emissions and fuel consumption (NRC 2012). The NRC set up its own committee to assess fuel economy technologies for MHDVs (NRC 2010b). The EPA also has several programs, including the Clean Diesel Campaign and the SmartWay freight program (EPA 2012, SmartTruck 2009), that focus on advanced engine and vehicle technologies and the promotion of alternative fuels to reduce petroleum consumption and improve environmental performance.

In addition to voluntary and collaborative public–private partnerships, the United States is poised for the first time to regulate fuel economy improvements in MHDV fleets. The federal government has mandated CAFE standards for light-duty vehicles since the late 1970s, but MHDVs were not previously subjected to analogous regulations. In May of 2009, though, President Barack Obama directed the NHTSA and the EPA to develop the Heavy-Duty National Program, which would specify fuel economy standards for combination tractors, heavy-duty pickup trucks and vans, and vocational vehicles (buses, refuse trucks, utility trucks, etc.). The proposed rulemaking for this program was issued in November 2010, and the rule was finalized in September of 2011. Under the new standards, which are set to take effect in 2014 and escalate through 2018, combination tractors will be required to achieve a 20% reduction in fuel use and greenhouse gas emissions, heavy-duty pickup trucks and vans will be required to achieve a 15% reduction, and vocational vehicles will be required to achieve a 10% reduction (EPA and NHTSA 2011).

Most MHDVs currently rely on diesel engines, in part for their power and fuel economy but also for their greater longevity, but an increasing number rely on gasoline. Many of the technical strategies for reducing petroleum use and emissions within the MHDV fleet have therefore focused on efficiency improvements for conventional diesel and gasoline power trains and vehicle configurations. Promising options in this vein include lighter-weight materials, improved aerodynamics and rolling resistance, gasoline direct injection, homogeneous charge compression ignition, and hybrid-electric and hybrid-hydraulic systems (NRC 2010b).

Alternative fuels are receiving increased attention for MHDVs as well. Depending on the specific application, potentially promising options include natural gas, biofuels, and hydrogen, with electricity offering some potential in niche markets.

3.7.2 Promising Applications

A common system for classifying MHDVs is by gross vehicle weight (GVW), a term describing the maximum operating mass of a vehicle as specified by the manufacturer, including the weight of the vehicle itself along with fuel, cargo, passengers, and the like. Classes 3 through 6, ranging from 10,000 pounds to 26,000 pounds GVW, are typically considered “medium duty,” while Classes 7 and 8, ranging from 26,000 to 80,000 pounds GVW, are designated as “heavy duty.” Class 8 can be further divided into Classes 8a, straight trucks, and 8b, combination (tractor-trailer) trucks. Because of their weight, number, and travel patterns, Class 8b vehicles account for about 60% of all fuel use among MHDVs (NRC 2010b). Another approach for classifying MHDVs that can be useful for certain analyses is by sector of use—for example, within the goods movement sector or the agricultural sector [Economics and Statistics Administration (ESA) 2004].

Alternatively, MHDVs may be classified according to application, which combines features of weight-based and sector-based classes. The previously referenced NRC study (2010b) classified MHDVs into seven general application categories: tractor-trailers, straight box trucks, straight bucket trucks, refuse trucks, transit buses, motor coaches, and pickup trucks and small vans. For evaluating the potential benefits and suitability of advanced vehicle technologies and alternative fuels within the MHDV fleet, this proves to be a helpful classification system, one that incorporates a range of relevant application characteristics:

- **Fleet use.** MHDVs are often operated in fleets. Examples of fleets are utility bucket trucks for line maintenance and emergency response, school buses, trash collection trucks, and cement trucks. Fleets, whether private or public, can benefit from shared vehicle maintenance and refueling stations. This can be quite helpful from the perspective of introducing alternative fuels because the fleet can be supported with minimal investment in refueling infrastructure. To convert a fleet of municipal service vehicles to natural gas, for example, it may be sufficient to install a single natural gas dispenser at a central fleet facility.
- **Daily range.** Operating range describes the distance from the central facility within which an MHDV must operate on a daily basis. Because some alternative fuels and technologies—most notably CNG and battery electric—offer more limited range than conventional fuels, quantifying the typical operating range provides insight into the potential applicability of such fuels and technologies for various MHDV classes and applications.
- **Annual mileage.** MHDVs are used heavily and, as a result, tend to travel more miles per year than passenger vehicles. Typical mileage by class ranges from 20,000 miles per year for local utility vehicles to over 200,000 miles per year for tractor-trailers used in long-haul applications (NRC 2010b). In comparison to passenger cars, then, this amplifies the relative benefit of alternative fuels and vehicle technologies that reduce fuel consumption for MHDVs. With

more miles traveled each year, fuel-cost savings can accrue more rapidly to offset increased capital costs associated with the vehicle purchase or conversion. Even with the potential for savings in fuel costs, though, there is still a delicate balance among capital and operating costs associated with MHDVs because newer technologies may increase system complexity and result in increased maintenance costs.

- **Duty cycle.** The term "duty cycle" refers to the pattern of use of a vehicle over a fixed time period. Duty cycles are as varied as the applications of MHDVs. For example, the duty cycle for a long-haul tractor-trailer may be as simple as driving 6 hours at an average speed of 60 mph. A waste-collection truck, in contrast, might drive to a neighborhood at moderate speed, and then creep along as workers gather trash in that neighborhood. The duty cycle for an application influences such factors as how often a vehicle has the opportunity to refuel, whether the vehicle would reap much benefit from aerodynamic improvements, whether the use of hybrid technology to capture power through regenerative braking would be valuable, and whether the vehicle would benefit from stored electric or hydraulic power, for example, to lift a trash receptacle or lift workers in buckets. The duty cycle can also have a strong effect on the emissions profile for internal combustion engines (NRC 2010b).
- **Ownership characteristics and life-cycle cost.** Finally, life-cycle ownership costs, including capital, financing, fuel, maintenance, and resale, are extremely important factors in evaluating alternative fuels and vehicle technologies. Alternative fuels often involve trade-offs in which certain cost components increase but others are reduced. For example, hybrid drivetrains and natural gas vehicles increase the purchase price of the vehicle significantly, adversely affecting both capital and financing costs. However, a hybrid drivetrain reduces fuel consumption, and natural gas vehicles can benefit from a lower-cost fuel. When purchasing new vehicles, MHDV owners typically assume that the vehicle will be sold for a certain resale value at the end of its term of service. Given the small installed base of support for both natural gas and hybrid vehicles, the ability of the purchaser to sell the vehicle could be compromised; diesel MHDVs operated using untraditional fuels such as biodiesel may likewise fetch less on the salvage market. By implication, given the importance of resale in most MHDV life-cycle-cost computations, the development of alternative fuels that substitute or may be blended with existing diesel is important.

Drawing on several sources of information, including from the ESA (2004), NRC (2010b), and ORNL (2012), Table 3.3 summarizes relevant class, usage, and fueling information for the various MHDV applications defined by the NRC (2010b).

Accounting for such characteristics, Table 3.4 summarizes the potential utility of various vehicle efficiency technologies and alternative fuels—taking into consideration their relative strengths and limitations, as well as information about where

Table 3.3. Summary characteristics for common MHDV applications.

Application	Classes	Fleet	Typical Duty Cycle	Typical Fuel	Typical Refueling Location
Tractor-trailer	7, 8	Local, regional, and national	Extended periods at high speed	Diesel	Truck stop, own facility
Straight truck, box	3–8	Local and regional	Urban delivery, moderate average speed	Diesel	Own facility
Straight truck, bucket	3–8	Local and regional	Urban and rural use, significant auxiliary load	Diesel	Own facility
Refuse truck	7, 8	Local	Urban use with frequent stops and creeping at low speed	Diesel	Own facility
Transit bus	7, 8	Local and regional	Urban use with frequent stops at low speed	Diesel but increasingly natural gas	Own facility
Motor coach	8	National	Extended periods at high speed	Diesel	Truck stop
Pickup trucks and small vans	2b	Local	Varied uses	Gasoline or diesel	Gas station

Source: Developed by authors based on material from ESA (2004), NRC (2010b), and ORNL (2012).

Table 3.4. Promising fuels and vehicle technologies for MHDV applications.

Application	Hybrid-Electric, Hydraulic	Natural Gas	Biodiesel, Ethanol	Battery Electric	Hydrogen
Tractor-trailer		●	●		●
Straight truck, box	●	●	●		●
Straight truck, bucket	●	●	●		●
Refuse truck	●	●	●		●
Transit bus	●	●	●		●
Motor coach			●		●
Pickup trucks and small vans	●	●	●		●

Notes: For pickup trucks and small vans, hybrid-electric technology is applicable, whereas hybrid-hydraulic is not generally feasible. As shown by the absence of bullets under the battery electric column, electric vehicle technology is not viewed as promising for most medium- and heavy-duty vehicle applications. A possible exception is for certain contexts—such as at ports—where the ability of electric vehicles to mitigate severe local air quality challenges may be highly prized.

they are already being applied (e.g., hydrogen transit bus demonstration programs)—for different medium- and heavy-duty vehicle applications.

References

Alvarez, R. A., S. W. Pacala, J. J. Winebrake, W. L. Chameides, and S. P. Hamburg. 2012. "Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure." *Proceedings of the National Academy of Sciences.* 109 (17): 6435–6440.

ANL. 2012. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)*, Fuel Cycle Model version 1. U.S. Department of Energy.

API. 2013. Oil & Natural Gas Overview: Service Station FAQs. http://www.api.org/oil-and-natural-gas-overview/consumer-information/service-station-faqs (accessed July 20, 2013).

CARB. 2009. Summary of Staff's Preliminary Assessment of the Need for Revisions to the Zero Emission Vehicle Regulation.

CBO. 2012. *Energy Security in the United States.*

CEC. 2004. *California Hydrogen Fueling Station Guidelines.*

Corts, K. 2010. "Building Out Alternative Fuel Retail Infrastructure: Government Fleet Spillovers in E85." *Journal of Environmental Economics and Management.* 59: 219–234.

Crane, K., A. E. Curtright, D. S. Ortiz, C. Samaras, and N. E. Burger. 2011. "The Economic Costs of Reducing Greenhouse Gas Emissions under a United States National Renewable Electricity Mandate." *Energy Policy.* 39 (5): 2730–2739.

Delucchi, M. 2006. *Lifecycle Analysis of Biofuels.* Institute of Transportation Studies, University of California, Davis.

DOE. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.*

EERE. 2010. *Clean Cities Alternative Fuel Price Report.*

EERE. 2011. Battery Chargers for Electric Vehicles. http://www1.eere.energy.gov/vehiclesandfuels/avta/light_duty/fsev/fsev_battery_chargers.html (accessed December 7, 2011).

EERE. 2012a. *Clean Cities Alternative Fuel Price Report.*

EERE. 2012b. Light-Duty Vehicle Search. Alternative Fuels Data Center. http://www.afdc.energy.gov/vehicles/search/light/ (accessed September 21, 2012).

EERE. 2013a. Flexible Fuel Vehicles. Alternative Fuels Data Center. http://www.afdc.energy.gov/vehicles/flexible_fuel.html (accessed October 21, 2013).

EERE. 2013b. Alternative Fueling Station Counts by State. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/stations_counts.html (accessed October 7, 2013).

EERE. 2013c. Fuel Prices. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/prices.html (accessed October 1, 2013).

EERE. 2013d. Alternative Fueling Station Locator. Alternative Fuels Data Center. http://www.afdc.energy.gov/locator/stations/(accessed October 17, 2013).

EIA. 2012. Natural Gas: U.S. Dry Natural Gas Proved Reserves. http://www.eia.gov/dnav/ng/hist/rngr11nus_1a.htm (accessed September 20, 2012).

EIA. 2013a. Renewable and Alternative Fuels: Alternative Fuel Vehicle Data. http://www.eia.gov/renewable/afv/index.cfm (accessed October 17, 2013).

EIA. 2013b. *Annual Energy Outlook 2013.*

EIA. 2013c. *Monthly Energy Review, September 2013.*

EPA. 2012. National Clean Diesel Campaign (NCDC). http://www.epa.gov/diesel/ (accessed September 24, 2012).

EPA and NHTSA. 2011. Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule. *Federal Register*, 76 (179).

EPA and NHTSA. 2012. "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule." *Federal Register*, 77 (199).

ESA. 2004. *2002 Economic Census: Vehicle Inventory and Use Survey, Geographic Area Series.*

Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammen. 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science*, 311 (5760): 506–508.

Fuel Cells 2000. 2012. *U.S. Hydrogen Fueling Stations.*

GM. Undated a. Chevrolet 2014 Cruze/2013 Cruze. http://www.chevrolet.com/cruze-compact-car.html (accessed October 14, 2013).

GM. Undated b. Chevrolet 2014 Volt/2013 Volt: Model Overview. http://www.chevrolet.com/volt-electric-car/ (accessed October 14, 2013).

Greene, D., P. Leiby, B. James, J. Perez, M. Melendez, A. Milbrandt, S. Unnasch, and M. Hooks. 2008. *Analysis of the Transition to*

Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements. Oak Ridge National Laboratory.

Honda. 2013. To Each Their Own Civic. http://automobiles.honda.com/civic/ (accessed October 1, 2013).

IEA. 2012. *World Energy Outlook 2012.*

INL. Undated. *Comparing Energy Costs per Mile for Electric and Gasoline-Fueled Vehicles.*

Joseck, F. 2012. Current U.S. Hydrogen Production. *DOE Hydrogen and Fuel Cells Program Record.*

Kintner-Meyer, M., K. Schneider, and R. Platt. 2007. *Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 1: Technical Analysis.* Pacific Northwest National Laboratory.

Knittel, C. R. 2011. "Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector." *American Economic Review*, 101 (7): 3368–3399.

Kobayashi, S., S. Plotkin, and S. Ribeiro. 2009 "Energy Efficiency Technologies for Road Vehicles." *Energy Efficiency*, 2: 125–137.

Mashayekh, Y., P. Jaramillo, C. Samaras, C. T. Hendrickson, M. Blackhurst, H. L. McLean, and H. S. Matthews. 2012. "Potentials for Sustainable Transportation in Cities to Alleviate Climate Change Impacts." *Environmental Science & Technology*, 46: 2529–2537.

May, E. and S. Johnson. 2011. "Top 10 EV Challenges: Utilities Prepare for a Bumpy Road." *Public Utilities Fortnightly*, pp. 56–60.

Michalek, J. J., M. Chester, P. Jaramillo, C. Samaras, C.-S. Shiau, and L. B. Lave. 2011. "Valuation of Plug-in Vehicle Life-Cycle Air Emissions and Oil Displacement Benefits." *Proceedings of the National Academy of Sciences*, 108(40): 16554–16558.

MIT. 2011. *The Future of Natural Gas.* MIT Energy Initiative.

Mullins, K. A., W. M. Griffin, and H. S. Matthews. 2010. "Policy Implications of Uncertainty in Modeled Life-Cycle Greenhouse Gas Emissions of Biofuels." *Environmental Science & Technology*, 45 (1): 132–138.

NETL. 2013. "Coal and Power Systems: Major Demonstrations." http://www.netl.doe.gov/technologies/coalpower/cctc/index.html (accessed September 26, 2013).

NGVA. 2011. *Fact Sheet: Converting Light-Duty Vehicles to Natural Gas.*

Nicholas, M. and J. Ogden. 2006. "Detailed Analysis of Urban Station Siting for the California Hydrogen Highway Network." *Transportation Research Record: Journal of the Transportation Research Board, No. 1983:* 129–139. Transportation Research Board of the National Academies, Washington, D.C.

Nissan. Undated a. 2013 Nissan Leaf. http://www.nissanusa.com/electric-cars/leaf/ (accessed October 14, 2013).

Nissan. Undated b. 2013 Nissan Versa Note. http://www.nissanusa.com/cars/versa-note (accessed October 14, 2013).

NPC. 2012. *NPC Future Transportation Fuels Study: Advancing Technology for America's Transportation Future.*

NRC. 2009. *Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts.* The National Academies Press, Washington, D.C.

NRC. 2010a. *Electricity from Renewable Resources: Status, Prospects, and Impediments.* The National Academies Press, Washington, D.C.

NRC. 2010b. *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.* The National Academies Press, Washington, D.C.

NRC. 2012. *Review of the 21*st *Century Truck Partnership, Second Report.* The National Academies Press, Washington, D.C.

NRC. 2013a. *Review of the Research Program of the U.S. DRIVE Partnership: Fourth Report.* The National Academies Press, Washington, D.C.

NRC. 2013b. *Transitions to Alternative Vehicles and Fuels.* The National Academies Press, Washington, D.C.

OFE. 2000. *Fuel Cell Handboo*k.

Ogden, J., C. Yang, J. Cunningham, N. Johnson, X. Li, M. Nicholas, N. Parker, and Y. Sun. 2011. Chapter 3: The Hydrogen Fuel Pathway. In J. Ogden and L. Anderson (eds.), *Sustainable Transportation Energy Pathways.* Institute of Transportation Studies, University of California, Davis.

ORNL. 2012. *Transportation Energy Data Book*, Edition 31.

Parker, N., B. Jenkins, P. Dempster, B. Higgins, and J. Ogden. 2011. Chapter 1: The Biofuels Pathway. In J. Ogden and L. Anderson (eds.), *Sustainable Transportation Energy Pathways.* Institute of Transportation Studies, University of California, Davis.

Perlack, R., L. Wright, A. Turhollow, R. Graham, B. Stokes, and D. Erbach. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.* U.S. Department of Agriculture and U.S. Department of Energy.

Plotkin, S. and M. Singh. 2009. *Multi-Path Transportation Futures Study: Vehicle Characterization and Scenario Analysis.* Argonne National Laboratory.

Searchinger, T., R. Heimlich, R. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change." *Science*, 319 (5867): 1238–1240.

SmartTruck. 2009. EPA Smart Truck Partnership. http://smarttrucksystems.com/epasmartway.php (accessed September 24, 2012).

Sun, Y., J. Ogden, and M. Delucchi. 2010. *Societal Lifetime Cost of Hydrogen Fuel Cell Vehicles.* Institute of Transportation Studies, University of California, Davis.

Tesla. 2013. Battery Swap. http://www.teslamotors.com/batteryswap (accessed October 11, 2013)

Toyota. 2013a. Prius 2013. http://www.toyota.com/prius/ (accessed October 14, 2013).

Toyota. 2013b. Prius Plug-in Hybrid 2013. http://www.toyota.com/prius-plug-in/ (accessed October 14, 2013).

Washington State DOT. 2009. *Alternative Fuels Corridor Economic Feasibility Study.*

West, T., K. Dunphy-Guzman, A. Sun, L. Malczunski, D. Reichmuth, R. Larson, J. Ellison, R. Taylor, V. Tidwell, L. Klebanoff, P. Hough, A. Lutz, C. Shaddix, N. Brinkman, C. Wheeler, and D. O'Toole. 2009. *Feasibility, Economics, and Environmental Impact of Producing 90 Billion Gallons of Ethanol per Year by 2030.* Sandia National Laboratory.

WGA. 2008. *Transportation Fuels for the Future: Natural Gas and Propane.*

Williams, P., D. Inman, A. Aden, and G. A. Heath. 2009. "Environmental and Sustainability Factors Associated with Next-Generation Biofuels in the U.S.: What Do We Really Know?" *Environmental Science & Technology*, 43 (13): 4763–4775.

Yacobucci, B. D. 2005. *Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues.* Congressional Research Service.

Yacobucci, B. D. 2008. *Natural Gas Passenger Vehicles: Availability, Cost, and Performance.* Congressional Research Service.

CHAPTER 4

Population, Economy, Land Use, and Policy Factors

As indicated in the introductory chapter, the plausible future transportation energy scenarios developed for this project include elements related to fuel sources and vehicle propulsion technologies, travel demand and mode choices, and federal policies in the areas of energy, climate, and transportation funding. Emerging fuel sources and vehicle technologies are the central focus of the study and may affect state DOTs in a variety of ways. Assuming current fuel-tax rates remain unchanged, for example, any major reduction in petroleum use—due to higher fuel economy for conventional vehicles or a major shift to alternative fuels—could severely undercut fuel-tax revenue as the major source of highway funding. Changes in the price and performance of fuels and vehicles may also affect state DOTs indirectly through their effects on total travel and mode split—potentially exacerbating traffic congestion, for example, or prompting calls for increased DOT involvement in supporting alternative travel modes. Finally, in addition to their potential role in influencing future energy demand and travel choices, shifts in relevant federal policy domains could also constrain or expand the policy options available to states for responding to changes in fuel sources and vehicle technologies.

The preceding chapter summarized the team's research on the prospects and challenges for advanced petroleum-fueled vehicles and emerging alternative-fuel options—research that supported the development of the future transportation energy scenario elements related to fuels and vehicle technologies. This chapter reviews complementary background research intended to inform additional elements of the future scenarios. Specifically, the first section in the chapter considers three broad socio-economic factors with important implications for both energy and travel demand in the coming decades: population growth, economic growth, and land use decisions. The second section examines challenges and ongoing policy debates in the areas of energy, climate, and transportation funding that offer clues about potential trajectories for future federal policy decisions. The chapter closes with a summary of how certain socio-economic or federal policy developments in the coming decades might be expected to influence the future transportation energy scenarios. More detailed discussions of the material reviewed in this chapter can be found in Appendices G and H.

4.1 Population, Economy, and Land Use Trends

The discussion begins by considering past trends and future prospects and uncertainties for population growth, economic growth, and land use. More detailed discussion of the material presented in this section can be found in Appendix G.

4.1.1 Population Growth

Other factors held constant, an expanding population translates to greater demand for energy and travel. The magnitude of such effects, however, depends on such factors as age, income, and generational tenure.

Past trends. The U.S. population has grown steadily in past decades, increasing from about 150 million in 1950 to almost 310 million in 2010 (U.S. Census Bureau 2000, 2011). This translates to an annual growth rate of approximately 1.2%. Contributing factors have included a sharp rise in birthrates in the decade following World War II (the so-called baby boom), increased life expectancies stemming from advances in medicine and improved living conditions, and positive net immigration. While there has been a significant decline in birthrates following the baby-boom generation (Shrestha and Heisler 2011), this has been more than offset by greater longevity and continued immigration. Population growth has been strongest in recent decades in the western and southern regions of the country and more modest in the Northeast and Midwest (U.S. Census Bureau 1995, 2005).

Future expectations and uncertainties. As discussed by Cheeseman Day (undated), the U.S. population is expected to continue to grow in future decades, albeit at a declining rate, and to become older and more diverse. Population growth in the West and South is expected to continue to exceed growth in the Northeast and Midwest, and the overall growth rate will be highly dependent on net immigration rates.

- **Continued population growth, but at a declining rate.** Owing in part to gradual declines in birthrates along with the aging of the baby-boom generation past childbearing years, population growth is expected to slow to an annual rate of 0.8% over the next 40 years (Cheeseman Day, undated).
- **An older population.** With continued advances in medicine—the U.S. Census projects average life expectancy to increase to 82.6 years by 2050 (Shrestha 2006)—the average age of the U.S. population is expected to increase over time.
- **A more diverse population.** Owing to differences in birthrates along with the effects of immigration, non-Hispanic whites are expected to decline as a share of the U.S. population, while other races are expected to grow at a faster pace. Asian and Pacific Islanders are currently the fastest growing segments of the population (Cheeseman Day, undated).
- **Regional variations in population growth.** U.S. Census Bureau projections suggest that population in the West and South will grow at an annual rate of 1.2% in the coming decades, whereas the growth rate will be much lower, at 0.2%, in the Midwest and Northeast (U.S. Census Bureau 1995, 2005).
- **Uncertain immigration rates.** Among the various factors contributing to overall population growth, immigration rates present the greatest uncertainty. In a recent exercise examining a range of assumptions regarding future net immigration rates, the U.S. Census Bureau (2009 a, b, c, d) found that the U.S. population in 2050 could vary between 320 million (zero net immigration scenario) and 450 million (high net immigration scenario).

4.1.2 Economic Growth

As with population growth, an expanding economy also contributes to increasing energy and travel demand, all else being equal. Growth in gross domestic product (GDP), a measure of the nation's total economic activity, tends to stimulate increases in goods movement. Another measure, personal income, tallies all sources of income received by U.S. citizens and residents. Gains in per-capita personal income in past decades have supported greater consumption of goods and services in general, including a rapid increase in automotive passenger travel.

Past trends. Adjusting for inflation, U.S. GDP has grown by about 1,500% over the past 80 years, reaching about 17 trillion dollars in 2012 [U.S. Bureau of Economic Analysis (BEA) 2013]. This translates to an average annual growth rate of around 3.38%. Contributing factors to the nation's past growth include an abundant natural resource base along with investments in physical and human capital, with the latter often viewed as being the most important. Between 1875 and 1975, the average years of education in the United States increased by seven grades, although this has since begun to level off (DeLong, Golden, and Katz 2003).

Per-capita personal income has also risen considerably, growing in real terms from about $8,500 in 1930 to about $42,400 in 2011, as measured in 2012 dollars [computed by the authors from BEA 2012 and U.S. Bureau of Labor Statistics (BLS) 2013]. This corresponds to a little under 400% cumulative growth over this period, or an average annual growth rate of 1.98%. In more recent decades, however, in part due to the severity of the recent recession, per-capita personal income growth has been much more sluggish; the average real annual growth rate over the past 20 years (1991 to 2011) was just 1.2%, and over the past 10 years it was just 0.5%. Additionally, income distribution in the United States, and in many other countries, has become increasingly uneven in recent decades, with income for poorer households declining in real terms. This has resulted from a variety of factors, ranging from changes in tax policy to globalization, automation, and other structural economic shifts [Organization for Economic Co-operation and Development (OECD) 2011].

Future expectations and uncertainties. Most forecasters assume that the U.S. economy will expand in the coming decades, although there is less certainty about what the growth rate will be. There are also concerns that income disparities will continue to widen, and it is possible that economic growth rates may vary from one region to the next.

- **Continued economic growth of an uncertain magnitude.** Owing in part to the depth of the recent recession, economic growth has slowed in recent years. Between 1930 and 2012, the average annual growth rate for real GDP was about 3.38%; between 1992 and 2012, in contrast, the rate slowed to just 2.51% (BEA 2013). Looking forward, the EIA has assumed an annual growth rate for real GDP of 2.5% through 2040 for the projections in its most recent *Annual Energy Outlook* (EIA 2013). More optimistically, Dadush and Stancil (2009) projected an average growth rate of 2.9% for 2009 to 2050. While such assumptions fall within the bounds of past experience, it is also possible to envision major disruptions—such as severe climate change—that could undercut growth rates or, alternatively, significant technological breakthroughs that could enable even faster growth.
- **Potential exacerbation of income inequality.** Some of the structural factors contributing to rising income inequality in past decades, such as globalization and automation, appear likely to continue in the coming years. Absent significant policy intervention—such as a much more progressive

taxation system coupled with redistributive investments—income disparities may continue to widen over time.

- **Geographic variations in growth.** It is also possible that growth rates could vary from one region to the next based on the regions' economic structures. Following the recent recession, for example, smaller cities in the oil- and gas-producing regions of the country have rebounded quickly, while sprawling metropolises in the Sunbelt region have been much slower to recover (Florida 2012).

4.1.3 Land Use

Land use—specifically, such factors as population density and the mixing of different types of land use (e.g., residential and commercial)—can have a significant influence on both total travel demand and choice among different modes of transportation. These, in turn, also affect energy demand. Thus, land use reforms are often considered as one of the policy options for addressing such challenges as climate mitigation.

Past trends. Before World War II, most of the U.S. population lived in rural areas. Since that time, however, the United States has experienced significant migration from rural areas to larger cities; by 2000, the share of Americans living in metropolitan areas had risen to 80%. Most metropolitan growth, however, has been concentrated in the suburbs rather than in central city areas; between 1950 and 2000, the share of the U.S. population residing in suburbs rose from 23% to around 50% (Hobbs and Stoops 2002). Both policy choices and market factors—for example, the federal tax deduction on mortgage interest, the development of the Interstate highway system, demand among baby-boom generation families for larger housing, and the so-called white flight from inner cities following the desegregation of urban school districts—contributed to the rapid rise in suburbanization. In more recent decades, however, there has been renewed interest in land use policies aimed at densifying and revitalizing central urban areas.

Future expectations and uncertainties. The United States will not run out of undeveloped land anytime soon. Of the nation's 2.26 billion acres of land, only 66 million, or about 3%, were urbanized as of 1997 (Lubowski et al. 2002). The federal government controls roughly 30% of the nation's land, which has been set aside for national parks, national forests, national wildlife reserves, military reserves, and other public-interest uses. Much of the remainder, though, could in theory be developed, allowing for continued suburbanization in future decades. While this has been the dominant land-use theme for much of the past century, the future trajectory of land use is much less certain.

- **Shifting policies and market forces.** Against the past backdrop of sprawling suburban development, many states and local jurisdictions are now implementing or considering smart growth policies intended to promote greater density, more mixed-use development, and better integration of land use and transportation. Such policies are usually aimed at improving sustainability and livability, and there is some evidence that both younger and older households (pre- and post-children) are attracted to vibrant urban locales. Broad adoption of smart growth land-use policies might therefore lead to an increasing share of the population living in denser and revitalized central city areas (Myers and Gearin 2001). In contrast, other authors have outlined more dystopian visions of the future in which energy or climate challenges render current urban structures supported by long-distance transport uneconomical, triggering a possible return to rural living with increased emphasis on local food production (e.g., Kuntsler 2005). It is thus possible to envision plausible futures involving denser urbanization, continued suburbanization trends, or even a reversal to more rural living. It is also possible that shifts in land use could vary from one state to the next based on different policy choices by states and local jurisdictions.

4.2 Energy, Climate, and Transportation Funding Policy Debates

The focus of the discussion now shifts to ongoing challenges and policy debates relating to energy, climate, and transportation funding. As noted earlier, future federal or state policy actions in these areas—for example, a decision to tax carbon emissions or to shift to greater reliance on general revenues versus user fees to fund transportation—may affect both aggregate energy and travel demand along with choices among competing fuels and travel modes. Additionally, federal policy choices in these areas may have the effect of constraining or expanding the options available to states as they seek to address any impacts associated with evolving fuel sources or vehicle technologies, making it useful to consider federal energy, climate, and transportation funding policy elements within the future scenarios developed for this project.

The discussion in this section focuses first on energy and climate policy and then transportation funding policy. While excise taxes on gasoline and diesel could arguably be categorized under either of these domains, the historic purpose of fuel taxes has been to raise highway revenue. Accordingly, fuel taxes are discussed in the context of transportation funding rather than energy and climate policy.

4.2.1 Energy and Climate Policy Debates

Through the 1800s and early 1900s, formal and informal U.S. energy policies focused mainly on developing and expanding access to cheap and reliable sources of fuel and electric power. While these efforts succeeded in facilitating strong economic growth and improving living standards, they also led to a rapid rise in the combustion of fossil fuels—most notably coal to generate electric power and petroleum to fuel a growing number of cars and trucks. Growing reliance on fossil fuels led to other policy challenges in turn. Poor air quality, resulting from, among other contributing factors, the combustion of coal for heat and power along with and auto and truck exhaust, became increasingly problematic for many urban areas in the earlier part of the twentieth century. In the 1970s, with spiking fuel prices and market disruptions following the Arab oil embargo of 1973, the adverse economic and national security implications of increasing U.S. reliance on foreign sources of petroleum emerged as a significant policy concern. Over the past two decades, as the significant risks of climate change resulting from fossil fuel combustion have become more apparent, strategies for mitigating climate change have slowly become intertwined with U.S. energy policy debates.

Past trends. Energy and climate debates in recent years have focused largely on three main objectives: promoting low and stable energy prices, enhancing energy security (reducing reliance on imported petroleum, particularly from potentially hostile regions of the world), and reducing greenhouse gas emissions. While air quality challenges persist, the regulatory framework for improving air quality—the Clean Air Act, as administered by the EPA—is already in place. Though there is some contention over the pace and rigor of EPA rulings issued under the Clean Air Act, the regulatory framework appears relatively well entrenched.

In contrast, the past few years have witnessed more spirited debate on potential policies for reducing energy costs, enhancing energy security, and mitigating climate change. Of these, the first two are broadly popular, while the third remains controversial at present. Some policies, such as more-stringent vehicle fuel economy standards, are able to address all three of these goals simultaneously. Others, however, may perform well for one of these objectives but poorly for another. Taxing greenhouse gas emissions, for example, could be a potent policy option for mitigating climate change, but it would also raise rather than lower fossil-fuel energy costs for the consumer. Efforts to increase domestic fossil-fuel production, in contrast, could help reduce energy costs and lead to greater energy independence, but also undermine efforts to reduce carbon emissions. This lack of alignment has led to strong disagreement among stakeholders with varying interests over the best set of energy and climate policies for the United States to pursue.

Potential policies aimed at some combination of lower energy costs, increased energy security, and mitigation of climate change can be broadly divided into supply-side approaches that seek to increase U.S. production of traditional energy sources and demand-side approaches that seek to reduce energy demand or displace fossil fuels with cleaner energy alternatives. Demand-side strategies can be further differentiated into the categories of regulatory mandates, subsidies, and pricing (taxation) mechanisms.

- **Supply-side policies to boost domestic energy production.** Based on the recent emergence of technologies designed to enhance recovery from existing wells and exploit reserves from unconventional sources such as tight oil and shale gas, domestic oil and natural gas production have experienced a significant resurgence in the past few years. Indeed, recent analysis by the IEA (2012) suggests that the United States could become the leading global oil producer by 2020 and a net oil exporter by 2030. Potential supply-side policies for accelerating domestic production, some of which are already in place, include offering subsidies for oil and gas exploration and development, opening more federal and state lands to drilling, and relaxing environmental and safety-related permitting requirements.
- **Demand-side policies involving regulatory mandates.** Regulatory mandates govern the quantity or qualities of goods or harmful wastes produced by individual firms or by an industry as a whole. Current federal mandates to reduce petroleum demand include CAFE standards, which govern the average fuel economy for new vehicles offered by major auto manufacturers and have recently been harmonized with federal and California emissions standards for greenhouse gases (EPA 2012), and renewable fuel standards (RFSs), which specify volumetric targets for various categories of liquid biofuels to be sold by major fuel vendors (EPA 2013). The regulatory-mandate approach has often been employed at the state level as well.
- **Demand-side policies involving subsidies.** Governments may employ subsidies to foster the emergence or increase the adoption rate of new products or technologies promising important public benefits. Examples of recent federal subsidies intended to reduce or displace petroleum consumption are tax credits for battery electric vehicles and plug-in hybrids authorized in the Energy Improvement and Extension Act of 2008 and the American Clean Energy Act of 2009; the 2009 Car Allowance Rebate System (also known as the "cash for clunkers" program), which provided rebates to consumers for replacing an older vehicle with a new model capable of much higher fuel economy (Knittel 2009); and recently expired tax credits on the production of corn-based ethanol. While subsidy programs are often popular, they also require an ongoing funding stream and thus can be difficult to sustain over a prolonged period.
- **Demand-side policies involving pricing.** As with subsidies, pricing (taxation) policies also involve the application

of financial incentives to motivate certain choices on the part of producers and consumers. In contrast to subsidies, however, pricing has the effect of reducing demand for products viewed as undesirable. With the imposition of fees or taxes, pricing tends to be more controversial than subsidies. On the other hand, pricing policies typically generate a positive revenue stream (or at minimum can be designed as revenue neutral); as such, they can be maintained over time without adverse budgetary consequences. Potential pricing policies aimed at reducing fossil-fuel consumption and greenhouse gas emissions include higher taxes on gasoline and diesel, carbon taxes, and carbon cap-and-trade programs (Burger et al. 2009). While the federal government has not yet instituted carbon pricing, several states have recently initiated cap-and-trade programs [Union of Concerned Scientists (UCS) 2012]. Another potential pricing approach, one that combines fees with subsidies, is often described as a feebate program. As applied to vehicle purchases, for example, a feebate program would include subsidies for those who purchase vehicles with higher fuel economy or purchase alternative-fuel vehicles along with penalty fees for those who opt for vehicles with lower fuel economy (German and Meszler 2010).

Current federal energy and climate policies in the United States can be viewed as relatively moderate in tone, consisting mainly of regulatory mandates and subsidies and generally eschewing more controversial pricing approaches. From the perspective of potentially relevant policy goals, the current policy mix might also be characterized as conflicted, a reflection of the seemingly inevitable competition among stakeholder interests seeking to influence policy choices based on their own goals. While current energy policy could be described as a combination of all of these approaches, it is quite possible that this may result in a combination of policies that tend to undermine one another. To illustrate, current federal policies simultaneously subsidize fossil-fuel development, require auto manufacturers to achieve much higher fuel economy, and offer tax credits to stimulate demand for electric vehicles. The first two of these policies, however, should have the combined effect of making petroleum-fueled vehicles cheaper to drive, in turn making it more difficult for electric vehicles to achieve commercial success.

Future expectations and uncertainties. Looking forward, and taking into consideration the current degree of partisan division in national politics, it is possible that the current mix of U.S. energy and climate policies could remain intact for the foreseeable future. It is also possible, however, to envision major shifts in federal policy by 2050, especially given mounting concerns related to climate change. Key uncertainties affecting future policy choices include potential shifts in the relative prioritization of policy goals and voter attitudes toward pricing as a policy mechanism.

- **Relative prioritization of policy goals.** With anticipated increases in U.S. oil and natural gas production, the past urgency of energy security concerns appears to be receding. The issue that now eludes consensus is whether the nation's policies should aim primarily at low energy costs or should instead focus more strongly on climate change. Some policy options such as CAFE standards can simultaneously reduce the energy cost of travel and mitigate climate change. Many other policies, however, such as support for petroleum production or the application of carbon pricing, involve trade-offs between the goals of energy cost and climate mitigation. Should a greater degree of agreement regarding the relative prioritization of these goals emerge—perhaps in response to changing economic conditions or new information about climate change—it could set the stage for significant shifts in federal energy and climate policies.
- **Application of pricing policies.** Should public opinion coalesce on the need for greater action to address climate, the next salient question is whether the application of pricing to achieve energy and climate goals will achieve broader adoption among states or at the federal level. Carbon pricing, for instance, could support even more rapid progress toward energy independence along with climate mitigation, but to date this idea has proven too divisive to gain sufficient support for federal implementation.

4.2.2 Transportation Funding Debates

Roads and transit systems are typically planned and funded by the public sector based on revenue raised at federal, state, and local levels. Common funding sources are user fees (e.g., fuel taxes or transit fares) and various general revenue sources (e.g., property taxes and sales taxes). Looking back over the past century, several major themes in transportation funding policy emerge.

First and foremost, the United States has traditionally relied to a significant degree on user fees to fund highways and, to a lesser degree, transit systems (Brown et al. 1999). Federal and state excise taxes on gasoline and diesel provide the majority of user-fee revenue for highways in the country, complemented by additional federal and state sales and registration fees for trucks or passenger vehicles along with facility tolls in many states. [For a recent breakdown of user fees and other highway revenues at federal and state levels, see table HF-10 of *Highway Statistics 2010* (OHPI 2012).] As the primary user fee, fuel taxes can be viewed as a fair way to apportion the cost of building and maintaining the road network since the burden for a given driver varies in proportion to the amount that he or she travels. In comparison to general revenue mechanisms, fuel taxes and other user fees also promote more economically efficient use of the road network (Wachs 2003).

Additionally, the federal government and states have historically increased fuel taxes and other transportation revenue sources as needed to fund desired improvements. Initially set at 1 cent per gallon in 1932, for example, the federal excise tax on gasoline has been increased nine times in the intervening years—most recently in 1993—and currently stands at 18.4 cents per gallon. Many states have instituted similar fuel-tax increases as needed or have indexed their per-gallon fuel taxes to automatically increase with inflation.

To garner public support for levying and increasing fuel taxes to pay for roads, the federal government and most states have chosen to hypothecate (dedicate) fuel-tax revenue for investments in highways and, more recently, transit and other alternative modes—an arrangement that is relatively rare outside of the United States. With the Highway Revenue Act of 1956, for example, Congress created the HTF account to serve as a repository for federal fuel-tax receipts, which are in turn allocated to states to fund the Interstate system and other federal-aid highways. In essence, hypothecation represents a pact between road users and the government that fuel taxes will be treated as a user fee; road users agree to pay, through fuel taxes, to fund the road network, and the government in turn agrees to invest the resulting revenue in construction and maintenance projects that benefit road users.

Past trends. While the broad themes just discussed held for much of the twentieth century, there have been several significant shifts in recent decades. Most importantly, the federal government and many states have not increased per-gallon fuel-tax rates to keep pace with inflation and improved fuel economy. This has reduced overall highway funding in relation to travel, diminished the share of highway revenue raised through user fees, and led to a gradual devolution of transportation funding responsibility to local jurisdictions. Important trends in transit funding include greater dependence on subsidies along with more rapid growth in transit funding than in ridership. Turning to investment choices, key themes in recent decades include insufficient overall levels of investment, diversion of highway user fees to other modes, and disproportionate investment in transit in comparison to mode share.

- **Decline in real fuel-tax revenue and total highway revenue in comparison to vehicle travel.** Because federal and most state fuel taxes are levied on a cents-per-gallon basis, they must be either indexed or increased periodically to keep pace with inflation and improved fuel economy. The politics of increasing fuel-tax rates, however, appear to have become more challenging in recent years. Federal fuel-tax rates, for example, were last raised in 1993; since then, they have lost at least a third of their value to inflation (NSTIFC 2009). Though a few states have indexed their fuel-tax rates for inflation, and others have instituted rate increases relatively recently, many states have instead allowed their fuel-tax rates to stagnate as well. Based on the most recent available data from the FHWA (OHPI 2011), it appears that as many as 19 states have not increased fuel-tax rates since the 1990s, and as many as six more have not increased rates since the 1980s or earlier. Because fuel-tax revenue constitutes such a large share of overall highway funding, the erosion of fuel taxes has led in turn to a significant reduction in real highway revenue in relation to vehicle miles of travel (VMT) over the last several decades. Based on author computations using data from OHPI (undated), BLS (2013), and ORNL (2012), real highway revenue per VMT declines by more than 30% between 1970 and 2010; absent the recent congressional transfers of general funds to keep the HTF solvent (roughly $15 billion combined in 2008 and 2009, necessitated by the decline in real fuel-tax revenue) along with subsequent stimulus funding under the American Recovery and Reinvestment Act, the decline in real highway revenue per VMT would be close to 50%.
- **Devolution of highway funding responsibility.** The erosion in federal and state fuel-tax revenue has had the effect of devolving greater funding responsibility to local governments (Goldman and Wachs 2003). Through the 1960s and early 1970s, during the height of the Interstate construction era, federal and state governments provided about 80% of all highway revenue, with local jurisdictions providing the remaining 20%; by the mid-2000s (preceding congressional transfers of general funds to the HTF and the subsequent stimulus), the combined federal and state share had declined to around 72%, while the local share had risen to 28% (based on data from OHPI, undated).
- **Reduced reliance on highway user fees.** Federal highway revenue has traditionally relied exclusively on user fees, including motor-fuel taxes along with several truck-related fees. While states make use of some general revenue sources such as income, sales, and property taxes to help fund highways, user fees—most notably, fuel taxes, vehicle registration fees, and tolls—still account for about almost three-quarters of all state highway revenue (OHPI 2012). In sharp contrast, local jurisdictions are much more likely to tap general revenue sources, such as sales taxes or general obligation bonds, to fund roads and other transportation infrastructure (Goldman and Wachs 2003). As such,

the recent devolution of highway funding responsibility has also translated to increased overall reliance on general revenue sources rather than user fees.

- **Increasing transit subsidies.** Shifting focus from highways to transit funding, one of the main themes in recent decades has been increased reliance on subsidies. Between 1988 and 2010, based on data from the American Public Transit Association (APTA 2012, Table 71), the share of annual transit capital and operating expenses derived from user fees (transit fares) and other direct sources of agency revenue (such as advertising and concessions) has declined from about 33% to just under 26%. Remaining funds are provided, in roughly even shares, by federal, state, and local subsidies.
- **Growth in transit funding relative to ridership.** Owing largely to the subsidies just discussed, total transit capital and operating expenditures have risen rather rapidly in recent years, growing by about 57% in real terms between 1996 and 2010 [based on expenditure data from the *2012 Public Transportation Fact Book* (APTA 2012, Table 56), and inflation data from the consumer price index (BLS 2013)]. Over this same period, total transit service capacity as measured by revenue miles has increased by about 47% (APTA 2012, Table 9), while ridership in passenger miles has increased by about 31%. In other words, the cost of providing additional transit capacity at the margin has been increasing, in real terms, while the level of ridership supported by additional capacity at the margin has been decreasing. This may portend challenges in continuing to expand transit funding through greater subsidies in the coming years, especially given the fiscal constraints currently faced by most local, state, and federal agencies.
- **Insufficient overall investment in surface transportation.** Owing largely to the stagnation in fuel-tax rates in recent decades, transportation funding shortfalls have become more severe. Relatively recent estimates (NSTIFC 2009) suggest that the gap between projected federal, state, and local revenue and the amount needed to maintain the nation's transportation networks in their current conditions falls in the range of $57 billion to $118 billion per year, while the shortfall in funding needed to substantially improve the networks falls in the range of $113 billion to $185 billion per year. Absent sufficient funding, many jurisdictions now find it challenging to fund needed maintenance, let alone to build new capacity.
- **Diversion of federal highway revenue.** When the HTF was established in 1956 to fund the Interstate system, federal excise fuel taxes on gasoline and diesel were designated as the main source of HTF funding (additional truck-related fees were also hypothecated to the HTF). In the intervening decades, through a series of federal transportation bills, the share of HTF funds directed to non-highway uses—including transit, air quality mitigation, bicycle and pedestrian improvements, and the like—has gradually grown. Based on analysis of data from a recent Government Accountability Office (2009) study, Poole and Moore (2010) estimated that as much as 25% of HTF funds may be allocated to projects not directly related to highway and bridge capacity, maintenance, operations, and safety. While many of the non-highway investments have merit, Poole and Moore posit that the diversion of fuel-tax revenue for other modes has made it more difficult to secure the support of road user groups for increasing federal fuel taxes to keep pace with inflation and total vehicle travel.
- **Disproportionate investment in transit relative to use.** U.S. highway investment greatly exceeds investment in transit. In 2010, for example, highway expenditures across all levels of government (inclusive of interest on debt and bond retirements) were about $205 billion (OHPI 2012), while total transit expenditures were about $55.6 billion (APTA 2012, Table 56). Yet transit receives a disproportionately large amount of funding relative to its use. Based on estimates from the 2009 National Household Travel Survey (Santos et al. 2011), and depending on the comparison metric (trips versus passenger miles and commute trips versus all trips), the ratio of personal vehicle travel to transit travel ranges from 25 to 1 to 59 to 1, while the ratio of highway investment to transit investment is closer to 3.7 to 1.

Future expectations and uncertainties. Mounting transportation revenue challenges, especially in relation to highway funding, have in recent years prompted increased discussion and debate over potential policy reforms aimed at bolstering investment in the nation's transportation networks [see, for example, items in the references section from Whitty (2003), TRB (2006), Cambridge Systematics et al. (2006), NSTPRSC (2007), and NSTIFC (2009)]. Many studies have outlined motivations for a renewed and more clearly defined federal role in transportation funding, and they have also highlighted policy advantages—such as fairness and economic efficiency—of greater reliance on user fees, including such options as tolls, congestion tolls, mileage-based user fees, and transit fares. Yet the recent trend has been toward devolution of greater funding responsibility to local governments along with increased reliance on general revenues. Transportation funding policy thus appears to be at a crossroads: future uncertainties include the respective roles of federal, state, and local governments and private industry in funding and operating transportation networks; funding levels for transportation; funding mechanisms; and the relative allocation of funding among different modes, most notably highways and transit.

- **Federal, state, local, and private roles in funding transportation.** With the Interstate system now complete, some argue that a shift toward greater local funding responsibility is appropriate, reasoning that local officials are in a better position to judge what investments will be most helpful and that residents will be more willing accept revenue measures when the money will be invested in local improvements and local officials can be held accountable. Yet there are at least three drawbacks to greater reliance on local funding. First, much of the Interstate system is nearing the end of its 50-year design life and will soon need to be rebuilt, a task of national importance likely to cost far more than the initial construction (Regan and Brown 2011). Second, greater reliance on local resources has to date led to reductions in total revenue relative to total travel; that is, increases in local funding have been insufficient to offset overall reductions in state and especially federal funding. Third, increased devolution of funding responsibility to local areas has typically resulted in greater reliance on general revenue sources such as sales taxes, which do not perform as well as user fees for many policy objectives. Absent sufficient public funding, it is also possible that private industry [most likely through public–private partnerships (PPPs)] could take a greater role in financing and operating transportation facilities in the United States.
- **Level of funding.** The recent pattern in surface transportation funding can be described as one of increasing disinvestment (Cambridge Systematics et al. 2006), and the question is whether voters will continue to support this trajectory. Strong arguments can be made that the nation's investment in a world-class transportation network in prior decades has been a key underpinning of its economic prosperity to date, and that further investment will be critical in ensuring success in future years. Yet constituencies favoring lower taxes and smaller government have gained greater political influence of late, reducing the likelihood of significant increases in the level of public investment for at least the near term. Over the longer term, it is difficult to predict whether leaders will continue to focus on austerity or instead ask the public to invest more in transportation to promote continued economic growth.
- **Funding mechanisms.** Recent technical innovations have enabled a range of advanced user-fee mechanisms, such as open-road tolling, congestion tolls, mileage-based user fees, and weight-distance truck tolls, that offer many compelling policy advantages (Sorensen and Taylor 2006). Yet such options also face significant public acceptance challenges. In contrast, general revenue measures to fund transportation, often levied by local governments, have enjoyed much greater success at the ballot box in recent decades (Goldman and Wachs 2003), and it remains unclear whether future transportation funding policies will continue to shift toward general revenue or instead return to the more traditional focus on user fees.
- **Investment in roads versus transit.** While the United States invests much less in transit than it does in roads, transit still receives disproportionate funding in relation to transit ridership versus automotive travel. This can be explained, in part, by the fact that transit represents a relatively uncontroversial means for addressing numerous worthy social and economic goals—for example, improving access for those unable to drive, easing traffic congestion, reducing greenhouse gas emissions, and making more livable urban communities. Yet the ability of transit to deliver on many of these goals depends on high ridership, which has yet to be achieved in many U.S. cities and is even less common in suburban and rural areas. At the same time, the state of repair for roadways is rapidly deteriorating in many states, leading some to argue that the share of road use fees (e.g., from federal fuel taxes) currently allocated to fund transit should be reduced or eliminated (Poole and Moore 2010). Looking forward, it is unclear—particularly if one assumes continued shortfalls in available transportation funding—whether the nation will continue to increase funding for transit or instead shift a greater percentage of revenue to the road network.

4.3 Implications for Transportation Energy Futures

Many of the trends and uncertainties discussed in this chapter—for population; the economy; land use; and future energy, climate, and transportation funding policy—could exert significant influence on future energy and transportation choices and outcomes. Faster population growth, for example, should translate to increased energy and travel demand, all else being equal. Any significant trend toward denser urban land use could help reduce automotive travel and increase transit mode share. The adoption of some form of carbon pricing would make it easier for low-carbon alternative fuels to achieve commercial success, while a continuation of the recent trend in transportation funding toward reduced reliance on user fees—most notably fuel taxes—could enable faster growth in automotive travel.

The material in this chapter on population, economy, and land use is discussed at greater length in Appendix G, while Appendix H provides additional background on energy, climate, and transportation funding policy options and debates. Drawing on available literature where available, the closing sections of these appendices consider how some of the plausible future trends, developments, or policy choices in these areas could affect the energy and transportation elements of the future scenarios developed for this study. Table 4.1 and Table 4.2 summarize the expected effects.

Table 4.1 focuses on the fuel and vehicle technology elements of the study, including price of oil, fuel economy for conventional vehicles, mix of different fuels used in transportation, vehicle cost, and energy cost of travel. Table 4.2 considers the transportation elements from the scenarios, including growth in automotive travel, growth in truck travel, and growth in transit mode share. In the two tables, rows correspond to the different potential trends, developments, or policy choices of interest, while columns present the future scenario elements. A black arrow pointing upward corresponds to a positive (increasing) effect on the element in question, whereas a light gray downward arrow indicates a negative (decreasing) effect. For example, the black upward arrow in the cell for greater population growth and the price of fuel indicates that faster population growth will tend to put increased pressure on oil prices, all else being equal. Additionally, note that the converse of each entry generally holds—for

Table 4.1. Expected effects on fuel and vehicle scenario elements.

Future Trends, Developments, or Policy Choices	Price of Oil (End Use)	Fuel Economy	Alternative Fuels	Vehicle Cost	Energy Travel Cost
Population					
Greater population growth	↑				
Longer lifespans					
Higher immigration rates					
More low-income births					
Economy					
Higher GDP	↑				
Higher personal incomes					
Increased income inequality					
Land Use					
Denser mixed land use	↓				
Energy and Climate Policy					
Expanded production	↓	↓	↓		↓
CAFE standards	↓	↑	↓	↑	↓
Renewable fuel standards	↓		↑		
Renewable fuel subsidies	↓		↑		↓
Clean vehicle subsidies	↓	↑		↓	↓
Feebate programs	↓	↑		↓	↓
Carbon pricing	↑	↑	↑		↑
Transportation Funding Policy					
Increased total funding	↑				
More funding for highways	↑				
More funding for transit	↓				
Tolling or MBUFs	↓	↓	↓		↑
Higher fuel taxes	↑	↑	↑		↑
General revenue sources	↑	↓	↓		↓

Note: ↑ = positive or increasing effect, ↓ = negative or decreasing effect; see Appendices G and H for analysis.

Table 4.2. Expected effects on transportation scenario elements.

Future Trends, Developments, or Policy Choices	Growth in Personal Automotive Travel	Growth in Transit Mode Share	Growth in Truck Travel
Population			
Greater population growth	↑	↑	↑
Longer lifespans	↓		
Higher immigration rates	↓	↑	
More low-income births	↓	↑	
Economy			
Higher GDP			↑
Higher personal incomes	↑	↓	
Increased income inequality	↓	↑	
Land Use			
Denser mixed land use	↓	↑	
Energy and Climate Policy			
Expanded production	↑	↓	↑
CAFE standards	↑	↓	↑
Renewable fuel standards			
Renewable fuel subsidies	↑	↓	↑
Clean vehicle subsidies	↑	↓	↑
Feebate programs	↑	↓	↑
Carbon pricing	↓	↑	↓
Transportation Funding Policy			
Increased total funding	↑		↑
More funding for highways	↑	↓	↑
More funding for transit	↓	↑	↓
Tolling or MBUFs	↓	↑	↓
Higher fuel taxes	↓	↑	↓
General revenue sources	↑	↓	↑

Note: ↑ = positive or increasing effect, ↓ = negative or decreasing effect; see Appendices G and H for analysis.

example, a lower rate of population growth will tend to ease the pressure on future oil prices. A downward gray arrow, in contrast, indicates a negative or decreasing effect. In cases where the effect is either uncertain or likely to be negligible, the cell is left blank.

References

APTA. 2012. *2012 Public Transportation Fact Book.* Washington, D.C.

BEA. 2012. SA1-3 Personal Income Summary. http://www.bea.gov/iTable/iTable.cfm?ReqID=70&step=1&isuri=1&acrdn=4 (accessed March 18, 2013).

BEA. 2013. Current-Dollar and Real Gross Domestic Product. National Economic Accounts. http://www.bea.gov/national/ (accessed March 18, 2013).

BLS. 2013. Consumer Price Index: All Urban Consumers – (CPI-U). ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt (accessed March 18, 2013).

Brown, J., M. DiFrancia, M. C. Hill, P. Law, J. Olson, B. D. Taylor, M. Wachs, and A. Weinstein. 1999. *The Future of California Highway Finance.* California Policy Research Center, Berkeley, CA.

Burger, N., L. Ecola, T. Light, and M. Toman. 2009. *Evaluating Options for U.S. Greenhouse-Gas Mitigation Using Multiple Criteria.* RAND Corporation, Santa Monica, CA.

Cambridge Systematics, Mercator Advisors, A. E. Pisarski, and M. Wachs. 2006. *NCHRP Web-Only Document 102: Future Financing Options* *to Meet Highway and Transit Needs.* Transportation Research Board of the National Academies, Washington, D.C.

Cheeseman Day, J. Undated. National Population Projections. http://www.census.gov/prod/1/pop/profile/95/2_ps.pdf (accessed March 18, 2013).

Dadush, U. and B. Stancil. 2009. "The G20 in 2050." *International Economic Bulletin.* http://www.carnegieendowment.org/publications/index.cfm?fa=view&id=24195 (accessed March 18, 2013).

DeLong, J. B., C. Golden, and L. F. Katz. 2003. "Sustaining U.S. Economic Growth." In: H. J. Aaron, J. M. Lindsay, and P. S. Nivola (eds.), *Agenda for the Nation.* Brookings Institution Press, Washington, D.C.

EIA. 2013. *Annual Energy Outlook 2013.*

EPA. 2012. Regulations & Standards: Light-Duty. Transportation and Climate. http://www.epa.gov/otaq/climate/regs-light-duty.htm (accessed March 22, 2013).

EPA. 2013. Renewable Fuels: Regulations & Standards. Fuels and Fuel Additives. http://www.epa.gov/oms/fuels/renewablefuels/regulations.htm (accessed March 22, 2013).

Florida, R. 2012 (October 2). "The Uneven Geography of U.S. Economic Growth." *The Atlantic Cities.* http://www.theatlanticcities.com/jobs-and-economy/2012/10/uneven-geography-economic-growth/3067/ (accessed March 18, 2013).

GAO. 2009. *Highway Trust Fund Expenditures on Purposes Other than Construction and Maintenance of Highways and Bridges during Fiscal Years 2004–2008.* GAO-09-729R.

German, J. and D. Meszler. 2010. *Best Practices for Feebate Program Design and Implementation.* International Council on Clean Transportation, Washington, D.C.

Goldman, T. and M. Wachs. 2003. "A Quiet Revolution in Transportation Finance." *Transportation Quarterly*, 57 (1): 19–32.

Hobbs, F. and N. Stoops. 2002. *Demographic Trends in the 20th Century.* CENSR-4. U.S. Department of Commerce.

IEA. 2012. *World Energy Outlook 2012.*

Knittel, C. 2009. *The Implied Cost of Carbon Dioxide under the Cash for Clunkers Program.* Institute of Transportation Studies, UC Davis.

Kuntsler, J. H. 2005. *The Long Emergency: Surviving the Converging Catastrophes of the Twenty-First Century.* Atlantic Monthly Press.

Lubowski, R. N., M. Vesterby, S. Bucholtz, A. Baez and M. J. Roberts. 2002 (May). *Major Uses of Land in the United States.* Economic Information Bulletin No. (EIB-14). Economic Research Service, U.S. Department of Agriculture.

Myers, D. and E. Gearin. 2001. "Current Preferences and Future Demand for Denser Residential Environments." *Housing Policy Debate*, 12 (4): 633–659.

NSTIFC. 2009. *Paying Our Way: A New Framework for Transportation Finance.* Report of the National Surface Transportation Infrastructure Financing Commission. Washington, D.C.

NSTPRSC. 2007. *Transportation for Tomorrow.* Report of the National Surface Transportation Policy and Revenue Study Commission. Washington, D.C.

OECD. 2011. *Divided We Stand: Why Inequality Keeps Rising.*

OHPI. Undated. Total Receipts for Highways, by Government Unit 1945-2010. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/2010recchrt.cfm (accessed March 25, 2013).

OHPI. 2011. Table MF-121T. Tax Rates on Motor Fuel – 2010. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/mf121t.cfm (accessed March 25, 2013).

OHPI. 2012. Table HF-10. Funding for Highways and Disposition of Highway-User Revenues, All Units of Government, 2010. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/hf10.cfm (accessed March 25, 2013).

ORNL. 2012. *Transportation Energy Data Book*, Edition 31. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Poole, R. W. and A. T. Moore. 2010. *Restoring Trust in the Highway Trust Fund.* Policy Study 386. Reason Foundation, Los Angeles.

Regan, E. and S. Brown. 2011 (Spring). "Building the Case for Tolling the Interstates." *Tollways*, pp. 6–21.

Santos, A., N. McGuckin, H. Y. Nakamoto, D. Gray, and S. Liss. 2011. Summary of Travel Trends: 2009 National Household Travel Survey. Federal Highway Administration.

Shrestha, L. B. 2006. *The Changing Demographic Profile of the United States.* Report to Congress. Congressional Research Service.

Shrestha, L. B. and E. J. Heisler. 2011. *The Changing Demographic Profile of the United States (Update).* Report to Congress. Congressional Research Service.

Sorensen, P. and B. D. Taylor. 2006. "Innovations in Road Finance: Examining the Growth in Electronic Tolling." *Public Works Management & Policy*, 11 (2): 110–125.

TRB. 2006. *Special Report 285: The Fuel Tax and Alternatives for Transportation.* Transportation Research Board of the National Academies, Washington, D.C.

UCS. 2012. Existing Cap-and-Trade Programs to Cut Global Warming Emissions. Global Warming. http://www.ucsusa.org/global_warming/solutions/big_picture_solutions/regional-cap-and-trade.html (accessed March 22, 2013).

U.S. Census Bureau. 1995. Intercensal Estimates of the Total Resident Population of States: 1950 to 1960. Population Estimates. http://www.census.gov/popest/data/state/asrh/1980s/tables/st5060ts.txt (accessed March 20, 2013).

U.S. Census Bureau. 2000. Historical National Population Estimates: July 1, 1900 to July 1, 1999. Population Estimates. http://www.census.gov/popest/data/national/totals/pre-1980/tables/popclockest.txt (accessed March 18, 2013).

U.S. Census Bureau. 2005. Table 6: Interim Projections: Total Population for Regions, Divisions, and States: 2000 to 2030. 2005 Interim State Population Projections. http://www.census.gov/population/projections/data/state/projectionsagesex.html (accessed March 20, 2013).

U.S. Census Bureau. 2009a. Table 1-C. Projections of the Population and Components of Change for the United States: 2010 to 2050 Constant Net International Migration Series (NP2009-T1-C). 2009 National Population Projections (Supplemental): Summary Tables: Constant Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009cnmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2009b. Table 1-H. Projections of the Population and Components of Change for the United States: 2010 to 2050 High Net International Migration Series (NP2009-T1-H). 2009 National Population Projections (Supplemental): Summary Tables: High Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009hnmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2009c. Table 1-L. Projections of the Population and Components of Change for the United States: 2010 to 2050 Low Net International Migration Series (NP2009-T1-L). 2009

National Population Projections (Supplemental): Summary Tables: Low Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009lnmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2009d. Table 1-Z. Projections of the Population and Components of Change for the United States: 2010 to 2050 Zero Net International Migration Series (NP2009-T1-Z). 2009 National Population Projections (Supplemental): Summary Tables: Zero Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009znmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2011. Table 1. Intercensal Estimates of the Resident Population by Sex and Age for the United States: April 1, 2000 to July 1, 2010. US-EST00INT-01. Population Estimates. http://www.census.gov/popest/data/intercensal/national/nat2010.html (accessed March 18, 2013).

Wachs, M. 2003. *Improving Efficiency and Equity in Transportation Finance.* The Brookings Institution, Washington, D.C.

Whitty, J. M. 2003. *Road User Fee Task Force: Report to the 72nd Oregon Legislative Assembly on the Possible Alternatives to the Current System of Taxing Highway Use Through Motor Vehicle Fuel Taxes.* Oregon Department of Transportation.

CHAPTER 5

Plausible Future Transportation Energy Scenarios

The preceding two chapters summarized past trends and future prospects for many of the variables likely to influence transportation energy use and travel demand over the coming decades. The review included opportunities and challenges for conventional and alternative fuels and vehicle technologies; trends and uncertainties in population, economic growth, and land use; and policy options and debates relating to energy, climate, and transportation funding. Drawing from that material, in this chapter a series of plausible future transportation energy scenarios are developed that serve to help identify potential impacts on state DOTs in subsequent stages of the analysis, in turn motivating the consideration of policy approaches and strategies to assist DOTs in preparing for an uncertain energy future.

The first section in this chapter outlines the structure and approach to developing the future scenarios. The next three sections then develop individual components of the scenarios, which span the areas of energy use and vehicle technologies, travel behavior, and applicable federal policy frameworks.

5.1 Structure and Approach to Developing Scenarios

This first section begins with a discussion of the underlying logic and general structure for the scenarios. It then enumerates several objectives that the scenarios should meet in order to support an effective application of the principles of robust decision making and outlines the approach to developing and employing the scenarios in more detail.

5.1.1 Scenario Elements

As indicated earlier, the scenarios encompass three broad categories of future outcomes. These are the mix and prices of fuels and vehicle technologies, travel patterns for goods movement and personal travel, and federal policies relating to energy, climate, and transportation funding. The categories are further broken down into discrete elements of interest—such as the price of oil or growth in truck freight—that will be helpful for identifying specific impacts for state DOTs in later stages of analysis. The following paragraphs outline the logic for including the three categories of outcomes within the scenarios and introduce the specific elements included in each category.

Energy use and technology elements. Evolving energy use patterns and technologies in surface transportation constitute the core subject matter for this project and thus represent the central organizing theme for the future scenarios. While certain energy elements included in the scenarios, such as the price of oil, could affect state DOTs directly, other elements, such as changes in the energy cost of travel, would be more likely to affect state DOTs indirectly through their influence on future travel behavior. Collectively, though, the included elements are intended to sample the range of potential changes in transportation energy sources and vehicle technologies in the coming decades. The specific elements, and the logic for their inclusion, are as follows.

- **Price of oil.** Oil is a significant input into the construction and maintenance of roads, both to power machinery and for the production of certain materials such as asphalt. Any major change in oil prices could therefore exert considerable influence on the costs faced by state DOTs. Additionally, to the extent that petroleum remains the dominant source of transportation fuels in future years, changes in oil prices would influence the marginal energy cost of travel, in turn potentially affecting trends in passenger travel and goods movement.
- **Conventional vehicle fuel economy.** State DOTs rely heavily on federal and state fuel taxes on gasoline and diesel to help fund highway expansion and maintenance activities. Assuming that states and the federal government leave current fuel-tax rates unchanged, any significant increase in average fuel economy for conventional vehicles

would translate to a severe reduction in available revenue. Changes in fuel economy, in concert with changes to the price of oil, could also affect the marginal energy cost of travel, in turn influencing future travel choices.

- **Energy mix.** Fuel use in the transportation sector is currently dominated by petroleum-based products, most notably gasoline and diesel. While many experts anticipate that petroleum will remain the dominant transportation fuel for decades to come, it is also possible—perhaps due to unexpected technology breakthroughs or active government policies—that one or more alternative fuels could emerge as a viable competitor to gasoline and diesel over the next 30 to 50 years. Discussion of this scenario element takes into consideration a range of plausible outcomes for the fuels that could achieve major market share by 2050. Given the aforementioned reliance of state DOTs on gasoline and diesel taxes, any major shift toward alternative fuels could negatively affect transportation revenue. Additionally, depending on the alternative fuels and vehicle technologies in question, such a shift could affect the cost of vehicles and the energy cost of travel, in turn stimulating changes in travel behavior. Finally, the mix of transportation fuels in use could either support or hinder the ability of state DOTs to address goals related to climate change and air quality.
- **Vehicle cost premium.** Many of the vehicle technologies required to make use of alternative fuels entail a considerable price premium. This is due in part to limited production to date but also, in many cases, reflects the need for further technology advances. Discussion of this element takes into consideration the degree to which the cost of new vehicles might change in the future depending on the emergence, or lack thereof, of the various alternative fuels and vehicle technologies. This could in turn influence ownership choices and aggregate travel behavior.
- **Energy cost of travel.** Many commentators have expressed concern that growing demand for oil among the world's rapidly emerging nations could lead to higher oil prices, in turn making vehicle travel more expensive. On the other hand, certain alternative fuels—most notably electricity, natural gas, and hydrogen—currently offer the promise of much lower energy costs for vehicle travel. Changes in the energy cost of travel, either positive or negative, could affect future travel behavior along with the costs required for state DOTs to operate their own vehicle fleets.

Travel elements. While certain of the energy elements just described could affect state DOTs directly, the indirect effects of energy and vehicle costs on passenger travel and goods movement could prove to be equally consequential. As described in the previous chapter, changes in aggregate travel behavior may also hinge on shifts in population, the economy, land use, and energy, climate, and transportation funding policies. The future scenarios include three elements to describe aggregate travel outcomes:

1. **Growth in passenger vehicle travel.** For this element, the plausible range of growth in aggregate passenger vehicle travel through 2050 is examined. The most obvious concerns for state DOTs are exacerbated traffic congestion and greater demand for new capacity, though safety outcomes could be adversely affected by greater vehicle travel as well.
2. **Growth in transit demand.** The current mode share for transit remains rather low at the national level, and most state DOTs have relatively little involvement in planning, constructing, or operating transit services. One can envision plausible futures, however, in which the demand for transit and other non-automotive modes could increase considerably. This might be stimulated, for example, by much higher energy costs, by increasing inequality in income distributions, by prolonged economic stagnation, by a shift toward much denser land use, or by more concerted efforts to reduce greenhouse gas emissions from the transportation sector. For this element, plausible future shifts in the mode share for transit, which would also tend to correlate with changes in other non-automotive modes such as walking and biking, are considered. Such shifts might motivate states to assign a more significant role for DOTs in the planning and provision of transit service or in the development of more integrated transportation and land use plans in order to support a broader array of mobility options.
3. **Growth in truck demand.** Goods movement has grown much more rapidly than passenger travel over the past few decades, and the same holds for trucking more specifically. The focus of the discussion for this element is on plausible future rates of growth in truck travel, which many expect to accelerate again as the economy recovers and strengthens. Continued expansion of trucking could pose several challenges to state DOTs, including increased traffic congestion, more rapid deterioration of road surfaces, and greater demands for transportation revenue to support road network improvements related to goods movement.

Federal policy elements. Future federal policies governing energy, climate, and transportation funding could have a strong effect on the adoption, or lack thereof, of alternative fuels and advanced vehicle technologies, as well as on aggregate travel demand and mode choice. They could also affect state DOTs in a more direct manner. A decision to devolve greater funding responsibility to states and local governments, for example, could exacerbate the revenue shortfalls that DOTs might face as a result of declining state fuel-tax receipts. Additionally, federal legislation could expand or constrain the policy choices available to states. If the federal government were to implement a nationwide carbon cap-and-trade program, for instance, then there would be little utility for a state to mount a similar program in parallel. Conversely, if the federal government relaxed current restrictions on tolling Interstate highways, states might look to increased tolling as a replacement for declining fuel taxes. It is for these latter two reasons—the potential to directly affect state DOTs and the potential to expand or constrain state policy options—that the scenarios encompass future federal energy, climate, and transportation policies. Two elements are considered: federal energy and climate policy and federal transportation funding and investment policy.

- **Federal energy and climate policy.** Because a major share of greenhouse gas emissions comes from the production and consumption of power and fuel, energy and climate policies are implicitly linked. Discussion of this element takes into consideration plausible shifts in the relative prioritization of federal energy and climate policy goals—for example, emphasizing the reduction of greenhouse gas emissions versus seeking to maintain lower energy costs from the end-user perspective—and the adoption of alternate policies to reflect such shifts.
- **Federal transportation funding and investment policy.** With fuel taxes increasingly undermined by inflation and improved fuel economy, leading in turn to growing funding shortfalls at all levels of government, federal transportation funding policy appears to be at a crossroads. Discussion of this element encapsulates alternate future directions for federal policy in this arena, entertaining such options as continued devolution, greater reliance on general revenue, and a reinvigorated emphasis on funding transportation through user fees.

5.1.2 Objectives and Approach to Developing Scenarios

As briefly discussed in Chapter 1, the methodological approach for this study can be described as a qualitative application of the principles of RDM. The goal is to assist state DOTs, and potentially state legislatures, in identifying effective policies to address an uncertain energy future. The principal audience for this work thus includes elected officials and other senior decision makers along with more technically oriented policy analysts and interested stakeholders. Taken together, the methodological approach and intended audience suggest several important objectives that the scenarios should meet to ensure that the analysis and results will be as helpful as possible. In this section, the most critical objectives are identified, and how the scenarios have been constructed to meet these objectives is described.

Developing realistic scenarios. Developing realistic scenarios is of course critical from the perspective of supporting a sound analysis that produces helpful findings for state DOTs. It should also help ensure that this study as a whole will be viewed as credible by the intended audience of state decision makers, making it more likely that the findings will be used to inform future planning efforts. To achieve the aim of realistic scenarios, the research team sought to identify and incorporate the results of rigorous and well-established forecasting efforts—such as the future oil price forecasts of EIA (2013)—in constructing base-case outcomes for each of the elements included. In cases where such forecasts were not available, the team extrapolated current trends, taking into account any relevant regulations or legislation, such as the recent increases to CAFE standards, to establish base-case outcomes. For each of the futures, underlying trends that might contribute to such an outcome are also described.

Exploring a broad range of plausible scenarios. The motivation for employing RDM in this study is that it is simply not possible to forecast many of the outcomes of interest with any degree of reliability when considering a planning time frame that extends over multiple decades. As such, the analysis includes not just a set of realistic base-case estimates, as described previously, but a much broader range of plausible futures. This helps to ensure that long-range strategic plans will perform well regardless of how the future unfolds. For some of the elements included in the scenarios, commonly consulted forecasts such as those produced by EIA (2013) include base or reference estimates along with high and low projections. Where appropriate, high and low projections are used to broaden the range of plausible futures considered. More commonly, however, the approach to identifying a broader range of plausible futures in this study involves considering how trends or shifts in some of the underlying variables examined in the previous two chapters—fuel sources and vehicle technologies; population, the economy, and land use; and energy, climate, and transportation funding policies—could lead to potentially significant deviations from realistic base-case outcomes.

Capturing variation among states within the scenarios. Most of the forecasts used to calibrate future outcomes for certain scenario elements have been developed to reflect the nation as a whole. This study, however, is intended to inform state-level planning, and for some of the elements there could be considerable variation from one state to the next. Consider, for example, the question of population growth. While population is not one of the elements included in the scenarios, it is an influential variable that will affect certain elements such as growth in vehicle travel. Barring some sort of catastrophic event, such as pandemic influenza or a nuclear war, most demographers expect the nation's population to continue to grow in the coming decades. At a more disaggregate level, however, it is certainly possible that one or more states might lose some share of their population, potentially as a result of ongoing structural shifts in the economy or even due to changing climate patterns. Accordingly, the range of plausible futures for some of the elements included in the analysis is even broader at the state level than it would be if viewed in terms of national averages.

Developing illustrative scenarios. As already discussed, this study involves a qualitative application of RDM principles. The implication, in the context of developing future scenarios, is that the values used to represent plausible outcomes for the various scenario elements do not need to be highly precise. They will not, for example, serve as inputs into a mathematical model, where precision would be much more important. Rather, they are simply meant to give a sense of the range of plausible outcomes for a given element based on the degree of uncertainty surrounding the underlying variables that will influence that element. This, in turn, makes it possible to better understand the types of impacts that state DOTs might face in the future. Consider, for example, growth in passenger vehicle travel. In terms of understanding potential impacts, it would make little difference whether travel were to increase by 50% or 75% over the next 30 to 50 years; it can be reasonably assumed that either of these would lead to much worse traffic congestion, in turn affecting state DOTs.

Constraining the number of scenarios. In a typical quantitative application of RDM, researchers might execute hundreds or even thousands of model runs to examine the expected effects of different policy options for different combinations of assumptions about future states of the world (Lempert, Popper, and Bankes 2003). This study, in contrast, pursues a qualitative application of RDM principles. The number of alternate futures considered must therefore be constrained in order to keep the analysis manageable.

When dealing with multiple elements of interest (e.g., price of oil, market share for different fuels, growth in trucking, future federal funding policy), one strategy for developing a relative small set of future scenarios is to combine plausible outcomes for different elements that appear to be logically consistent with one another in order to construct a small set of perhaps five to 10 integrated scenarios, each of which can be explained with a coherent narrative. For example, lower future oil prices might be linked to higher future rates of automotive and truck travel, while higher future oil prices might be linked to a greater shift to transit and rail freight. The development of such integrated scenarios is an important element of scenario-based planning.

From an analytic perspective, the main problem with creating just a small set of integrated future scenarios that incorporate multiple elements of interest is that certain plausible combinations must inevitably be omitted. To illustrate this point, the futures developed in this study include a total of 10 separate elements—oil price, conventional vehicle fuel economy, future mix of fuels, vehicle premium cost, energy cost of travel, passenger vehicle travel, transit use, trucking, federal energy and climate policies, and federal transportation funding policies—each of which involves multiple plausible futures. As presented subsequently, two of the elements include two plausible futures, seven of them include three plausible futures, and one includes six plausible futures. Multiplying these together (i.e., $2^2 \times 3^7 \times 6$) yields 52,488 distinct combinations. In focusing on perhaps five or 10 of these combinations, many more plausible futures would need to be discarded. And some of the discarded possibilities might involve specific combinations of elements' outcomes that create distinct impacts for state DOTs and thus are important to include in the analysis.

To avoid this possibility, the approach taken in this study was to leave the potential outcomes for the different elements of interest in disaggregate form. That is, rather than seeking to combine potential values for different elements, based on their expected degree of correlation, into integrated future scenarios with composite narratives, the potential futures for each element are presented in stand-alone form. This reflects a recognition that, while certain combinations might appear more likely than others, the vast majority of the possible combinations of outcomes for the various elements still fall within the realm of possibility.

As described at greater length in the next chapter, the alternate futures for the different scenario elements were employed at a later stage of the analysis to identify possible impacts on state DOTs. Based on insights gleaned through interviews with state DOT staff, the team considered how the different plausible futures for each of the scenario elements could—either in isolation or in combination with other element outcomes—affect the roles, mandates, funding, or operations of state DOTs. This allowed the team to reason with a relatively constrained set of futures—the union of the different plausible outcomes for each of the nine scenario elements—while still allowing for the potential complexities and subtle nuances of certain elements interacting with one another.

5.2 Scenarios for Fuel and Vehicle Technology Elements

This section presents plausible futures for scenario elements related to fuels and vehicle technologies in the 2040 to 2060 time frame, including the price of oil, changes in fuel economy for conventional vehicles, the mix of alternate fuels in use, the cost of vehicles, and the energy cost of travel.

5.2.1 Price of Oil

For its Annual Energy Outlook (AEO) series, the EIA develops long-range forecasts for the price of crude oil along with many other energy-related measures. These include a reference-case projection (loosely interpreted as the most probable trajectory for oil prices barring major changes from past trends) along with a high oil price and a low oil price projection. The most recent EIA forecasts (EIA 2013), which project prices out to 2040 in 2011 dollars, serve as a helpful point of departure for developing plausible oil price futures for the 2040 to 2060 time frame. For the reference case, EIA estimates that imported crude oil prices will rise slowly but steadily, climbing from a little over $90 per barrel in 2012 to around $155 per barrel by 2040, translating in turn to $4.32 per gallon of gasoline in 2040. (This assumes inclusion of current rates of taxation on motor fuels.) In the low oil price scenario, the price of crude oil quickly falls to about $65 per barrel over the next few years and then gradually increases thereafter, reaching just over $70 per barrel by 2040, with a corresponding price for gasoline of $2.64 per gallon. Finally, in the high price scenario, imported crude prices rise rather quickly and steadily, reaching almost $230 per barrel by 2040, with gasoline prices increasing to $5.86 per gallon as a result.

Starting with EIA's reference, low, and high oil price forecasts through 2040, plausible oil price futures for the 2040 to 2060 time frame are now considered. Note that for each of EIA's scenarios, oil prices are rising—either modestly or more rapidly—leading up to 2040. Additionally, petroleum is a finite resource, which should tend to put upward pressure on prices over time. Accordingly, the scenarios developed for the 2040 to 2060 time frame, which are presented as ranges (e.g., $150 to $170 per barrel), are structured with the assumption that prices will most likely continue to rise past 2040.

In developing these futures, comment is also made on how alternate outcomes for certain influential variables discussed in Chapters 3 and 4—for example, the emergence of competing fuel and vehicle technologies, shifts in land use patterns, or changes in energy policies—could contribute to the different oil price futures.

- **Oil prices decline modestly.** Building on EIA's low oil price projection, in this future oil prices fall to about $65 per barrel over the next few years, climb back to $70 per barrel by 2040, and then vary in the range of $70 to $80 per barrel in 2011 dollars in the 2040 to 2060 time frame. Gasoline, assuming current rates of taxation, retails for around $2.50 to $3 per gallon between 2040 and 260. Future developments that could lead to this result—by expanding petroleum supplies or by reducing the demand for gasoline and diesel—include greater oil production, possibly resulting from continuing technological advances reducing the cost of exploiting remaining resources; the development and broad adoption of more fuel-efficient conventional vehicles that require much less petroleum per mile of travel; the emergence of competitively priced alternative fuels and vehicle technologies that undercut petroleum demand; prolonged stagnation in the economy or lower than expected population growth; a shift to much denser land-use patterns with significant reductions in vehicle travel; and the introduction of aggressive carbon pricing or much higher road-use fees, either of which should reduce the demand for driving and petroleum consumption.
- **Oil prices rise slowly but steadily.** This future represents an extrapolation of EIA's reference case, with oil prices rising to $155 per barrel by 2040 and then ranging between $150 and $170 per barrel in the 2040 to 2060 time frame. This results in gasoline prices of about $4.25 to $5 per gallon. Under this potential outcome, despite any efforts to reduce demand and expand supply, growth in global demand for petroleum would continue to outpace growth in supply.
- **Oil prices increase significantly.** This final future extends EIA's high oil price projection, with the cost per barrel of imported crude in 2011 dollars rising to almost $230 by 2040 and then costing between $225 and $250 per barrel in the 2040 to 2060 time frame. The retail price for a gallon of gasoline, in turn, would be in the range of $5.75 to $7.00 between 2040 and 2060. Factors that might lead to such an outcome—by restricting oil supplies or by enhancing growth in demand—include continued political instability in some of the world's leading oil producers, policy choices that restrict exploitation of remaining reserves, higher than expected technology costs for extracting unconventional oil resources (e.g., shale oil or Arctic drilling), a suspension of current policies calling for greater vehicle fuel economy, a failure to develop cost-competitive alternative fuels and vehicle technologies, significant population growth or economic expansion, a continuation of the past trend toward lower-density land-use patterns resulting in greater overall vehicle travel, and a shift toward reduced reliance on fuel taxes and other user fees to fund highways, resulting in lower costs for vehicle travel and in turn greater demand.

Table 5.1 summarizes the plausible oil price futures considered, including both the cost per barrel of imported crude and the resulting effect on gasoline prices (including the current level of fuel taxation).

5.2.2 Conventional Light-Duty Vehicle Fuel Economy

Vehicle fuel economy is governed by CAFE standards, which specify a minimum average fuel economy rating for the vehicles sold by major auto manufacturers in the United States each year. First instituted in the 1970s following the Arab oil embargo and ensuing price shocks, the standards were increased at an aggressive pace through the early 1980s and then allowed to stagnate over the next two decades. Over the past few years, however, amid increasing concerns related to climate change and more volatile oil prices, the

Table 5.1. Plausible oil price futures.

Oil Price Futures	Imported Crude (2011 $/Barrel)		Retail Gasoline (2011 $/Gallon with Taxes)	
	EIA 2040	2040–2060	EIA 2040	2040–2060
Prices decline modestly	$71	$70 to $80	$2.64	$2.50 to $3.00
Prices rise slowly but steadily	$155	$150 to $170	$4.32	$4.25 to $5.00
Prices rise significantly	$228	$225 to $250	$5.86	$5.75 to $7.00

Source: Data in the "EIA 2040" columns from *Annual Energy Outlook 2013* (EIA 2013).

federal government has set forth a series of increasingly stringent CAFE standards for the coming years, which now cover medium- and heavy-duty vehicles in addition to the light-duty fleet and have been harmonized with EPA and California greenhouse gas emission standards. Most recently, the Obama administration increased CAFE standards for the light-duty fleet to an average of 54.5 miles per gallon by 2025, corresponding to an approximate doubling of current standards for passenger vehicles. The CAFE rules for 2017 to 2025 were structured in two phases, with a comprehensive mid-term evaluation to review the current state of technical progress and economic conditions prior to finalizing the standards for 2022 to 2025 (EPA and NHTSA 2012). Depending on the outcome, it is conceivable that the most demanding improvements scheduled for the latter years could be delayed, though it seems unlikely that they would be permanently cancelled. Thus, the currently scheduled standards for 2025 are considered as an appropriate lower bound for fuel economy improvements through the 2040 to 2060 time frame, along with an additional future in which standards are raised even further after 2025. The two scenarios are framed in terms of average fuel economy gains in relation to pre-2012 vehicle fuel economy standards.

- **Average fuel economy doubles.** In this future, CAFE standards would progress, as planned, to an average of 54.5 mpg by 2025, but would not be subject to continued increases thereafter (just as standards remained largely static through the late 1980s, 1990s, and early 2000s). In the ensuing decades, older vehicles would gradually be replaced with newer models meeting the 2025 target such that nearly the entire on-road fleet would be averaging around an EPA rating of 54.5 mpg by the 2040 to 2060 time frame. This would double the current average fuel economy for new passenger vehicles, and would more than double the current fuel economy for the on-road fleet of light-duty vehicles.
- **Average fuel economy quadruples.** In this second scenario, federal decision makers choose to implement even more-stringent fuel economy standards after 2025, with the target eventually increasing to over 100 mpg. To meet such standards, auto manufacturers would likely deploy the most advanced technologies envisioned, including engine efficiency improvements, streamlined aerodynamics, lighter-weight materials, and much broader application of hybrid technology. This level of improvement is broadly consistent with optimistic 2050 projections for conventional vehicles discussed in Appendix A.

5.2.3 Mix of Fuels in the Light-Duty Vehicle Fleet

Cars and trucks have been powered almost exclusively by petroleum over the past century, and many of the experts and sources consulted during the course of this study suggest that petroleum is likely to remain dominant for the foreseeable future. There is already an extensive network of gasoline and diesel refueling stations in place, recent advances in extraction technologies for unconventional sources such as tight oil have led to a resurgence in U.S. petroleum production, and the increasingly stringent CAFE standards through 2025 will enable future vehicles to travel much farther on a gallon of gasoline or diesel. These factors will make it more difficult for alternative fuels to compete effectively with petroleum.

Yet society is also now witnessing the emergence of several promising alternative fuels and compatible vehicle technologies. With significant subsidies for corn-based ethanol in past decades, the use of biofuels has experienced a slow but steady rise, and the nation's aggressive RFS regulations call for continued growth in the biofuels industry in the coming years. Natural gas is already well established in certain fleet markets, but the recent drop in natural gas prices resulting from horizontal drilling and hydraulic fracturing technology could set the stage for broader adoption among the general population. Meanwhile, the first battery electric and plug-in hybrid-electric vehicles are now entering the market; though still facing cost and performance limitations, the much lower energy costs associated with electric vehicles offer potential promise for future market penetration. Finally, many of the large automakers have now announced their intent to initiate early commercialization efforts for hydrogen vehicles in the 2014 to 2016 time frame.

Though petroleum appears likely to remain dominant over the near term—in EIA's most recent AEO (EIA 2013), for example, the reference-case forecast assumes that almost 90% of all light-duty vehicle miles in 2040 will still be powered by gasoline or diesel (inclusive of conventional non-plug-in hybrids, which ultimately derive all of their power from gasoline or diesel)—it is plausible that one or more alternatives could gain significant market share by the 2040 to 2060 time frame. This is likely to require, however, some combination of technical breakthroughs—which are inherently difficult to predict—and government policies aimed at promoting lower-carbon fuels. Given the uncertainties, this study entertains a scenario in which petroleum remains dominant, along with several other plausible futures in which one or more alternative fuel sources emerge to displace petroleum. For each scenario in which alternative fuels displace a significant share of petroleum, it is assumed that promising advances in the fuel and vehicle technologies along with supportive government policies in turn spur private investment in any needed fuel distribution infrastructure to enable broader adoption.

- **Petroleum remains dominant.** In this scenario, oil remains moderately priced and the cheaper per-mile energy cost of driving resulting from higher CAFE standards acts to undercut the competition from alternative fuels. Technological breakthroughs that would enable other fuels and vehicle technologies to out-perform petroleum fail to emerge. Petroleum therefore remains the dominant fuel within the light-duty fleet, powering over 90% of vehicle miles of travel.
- **Moderate shift to biofuels.** Spurred in part by the nation's aggressive RFS and comparable policies enacted at state levels, biofuel production rises steadily for several decades, eventually accounting for over 30% of all mileage by the light-duty fleet. Limits on arable land and competition with food production, however, ultimately act to constrain further expansion of biofuels. Petroleum dominates the remainder of the light-duty vehicle fuels market.
- **Significant shift to natural gas.** With the prospect of less-expensive, domestically produced natural gas, vehicle manufacturers begin to develop and market a broader array of natural-gas models, eventually reducing the premium currently associated with this type of vehicle. The market for natural gas as a transportation fuel steadily expands, first gaining market share within medium- and heavy-duty vehicle fleets but eventually within the passenger vehicle fleet as well. Natural gas ultimately accounts for over 50% of all vehicle miles of travel within the light-duty fleet.
- **Significant shift to electric vehicles.** Significant battery technology breakthroughs are achieved, leading to more affordable plug-in hybrid and battery electric vehicles and allowing for greater driving range in all-electric mode. Because of the inherent energy cost advantages of electric power in comparison to petroleum, a significant shift to electric vehicles unfolds rapidly in the passenger vehicle market along with certain medium- and heavy-duty vehicle markets. Electricity, via some combination of PHEVs and BEVs, eventually accounts for more than 75% of light-duty vehicle miles of travel.
- **Significant shift to hydrogen vehicles.** Under this scenario, manufacturers fail to achieve envisioned breakthroughs in battery technology, but rapid advances in hydrogen fuel cells, onboard hydrogen storage capacity, and hydrogen production methods do occur. As a result, hydrogen rather than electricity begins to displace petroleum, eventually powering over 75% of light-duty vehicle miles.
- **Mix of fuels and vehicle technologies.** In this final scenario, several fuel and vehicle technologies become cost-competitive with petroleum, but none emerge as a clearly superior alternative. Thus natural gas, biofuels, electric vehicles, and hydrogen fuel-cell vehicles all gain market share within various market segments, collectively displacing over 75% of current petroleum use. No individual alternative, however, achieves greater than 25% market share.

Table 5.2 summarizes market share for different fuels and vehicle technologies within the light-duty fleet under these six alternate futures.

Table 5.2. Plausible futures for fuel mix within the light-duty fleet.

Fuel Mix Scenarios	Percent of Light-Duty Vehicle Miles Powered By:				
	Petroleum	Biofuel	Nat. Gas	Electricity	Hydrogen
Current status	~94%	~6%	~0	~0	~0
Petroleum dominates	~90%	~10%	~0	~0	~0
Shift to biofuels	~70%	~30%	~0	~0	~0
Shift to natural gas	~45%	~5%	~50%	~0	~0
Shift to electric	~20%	~5%	~0	~75%	~0
Shift to hydrogen	~20%	~5%	~0	~0	~75%
Mix of competing fuels	~20%	~5%	~25%	~25%	~25%

5.2.4 Vehicle Premium Cost

The current retail cost of conventional vehicles spans a considerable range—from perhaps $10,000 to hundreds of thousands of dollars—depending on size, speed, power, luxury amenities, and the like. Rather than focusing on such variations, here the concern is with the degree to which the price of an average vehicle (such as an affordable mid-size sedan or pickup truck) might rise in future years as a result of the inclusion of advanced technology to meet higher fuel economy standards or to support alternative fuels. Two potential futures are outlined that are intended to bracket the plausible range: that the cost of new vehicles in 2040 to 2060 is similar, in real terms, to today's prices, and that the cost of new vehicles increases by about $10,000 over today's costs. The logic for these two futures is as follows.

- **New vehicle costs remain the same.** This scenario would be most probable if the future light-duty vehicle fleet were powered mainly by a combination of petroleum and biofuels. The additional cost to configure a vehicle to run on higher blends of biofuels is just a few hundred dollars, and this is not expected to increase in future decades. Auto manufacturers will, however, need to install more advanced efficiency-oriented technology on conventional vehicles in order to achieve higher CAFE standards by 2025, and this is expected to increase vehicle costs. EPA and NHTSA (2012) have estimated, for example, that a vehicle able to meet the 2025 standards of 54.5 mpg will cost around $2,000 more than an otherwise comparable vehicle designed to meet the 2016 standards of 37.5 mpg. But if one assumes that CAFE standards are not subject to further increases following 2025, then it seems plausible that the cost of the technology required to meet the 2025 standards could slowly decline over time with increased production and manufacturing experience such that the cost of new vehicles in the 2040 to 2060 time frame is similar, in real terms, to today's costs.
- **New vehicle costs increase by $10,000.** At the other end of the spectrum, the premium associated with certain alternative-fuel vehicles—especially electric vehicles and hydrogen fuel-cell vehicles—could be considerable. Battery electric and plug-in hybrid vehicles have just entered the market and currently entail price premiums, depending on specific configuration details, well in excess of $10,000. They also face performance constraints in comparison to conventional petroleum-fueled vehicles, including long recharge times and significant range constraints for battery electrics. Hydrogen fuel-cell vehicles have yet to reach the market, but it is certainly reasonable to assume that the initial premium will be greater than $10,000. Over time, it is hoped that further technical advancements along with higher production volumes will help reduce the premiums associated with these vehicle types, but this is not a certainty. On the other hand, if premiums remain much higher than $10,000, then it would become very difficult for the vehicle type in question to achieve significant market share. Although electric and hydrogen vehicles promise significant savings in per-mile energy costs, it would be impossible for all but the highest-mileage drivers to recoup such a high initial premium through fuel savings. Therefore, $10,000 is viewed as an upper bound for the premium price that could be associated with any commercially successful vehicle type.

5.2.5 Energy Cost of Driving

Depending on which alternative fuels emerge as competitive in the coming decades, as well as how changes in oil prices compare with increased fuel economy, the energy cost of driving on a per-mile basis could drop, remain stable, or rise in comparison with the average cost of driving a conventionally fueled vehicle today.

- **Energy cost of driving declines by at least a half.** Depending on technology breakthroughs and changes in the cost of underlying energy feedstocks, a significant decline in the energy cost of driving is theoretically possible for any of the fuel types considered in this study, including petroleum. It seems most likely, however, for electric vehicles, for natural gas (with its recent drop in price), and perhaps for hydrogen. Consider an example with electric vehicles to illustrate the potential for substantial savings. The fuel economy for Nissan Leaf is rated at about 3 miles per kWh (fueleconomy.gov, undated). With the cost of residential electricity in the United States averaging 11.8 cents per kWh as of 2012 (EIA 2012), the energy cost of driving a Leaf is a little less than 4 cents per mile. By way of contrast, if one assumes that gasoline costs, say, $3 per gallon (net of taxes), then the energy cost of driving a conventionally fueled vehicle that achieves the recent CAFE standard of 27.5 mpg would be just under 11 cents per mile, almost three times higher than the cost of driving a Leaf. Future conventional vehicles will of course have higher fuel economy, but fuel economy for alternative-fuel vehicles is likely to improve over time as well.
- **Energy cost of driving remains at current levels.** Such an outcome would be most likely with petroleum (with any future increase in the cost of oil being offset by improved fuel economy), with biofuels, or perhaps with hydrogen. In theory it might also occur with electric or natural gas vehicles, but only if their prices rise well beyond what is currently forecast.
- **Energy cost of driving increases by a third.** Given the significant increase in CAFE standards scheduled through 2025, the prospects for driving to become more costly on a per-mile basis appear somewhat remote. It is plausible,

though, that the rapid growth in world petroleum demand could outpace increased supply, in turn leading to a rise in oil prices that outgains improvements in vehicle fuel economy. Assuming that other alternative fuels fail to achieve significant market penetration, the energy cost of driving a conventional vehicle would slowly increase. If driving conventional vehicles were to become much more expensive than at present, however, it would be more likely that alternative fuels would emerge as a cost-competitive alternative to petroleum.

5.3 Scenarios for Travel Elements

The focus now shifts to the development of plausible scenarios for future trends in personal travel and goods movement. Specifically, this section considers potential changes in passenger vehicle travel, transit mode share, and freight trucking.

5.3.1 Total Passenger Vehicle Travel

Based on BTS data (2012a), total vehicle miles of travel for light-duty vehicles (i.e., passenger cars, pickup trucks, sport utility vehicles, and minivans) and motorcycles in the United States increased from about 1.04 trillion in 1970 to about 2.96 trillion in 2010, representing a cumulative gain of 184% and an average annual growth rate of 2.65%. It seems unlikely, however, that such rapid growth will continue over the coming years. Many of the trends that spurred such rapid VMT growth in previous decades—increased automotive ownership, dramatic expansion of the road network, a growing share of two-worker households, greater automobility among older adults, and the like—have either slowed or reached their natural saturation points. At the same time, some younger adults now appear to be waiting longer to get a license and begin driving, possibly due to a generational shift in attitudes about mobility or to improved telecommunications technologies and the rise of social networking. Indeed, total VMT in the United States actually peaked in 2007 and declined for several years, though it began to rise again in 2010 (BTS 2012a). During the brief period of decline, the nation also faced spiking fuel prices followed by a steep and prolonged recession—factors that correlate with reduced VMT as well.

It is too early to discern whether this decline in VMT represents just a brief aberration related to economic conditions or instead heralds a major shift in long-term automobility trends. Many expect that growth in population and the economy will contribute to continued increases in VMT in the coming decades, although the rate of growth may be lower. The most recent reference-case projections from EIA (2013) assume, for example, that total mileage within the light-duty fleet will continue to rise through 2040, albeit at a much-reduced annual rate of about 1.2%. This provides a helpful anchoring point for the future scenarios for passenger vehicle travel. A plausible future in which passenger vehicle travel could increase even more rapidly, though still at less than historical rates, is also considered, as well as is a case in which passenger vehicle travel declines slightly. While the latter case may be improbable for the nation as a whole, it could occur in certain states due to plausible shifts in migration patterns.

- **Passenger vehicle travel declines by 10%.** While many expect total VMT in the United States to rise in the coming years, such a trend may not hold in all states. Already the country has witnessed major migratory shifts—from the rust-belt states to the Sunbelt states, for example—related to structural changes in the economy. It is certainly possible that these trends could continue in future decades, potentially leading to absolute declines in population and economic activity in some states. As another possibility, acceleration in the effects of climate change—worsening heat waves and drought conditions in the Southwest, for instance—could make certain regions of the country much less desirable as a place to live, triggering a potential reversal in recent migration patterns. Given that this study is intended to inform state-level long-range planning, it therefore seems prudent to allow for the possibility of declining passenger vehicle travel within the futures considered, even if such an outcome only occurs in a few states. Thus, a future is included in which passenger vehicle travel in a state declines by 10% by the 2040 to 2060 time frame, which would correspond to an annual rate along the lines of negative 0.25%.
- **Passenger vehicle travel increases by 60%.** For the mid-range scenario, EIA's most recent reference-case projection for total VMT growth in the light-duty vehicle fleet, with its implied annual growth rate of 1.2%, is used to begin, and then that same rate is extrapolated out to the 2040 to 2060 time frame. This would result in an increase of about 60% over the next 40 years. As discussed in Chapter 4, it is expected that the U.S. population as a whole will grow at an annual rate of slightly less than 1% in the coming decades. A growth rate of 1.2% in vehicle travel therefore implies that the rate of per-capita vehicle travel will continue to expand. This might be explained by rising incomes (which generally correlate with increased vehicle ownership and travel) or by the possibility that the energy cost of travel could decline in future years. Still, an annual growth rate of 1.2% marks a significant reduction from trends over the past 40 years, implying that the rate of growth in per-capita travel would at least slow to some degree. This slowing could reflect the outcome of efforts to improve alternative modes of travel, to foster denser land-use patterns, or to rely more heavily on user fees for funding transportation.

Table 5.3. Plausible futures for light-duty fleet VMT.

Future	EIA Forecast Case	Annual Growth	Cumulative 40-Year Growth
Historical rate for 1970–2010	N/A	2.65%	184%
10% decline	N/A	-0.25%	-10%
60% increase	Reference case	1.2%	60%
80% increase	High economic growth	1.5%	80%

Source: Historical rates from BTS (2012a); EIA forecast cases from *Annual Energy Outlook 2013* (EIA 2013).

- **Passenger vehicle travel increases by 80%.** Should total light-duty vehicle travel increase by 60% by the 2040 to 2060 time frame, as envisioned in the prior scenario, many state DOTs will face significant increases in traffic congestion and other daunting challenges. From the perspective of identifying potential impacts on state DOTs, then, it may not be necessary to consider a future in which light-duty vehicle travel grows at an even faster rate. Yet EIA's most recent AEO also includes a "high economic growth scenario" in which total passenger vehicle travel increases at an annual rate of 1.5%. Projected out to the 2040 to 2060 time frame, this would result in a cumulative increase of 80%. Beyond significant economic growth, additional factors that could contribute to such an outcome include faster-than-expected population growth within a state, major reductions in the energy cost of vehicle travel, continued decentralization of land use patterns, and a shift toward greater reliance on general revenue sources, as opposed to user fees, to fund transportation, further reducing the cost of driving.

Table 5.3 summarizes the three plausible futures outlined for future trends in passenger vehicle travel.

5.3.2 Transit Mode Share

Next are examined potential changes in transit use. Because many of the elements that support increased transit use—for example, denser land-use patterns or higher costs of vehicle travel—could also stimulate increases in walking or biking, changes in transit are intended to serve as a surrogate for trends in other non-automotive travel modes as well. In contrast, transit use should vary inversely with automotive travel, as one often substitutes for the other. Yet the current mode share for transit in the United States is so low that even significant percentage gains in transit use would not necessarily preclude ongoing growth in total VMT for the light-duty fleet. Thus, one could see both high percentage gains in transit mode share and high absolute increases in VMT.

Looking at the historical record, transit use in the United States declined significantly over the latter half of the 20th century. Total transit use peaked at about 23.5 billion annual trips in 1946 when the size of the U.S. population was around 141 million, translating to 166 transit trips per person each year. As of 2010, the total number of transit trips was around 10.2 billion, while the size of the U.S. population had grown to around 307 million, corresponding to 33 transit trips per person per year (APTA 2012, Table 1; U.S. Census Bureau 2000, 2011). In other words, per-capita transit use has declined by nearly 80% over the past 65 years.

The trend over the past decade, though, has been generally upward. This is illustrated in Table 5.4, which presents statistics on transit mode share from the two most recent National Household Travel Surveys in 2001 and 2009 (Santos et al. 2011) and on total transit use for those same years from the *2012 Public Transportation Fact Book* (APTA 2012).

Given that transit use, despite recent gains, is still low in historical terms, there would seem to be little apparent utility in developing future scenarios where the transit share drops much further. On the other hand, it is plausible that transit mode share—owing to some combination of changes in land use, driving prices, and government policy—could increase considerably. Three plausible futures are formulated

Table 5.4. Recent growth in transit use.

Year	Transit Mode Share		Total Transit Use	
	Share of Person Trips	Share of Person Miles	Unlinked Passenger Trips	Passenger Miles
2001	1.6%	1.2%	9.65 billion	49.07 billion
2009	1.9%	1.5%	10.21 billion	54.01 billion

Source: Santos et al. (2011, Tables 9 and 12), APTA (2012, Tables 1 and 3).

for transit use as a share of all person trips—one in which it holds constant, one in which it increases by 150%, and one in which it increases by 400%. The latter would bring per-capita transit trips for the nation as a whole back to about the same level as at the end of World War II, a time during which U.S. citizens were being asked to ration gasoline and other scarce resources. This scenario, though promising some social benefits, would strain existing transit systems, potentially motivating a more integral role for state DOTs in supporting transit and other non-automotive alternatives.

Note that the plausible scenarios are presented in terms of percentage increases for mode share (e.g., transit mode share increases by 150%) as opposed to absolute increases (e.g., transit mode share rises to 5%). This is because current transit use varies considerably from one state to the next. Most rural states, for instance, have very little transit use, while states with large metropolitan areas have much higher rates. To illustrate the effects of the envisioned growth rates, corresponding mode share measures are indicated for the nation as a whole. In considering the effect for any given state, however, the envisioned percentage changes should be interpreted in the context of the current baseline for transit use within that state.

- **Transit mode share remains constant.** Total transit use increases in this scenario, but only at the same pace as growth in automotive travel. Thus, transit maintains its current mode share. Underlying trends that might support this outcome—that is, that might hinder further expansion in transit mode share—include lower vehicle premium costs, lower energy costs for vehicle travel, greater reliance on general revenues in place of user fees to fund transportation, a continuation of low-density development patterns, and rising incomes.
- **Transit mode share increases by 150%.** In this future, which would represent a slight acceleration in trends over the past decade, growth in transit use outpaces growth in vehicle travel, with the transit mode share for person trips rising to 5% for the nation as a whole by the 2040 to 2060 time frame. Achieving such a gain would likely require concerted efforts on the part of policy makers, including planning for denser land use, significant investments in transit capacity and other alternative travel modes, and renewed emphasis on road use fees to charge the full costs of automotive travel. Additional developments that might contribute to this outcome include significantly higher vehicle premium prices, rising energy costs for vehicle travel, prolonged economic stagnation, and rising income inequality.
- **Transit mode share increases by 400%.** In this final future, transit use grows quite rapidly over the next 30 to 50 years, accommodating 10% of all trips for the nation as a whole by 2050. Achieving this endpoint would likely involve quite aggressive policies to make transit more attractive in relationship to driving. These could include zoning for much denser and more integrated land use, investing in rail or bus rapid transit lines with dedicated right-of-ways and grade separation to make transit a faster option for many trips, imposing road use fees that encompass congestion and emissions pricing in addition to base-level mileage fees, and doing away with most forms of subsidized parking. Other elements, such as higher vehicle premiums, increased energy costs for travel, low economic growth, and increasing income disparities, could contribute to this scenario as well.

5.3.3 Freight Trucking

As of 2010, according to BTS data (2012a), combination trucks (i.e., tractor-trailer combinations) were responsible for roughly 176 billion VMT, representing just less than 6% of all VMT on the U.S. road network. If one adds in the estimated VMT from smaller single-unit trucks (i.e., two or more axles and six or more wheels, often referred to as light-duty commercial trucks), the VMT share for trucking grows to over 9.5%. BTS estimates indicate that the U.S. trucking industry moved about 1.32 trillion ton-miles of freight in 2009, slightly less than 31% of the total for all freight modes (BTS 2012b). By way of comparison, rail carried a little less than 37% of all ton-miles, pipelines carried a bit more than 21%, domestic water transportation was responsible for another 11%, and aviation was responsible for less than 1%.

Examining the trucking industry over the past several decades, two important trends stand out. First, truck VMT have been growing much more rapidly than passenger VMT. Since 1970, per BTS data (2012a), the average annual growth rate for VMT in the light-duty passenger vehicle fleet has been about 2.65%, as mentioned previously. For combination trucks, in contrast, the growth rate has been about 4.11%, and for combination trucks and smaller single-unit trucks together, the annual growth rate has been about 3.89%. Second, the share of goods movement handled by trucking has also been rising. Based on BTS data (2012b), total ton-miles of freight across all modes increased by about 26% between 1980 and 2009. (It actually increased by an even greater extent through 2007, but then suffered declines in 2008 and 2009 as a result of the recession.) Over this same period, trucking ton-miles increased by 110%. Ton-miles by aviation grew at an even faster rate, increasing by 148% since 1980, but aviation carries only a fraction of a percent of all ton-miles (though it carries a much larger share of freight by value). The closest competitor to trucking, rail freight, has also grown at a significant, though slightly lower, rate since 1980, with a cumulative increase of about 70%. The strong growth for rail reflects, in part, increasing volume for intermodal containers carried by rail. In contrast, ton-miles by pipeline have dipped slightly, while ton-miles by domestic water transportation have fallen precipitously.

Looking forward, many view these two trends—more rapid growth for truck travel than for passenger vehicle travel and increasing ton-mile mode share for trucking—as likely to continue. In the most recent AEO from EIA (2013), the reference-case projection shows medium- and heavy-duty truck VMT growing at an annual rate of 2.1%. While substantially lower than historical trucking growth rates, this is still greater than the 1.2% growth rate projected for passenger VMT in the reference case.

The prospects for continued growth in mode share for truck freight remain strong as well. While the shares of ton-miles carried by trucks and by rail have both increased significantly in recent decades, the rail network faces increasingly stringent capacity constraints. Between 1960 and 2009, the nation's Class 1 rail mileage shrank by almost 55%, improving profits for rail companies but also restricting total rail capacity. Over the same period, the U.S. road network, measured in centerline miles, grew by about 14% (BTS 2013a), and total lane miles within the road network have increased by close to 8% since 1980 (BTS 2013b). Based on these trends, trucking now appears to represent the path of least resistance for accommodating further growth in goods movement; it is comparatively easy to add more trucks to the road network, albeit at the cost of increased traffic congestion and road wear. In contrast, expanding the rail network in a significant way would require considerable private investment.

The most recent EIA (2013) projections were used for the development of scenarios for growth in trucking, and it was assumed that trucking is likely to continue to gain in mode share for the reasons just discussed. Included are the annual growth rate of 2.1% modeled within EIA's reference case and a more rapid annual growth rate of 2.9% based on EIA's high economic growth scenario. To round out the scenarios, also included is a no-growth future; this is not linked to a specific EIA scenario but rather is intended to reflect the potential for variation in goods movement patterns in different states given uncertain future growth and migration patterns.

- **No growth in freight trucking.** As discussed earlier in relation to the development of scenarios for passenger vehicle travel, one can construct plausible narratives in which certain states might lose population in the coming decades. This could in turn lead to a zero growth rate for trucking within those states. The reason that the rate is not assumed to be negative is that a significant share of trucking involves interstate travel. Within this scenario, declines in freight trucking serving destinations within a state are offset by increases in interstate trucking that passes through the state. Other elements that might contribute to such an outcome include higher road-use fees for trucks (e.g., weight-distance truck fees, congestion pricing, and emissions fees), rapidly rising oil prices, a stagnant economy, or aggressive public subsidization of rail investments aimed at enabling a shift in freight ton-miles away from trucking to help reduce traffic congestion and harmful emissions.
- **Freight trucking VMT increases by 125%.** This scenario is based on the EIA reference case for annual VMT growth rate for freight trucks over 10,000 pounds and is broadly consistent with the FHWA's Freight Analysis Framework forecast for truck ton movements to 2040 (FHWA Office of Operations 2011). The growth rate is 2.1% per year, resulting in a cumulative increase of 125% by around 2050. Consistent with this robust growth rate, the economy expands at a healthy rate, the cost of driving increases modestly at most, and some investment in additional rail capacity is made, although not enough to prevent overall ton-mile mode share gains for trucking.
- **Freight trucking VMT increases by 200%.** The outcome in this case is similar to EIA's high economic growth forecast for annual VMT of freight trucks over 10,000 pounds. With an annual growth rate of 2.9%, truck VMT increases 200% by around 2050. In this future, the economy grows rapidly, per-mile hauling costs remain relatively low due to inexpensive oil or significant fuel economy gains, and there is not a significant shift to greater reliance on user fees to raise highway funds. The system of Class 1 railroads, absent significant expansion, begins to experience severe capacity constraints and is unable to maintain a constant share of growing ton-miles. Mode share for trucks thus increases significantly.

Table 5.5 summarizes the growth in trucking VMT over the past 40 years along with the rates of growth considered in the three scenarios developed for this study.

Table 5.5. Plausible futures for growth in freight trucking VMT.

Future	EIA Forecast Case	Annual Growth	Cumulative 40-Year Growth
Historical rate for 1970–2010	N/A	3.89%	360%
Zero increase	N/A	0.0%	0%
125% increase	Reference case	2.1%	125%
200% increase	High economic growth	2.9%	200%

Source: Historical rates from BTS (2012a), EIA forecast cases from *Annual Energy Outlook 2013* (EIA 2013).

5.4 Scenarios for Federal Policy Elements

This final section presents the development of scenarios for future federal policies involving energy and climate along with policies related to transportation funding. As noted earlier, these could influence both energy use and travel patterns, and they might also act to expand or constrain the types of policies that states can pursue.

5.4.1 Federal Energy and Climate Policies

Much of the current framework for federal energy and climate policy aims to ensure affordable energy supplies, reduce reliance on foreign oil for economic and security reasons, and reduce greenhouse gas emissions for climate mitigation. While a few policies—most notably vehicle fuel economy standards—can address all of these goals, most instead pose trade-offs among the goals. For example, expanded domestic drilling could help to lower oil prices and reduce the need for imported oil. To the extent that it is effective in reducing prices, however, it could also stimulate increased demand and in turn higher greenhouse gas emissions. With the recent increase in U.S. oil and gas production made possible by improved extraction technologies, forecasts now suggest that the United States could be a net fossil-fuel exporter by 2030 (IEA 2012). This could lead to a reduced policy focus in the coming decades on U.S. energy independence. In contrast, barring unexpected technology breakthroughs in lower-carbon energy sources, the fundamental tension between the goals of maintaining low energy prices for the end user and stemming greenhouse gas emissions is likely to persist.

Policy options can also be categorized in terms of approach; possibilities include pricing mechanisms (e.g., charging more for high-carbon fuels to discourage their use), regulatory mandates (e.g., requiring that fuel producers develop more biofuels or that auto manufacturers offer vehicles with greater fuel economy), and voluntary incentives or subsidies (e.g., offering rebates on the purchase of electric vehicles or subsidizing the production of ethanol). While pricing mechanisms can be quite effective, they are also politically contentious. Most U.S. policies to date have therefore emphasized either the regulatory approach or subsidies and other voluntary incentives.

This study considers three potential scenarios for future federal energy and climate policy that differ from one another in their relative prioritization between the goals of low energy costs for end users and climate mitigation and in whether pricing policies are employed to incentivize shifts away from carbon-intensive fuels.

- **Moderate energy and climate policies.** In this future, federal policy makers as a group remain ambivalent regarding the relative importance of climate mitigation versus energy prices. Those more focused on climate mitigation actively oppose aggressive efforts to expand petroleum production or develop synthetic fuels such as those from coal-to-liquid technology, policies that could put downward pressure on prices but at the possible cost of increased GHG emissions. Those unconcerned with climate change, in contrast, rally against policies to employ pricing as a means of reducing carbon emissions. This results in policy stalemate, the outcome of which is simply to continue with the current mix of energy and climate policies. These include a continuation of current fossil-fuel subsidies along with CAFE standards, RFSs, modest investments in alternative fuels and vehicle propulsion technology research, and modest subsidies for alternative-fuel vehicle purchases.
- **Aggressive policies focused on low energy cost for end users.** In this next future, Congress agrees to aggressively pursue the goal of maintaining low and stable energy costs for end users, even though some of the policies could exacerbate climate concerns. The adopted mix of policies, some of which are already in place, include increased CAFE standards; renewable fuel standards; public investments to help expand petroleum production, including from unconventional sources; and larger investments in synthetic fossil-fuel production technologies.
- **Aggressive policies focused on climate mitigation.** In this final future, perhaps in response to increasing evidence of and costs associated with a changing climate and more frequent severe weather events, Congress prioritizes efforts to mitigate climate change. This creates the basis for agreeing to enact pricing policies to help reduce carbon emissions. It also results in the discontinuation of policies, such as support for expanded drilling on public land, which could undermine climate goals. The emergent mix of policies includes higher CAFE standards, low-carbon fuel standards (LCFSs), vehicle feebate programs, and higher gas taxes or carbon fees, with much of the proceeds directed toward clean-energy research and adoption incentives.

Table 5.6 summarizes the mix of approaches employed under the three plausible scenarios for future federal energy and climate policy.

5.4.2 Federal Transportation Funding Policies

With motor-fuel taxes, the major source of highway revenue, losing ground to inflation and improved fuel economy, transportation funding at the federal level (and in many states) is facing severe shortfalls and stands at a crossroads. Three scenarios are considered that trace out distinct trajec-

Table 5.6. Summary of federal energy and climate policy futures.

Scenarios	Regulatory Mandates	Subsidies	Pricing Policies
Moderate energy and climate policies	Modest increases to CAFE standards and RFSs	Moderate research and development (R&D) support, limited vehicle and fuel subsidies	None
Aggressive policies focused on low energy prices	Modest increases to CAFE standards and RFSs	More R&D and subsidies for expanded petroleum production and synthetic fuels	None
Aggressive policies focused on climate mitigation	Aggressive increases to CAFE standards and shift from RFSs to LCFSs	More R&D and subsidies for low-carbon fuels and vehicle technologies	Carbon tax or cap and trade along with vehicle feebate programs

tories for future federal transportation funding policies that might unfold in the coming decades.

- **Declining federal revenue and investment capacity.** The first future scenario represents an extension of more recent trends in transportation funding over the past 10 to 20 years. In the context of higher and more volatile oil prices along with growing partisan divisions, Congress does not institute significant motor-fuel tax increases in the coming decades, nor does it augment declining fuel-tax receipts with an alternate source of revenue. The size of the federal program thus declines, with a greater share of the transportation funding burden shifting to state and local jurisdictions. Following recent experience, states, counties, and cities find it more feasible to augment transportation funding through increased reliance on general revenue sources such as sales taxes, property taxes, and project impact fees rather than by increasing highway user fees. Increased state and local funding, however, is not sufficient to offset the reduction in federal revenue, leading to reduced aggregate investment capacity. The shift toward greater reliance on general revenue also diminishes the incentive for motorists to use the system efficiently.
- **Renewed federal commitment to transportation investments.** The second scenario represents a reinvigoration of the philosophies that guided transportation funding and investment for most of the twentieth century—specifically, strong reliance on user fees as an equitable and efficient means of funding transportation investments. As the current recession subsides, members of Congress recognize the critical linkage between the nation's transportation system and its prosperity and achieve consensus to shore up the federal transportation program and its underlying revenue sources. In the near term, this includes a significant increase in federal taxes on gasoline and diesel, with revenues dedicated to the Highway Trust Fund. Over the longer term, as fuel taxes decline with greater fuel economy and a shift to alternative fuels, the nation replaces fuel taxes with direct user fees—perhaps in the form of tolling on federal-aid highways or alternatively through mileage-based user fees—to fund the transportation network. Under this regime, revenues are adequate to support highway maintenance requirements and needed system expansions. While transit funding receives its share from the HTF, it remains largely reliant on state and local subsidies and thus struggles for enough revenue to maintain and expand operations.
- **Shift to efficiency-oriented funding mechanisms.** This last future might be characterized as the most progressive vision, with increased emphasis on funding mechanisms that stimulate much more efficient use of the transportation system. Similar to the prior option, Congress takes steps to shore up federal transportation funding, initially increasing fuel taxes then later shifting to direct mileage-based user fees. Additionally, Congress recognizes that the form of transportation funding, beyond revenue implications, can have a profound effect on vehicle purchase and travel decisions. It thus directs the administration to develop a mileage-fee system with sufficient flexibility to allow per-mile fees to vary with such elements as time, location, axle weight, and vehicle emissions class in order to more accurately reflect the costs associated with any given trip. This in turn enables broad application of congestion tolls, weight-distance truck tolls, and emissions fees. These pricing structures encourage much more efficient use of the system, thus reducing the amount of new capacity needed, and at the same time raise much more revenue than current mechanisms. There is thus ample funding not only for highways but also for transit investments. The latter becomes important given that congestion pricing stimulates at least some degree of mode shift.

Table 5.7 summarizes the approaches, characteristics, and likely outcomes associated with the transportation funding policy scenarios just described.

Table 5.7. Summary of federal energy and climate policy futures.

Scenarios	Federal Funding	Federal Fuel Taxes	Expanded Tolling or MBUFs	Variable Pricing Policies
Declining federal revenue	Federal program continues to diminish	Not increased significantly	Limited	Some congestion-priced facilities
Renewed federal commitment	Federal program expands moderately	Increased in the near term	Introduced in the 2020 time frame	Some congestion-priced facilities
Shift to efficiency-oriented funding mechanisms	Federal program expands considerably	Significantly increased in the near term	Introduced in the 2020 time frame	Extensive use of congestion tolls, weight-distance truck tolls, and emissions fees

References

APTA. 2012. *2012 Public Transportation Fact Book.* Washington, D.C.

BTS. 2012a. Table 1-35: U.S. Vehicle-Miles. *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html (accessed April 11, 2013).

BTS. 2012b. Table 1-50: U.S. Ton-Miles of Freight (BTS Special Tabulation). *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_50.html (accessed April 15, 2013).

BTS. 2013a. Table 1-1: System Mileage Within the United States. *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_01.html (accessed April 15, 2013).

BTS. 2013b. Table 1-6: Estimated U.S. Roadway Lane-Miles by Functional System. *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_06.html (accessed April 15, 2013).

EIA. 2012. Electricity Explained: Factors Affecting Electricity Prices. http://www.eia.gov/energyexplained/index.cfm?page=electricity_factors_affecting_prices (accessed July 21, 2013).

EIA. 2013. *Annual Energy Outlook 2013.*

EPA and NHTSA. 2012. 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule. *Federal Register*, 77 (199).

FHWA Office of Operations. 2011. Freight Analysis Framework. Freight Management and Operations. http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm (accessed May 10, 2011).

Fueleconomy.gov. Undated. 2012 Nissan Leaf. http://www.fueleconomy.gov/feg/noframes/32154.shtml (accessed December 8, 2011)

IEA. 2012. *World Energy Outlook 2012.*

Lempert, R. J., S. W. Popper, and S. C. Bankes. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Policy Analysis.* RAND Pardee Center, Santa Monica.

Santos, A., N. McGuckin, H. Y. Nakamoto, D. Gray, and S. Liss. 2011. Summary of Travel Trends: 2009 National Household Travel Survey. Federal Highway Administration.

U.S. Census Bureau. 2000. Historical National Population Estimates: July 1, 1900 to July 1, 1999. Population Estimates. http://www.census.gov/popest/data/national/totals/pre-1980/tables/popclockest.txt (accessed March 18, 2013).

U.S. Census Bureau. 2011. Table 1. Intercensal Estimates of the Resident Population by Sex and Age for the United States: April 1, 2000 to July 1, 2010. US-EST00INT-01. Population Estimates. http://www.census.gov/popest/data/intercensal/national/nat2010.html (accessed March 18, 2013).

CHAPTER 6

Scenario Impacts on State DOTs

After developing the future transportation energy scenarios and reviewing current state DOT roles, mandates, funding, and operations, interviews were conducted with senior DOT staff in a number of states around the country. The research team also interviewed several senior transportation thought leaders not attached to specific state DOTs to gain their broader perspectives. The individuals involved in the interviews are mentioned in the Author Acknowledgments section at the beginning of the report.

There were two main objectives for the state DOT interviews. The first was to gain insights into the types of challenges that the transportation energy scenarios might create for state DOTs in the future and that are the focus of this chapter. The second was to solicit thoughts on potential policies that states might consider in response to these challenges. These are considered further in the next chapter. For both of these questions the team supplemented findings from the interviews with additional research and analysis.

In conducting the interviews, the team first prepared a brief description of the future transportation energy scenarios and distributed it to participants in advance of the discussion. During the interviews, the researchers then asked a series of broad and somewhat open-ended questions intended to stimulate thoughtful discussion not only about specific challenges and potential policy responses but also about the mission and role of a state DOT and whether and how it might evolve in the coming decades. Some of the questions were:

- How might the mission, organizational roles, and responsibilities of a state DOT evolve in the future?
- How might the core operations of the DOT change?
- What can be expected of future federal and state DOT revenue trends?
- How could future federal energy or climate policy affect states?
- What policies might DOTs consider to meet future challenges, either proactively or reactively?

Responses, of course, varied significantly from state to state, reflecting the distinct combination of each state's mandates, priorities, organization, and geographic and economic context. However, several general themes recurred throughout many of the interviews, and participants also identified a number of specific concerns that could result from some of the plausible transportation energy futures. These are considered in the next two sections.

6.1 Recurring Themes in the State DOT Interviews

To provide a sense of the issues, opportunities, and concerns that arose throughout the interviews, Figure 6.1 shows relevant words that appeared with the greatest frequency in the team's interview notes, with the size of each word indicating its relative frequency. (This figure should not be viewed as a scientific representation of word use frequency since the team did not record exact transcripts for each interview, but it is still illuminating.)

The interview participants articulated a diverse mix of views, insights, and philosophical perspectives on the current roles and responsibilities of state DOTs, on funding needs and opportunities, on operational requirements and challenges, and on how some of these might undergo fundamental shifts in the future. Some of the most frequently voiced opinions and observations were:

- The future state DOT will need to be smarter, faster, and leaner.
- The core mission and responsibilities of state DOTs are unlikely to change radically.
- The typical state DOT will in all likelihood still be highway focused, but new roles in other areas are very likely to emerge.
- There will need to be greater focus on meeting customer expectations through preservation of existing assets and

Figure 6.1. Words frequently repeated by state DOT interview participants.

advanced operations and less of a focus on construction of new facilities and system capacity expansion.

- The current system of relying on gasoline and diesel taxes will need to be replaced, and a national approach to user fees would be desirable.
- There will be expanded interest in longer-range planning with more attention to energy issues and an increased role for the DOT in facilitating change to adapt to evolving energy costs and types.

6.2 Potential Scenario Impacts on State DOTs

This section focuses on how some of the plausible transportation energy futures developed in Chapter 5—alone or in combination—might adversely affect state DOTs in the coming decades. A total of seven distinct concerns arose during the course of the interviews. The text that follows describes each of these potential impacts, discusses which of the plausible futures could contribute to or exacerbate the challenges, provides additional analysis and commentary as appropriate, and highlights one or two quotations from the interviews to provide a flavor of the thoughts and concerns expressed by DOT staff. Note that the quotations do not necessarily represent consensus views—indeed, some may be controversial—but rather are intended to be illustrative. Also, the interviews were confidential, and the quotes are not attributed to specific DOTs or individuals.

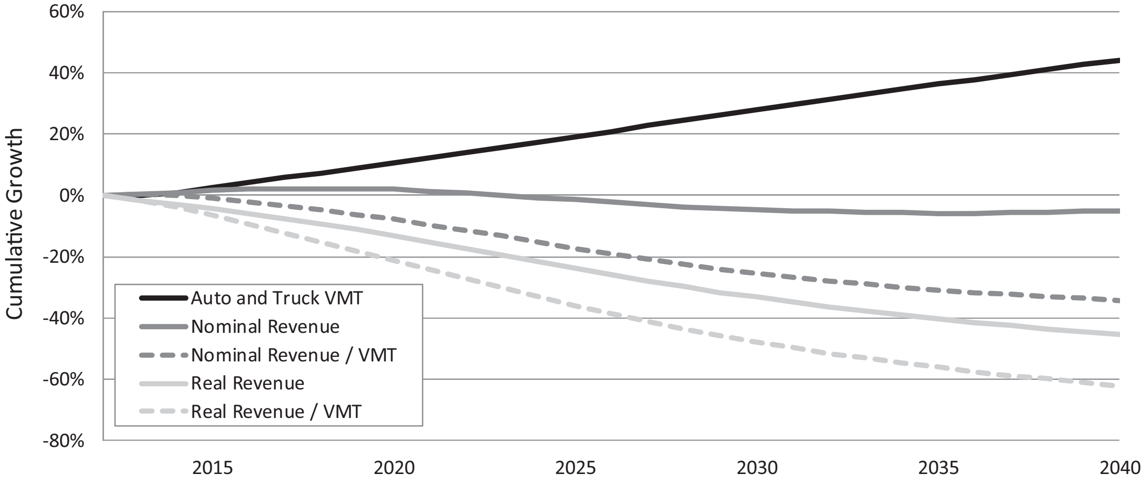
6.2.1 Declining Fuel-Tax Revenue

Declining fuel-tax revenue, perhaps the most frequently cited impact, was perceived as a looming challenge regardless of how the future unfolds. Should petroleum remain the dominant fuel, the higher CAFE standards scheduled through 2025 will severely undercut fuel-tax revenue per mile of travel unless per-gallon rates are raised significantly. If any of the alternative fuels gain considerable market share, an increasing number of drivers could be paying no fuel taxes at all.

Elaborating on the latter point, federal and state fuel taxes are currently collected at the wholesale level. This same collection regime might be extended to include certain liquid biofuels, such as cellulosic ethanol or renewable diesel, that would likely be produced in large quantities and integrated, to some degree, into the existing distribution system for gasoline and diesel. Finding a way to easily collect transportation-related taxes for other alternative fuels, however, could be much more challenging. Both electricity and natural gas, for example, allow for at-home refueling or recharging and serve purposes other than transportation as well. Any effort to systematically collect transportation user fees based on the consumption of electricity or natural gas might therefore require a shift from wholesale collection to end-user collection and the installation of multiple meters within a household. Another challenge is that electricity, hydrogen, and lower-tech biofuels (such as traditional biodiesel from waste grease or vegetable oils) offer the possibility of local production, either at home or at a refueling station, which could prove quite difficult for taxing authorities to track. Seeking to collect fuel taxes for many of the possible alternative fuels would thus require a shift from collecting taxes from the wholesale level to either the retail level or to individual end users, and in some cases it could prove quite difficult to prevent fuel-tax evasion.

The looming revenue challenge for state DOTs will be further exacerbated if the federal government continues along its current path of not increasing fuel taxes and devolving greater funding responsibility to state and local governments. To illustrate this concern, the research team used recent reference-case projections from the EIA's *Annual Energy Outlook 2013* (EIA 2013) to examine what could happen to federal fuel-tax revenue in relation to vehicle travel through 2040 assuming that current federal tax rates for gasoline and diesel—18.4 cents per gallon and 24.4 cents per gallon, respectively—are left unchanged over that period. The results are shown in Figure 6.2.

The dark line in the figure shows cumulative percent growth in auto and truck travel, while the dark gray line estimates percent growth in nominal fuel-tax revenue (i.e., in dollars in the years received, not accounting for reduced buying power due to inflation) based on changes in gasoline and diesel consumption and their relative taxation rates. (According to EIA's projections, aggregate gasoline consumption will decline by about 25% over this period, while total diesel use will rise by about 40%.) Next, the light gray line shows growth in real revenue [i.e., the value of future fuel federal tax receipts in today's dollars, accounting for inflation as measured by the consumer price index (CPI)] based on EIA's assumption that inflation grows at 2% per year. Finally, the dashed dark gray



Source: Calculations by authors using data from *Annual Energy Outlook 2013* (EIA 2013).

Figure 6.2. Forecast changes in VMT and federal fuel-tax revenue through 2040.

and light gray lines indicate changes in nominal and real revenue in relation to total VMT. If EIA projections hold and the federal government leaves current fuel-tax rates at their current levels, real federal fuel-tax revenue could decline by more than 40% by 2040, while real revenue per VMT could decline by over 60%.

Any such decline would have a severe effect on state highway funding. Federal fuel taxes account for about 92% of HTF revenue (OHPI 2011), and the HTF in turn provides about 26% of all state highway funding on average (OHPI 2012). To compound matters, the same trends projected to undercut federal fuel-tax revenue could also affect state fuel taxes, which account for another 26% of all state highway funding. Most states levy fixed per-gallon taxes for gasoline and diesel, much like the federal government. If such states fail to increase their per-gallon rates, the overall effect on real revenue per mile of travel should be similar to that depicted in Figure 6.2. (The exact outcome would depend on the relative per-gallon rates for gasoline and diesel.) For the smaller share of states that already index fuel-tax rates to increase with inflation, growth in total real revenue would instead track with the line shown for nominal revenue in the figure; that is, the act of indexing the rates to increase with inflation would result in real revenue tracking the modest decline in combined gasoline and diesel fuel consumption. Even in such cases, however, total real revenue per VMT would decline by more than 30%, reflecting the fact that current fuel-tax indices do not as a general rule account for improvements in average vehicle fuel economy.

To sum up, projected improvements in conventional vehicle fuel economy along with the possible growth in alternative fuels threaten to undermine both federal and state fuel-tax revenue, which collectively accounts for around half of all state highway funds. Unless the federal government and states either institute significant rate increases for fuel taxes or develop alternate revenue sources, state highway funding shortfalls could become increasingly severe in the coming decades.

Excerpts from the interviews:

> *". . . there must be a fundamental shift in our revenue structure."*
> *". . . we need a national solution for taxing alternative fuels."*

6.2.2 Increasing DOT Costs

Interview participants observed that certain future scenarios could lead to an escalation in DOT costs, although this would not be a problem in all futures. Oil plays a major role in road maintenance and construction—as an ingredient in some construction materials (e.g., asphalt), as an energy input in the production of other materials (e.g., steel and cement), and as a fuel to operate heavy machinery. Any significant rise in the cost of oil would therefore drive up the cost of road repairs along with new construction.

Illustrating this potential concern, highway construction and maintenance costs surged by more than 70% between 2003 and 2006, a period marked by rapidly increasing oil prices. In an FHWA study (2007) that examined the rise in construction and maintenance costs during these years, the authors identified four contributing factors, two of which related to oil. First, higher prices for gasoline and diesel led refiners to further improve the efficiency of their production processes, resulting in lower production of by-products such as asphalt. The price of asphalt thus needed to rise as well to ensure that refiners would continue to produce an adequate supply for highway needs. Second, the production of cement is a fuel-intensive process, and because of this, cement prices tend to rise with oil prices. (The two additional factors not related to oil prices were reduced supplies of scrap steel and aggregate.)

State DOTs also operate large fleets of vehicles for a variety of purposes. Should future oil prices rise more rapidly than gains in vehicle fuel economy, the cost of operating DOT fleets could increase as well.

A final factor of concern is the potential for continued rapid growth in trucking. This could accelerate the pace of pavement damage, in turn demanding more frequent maintenance activities for a given stretch of road.

An excerpt from the interviews:

> *". . . whether or not states can do more than maintain what they have right now is a good question."*

6.2.3 Increasing Traffic Congestion

The scenarios for passenger vehicle and truck travel allow for the possibility of zero or even negative growth for the 2040 to 2060 time frame. The reason for entertaining a potential decline in vehicle travel is to accommodate the possibility that some states, for economic or even climatic reasons, could plausibly lose population in future years. For the nation as a whole, however, and therefore for most states, both the economy and the population are expected to grow in coming decades. Even with some preliminary data suggesting shifts in mobility patterns among younger adults, growth in population and the economy are projected to result in appreciable growth in both passenger and truck VMT, albeit at less than historic rates. This could lead to much worse traffic congestion in the decades to come. Traffic congestion could be further exacerbated if states are unable, due to revenue shortfalls, to invest in new capacity where needed.

Traffic congestion is a nonlinear phenomenon. If few cars and trucks are on the road, then additional vehicle travel can be added without producing traffic congestion. If a system is already operating near capacity, in contrast, then even modest increases in vehicle travel can lead to significant increases in traffic congestion (Sorensen et al. 2008). Because the road network is heavily used in many urban and suburban areas across the country, aggregate growth in auto and truck travel tends to result in an even more rapid deterioration in travel conditions. This is reflected in Table 6.1, which compares estimated growth in vehicle travel (ORNL 2012, Table 3.7) and annual travel delays per peak-hour automotive commuter (Schrank, Eisele, and Lomax 2012, Table 9) between 1982 and 2010. Over this period, per-commuter congestion delays increased at more than twice the rate of total VMT.

Looking forward and considering plausible futures for 2050 in which auto travel could increase by as much as 80% and truck travel could increase by as much as 200%, concerns about deteriorating congestion are well-founded. With already-severe delays during peak hours in major travel corridors, however, it is worth considering just how much worse traffic could become. As it turns out, additional vehicle travel may not lead to much worse delays in the most congested corridors during peak hours. Rather, once traffic conditions are bad enough, drivers will begin to shift their trips to other times or other routes to avoid delays. This has the net effect, though, of lengthening the peak-hour period and creating traffic congestion on other links throughout the road network. In other words, in response to additional vehicle travel, traffic congestion can spread both spatially and temporally. This is reflected in Table 6.2, which shows two measures of the spread of congestion—the percentage of system lane miles subject to recurring congestion delays and the daily length of the rush-hour period—for five major metropolitan areas, as computed by the Texas Transportation Institute (TTI, undated a, b, c, d, and e) for their annual *Urban Mobility Report 2012* (Schrank, Eisele, and Lomax 2012).

As shown in the Table 6.2, the percentage of the road network subject to congestion delays has expanded considerably for all of these metropolitan areas between 1982 and 2011. While the TTI study does not provide data on the length of the rush-hour period for earlier years, the data in the table suggest that congested travel conditions have spread far beyond the typical commuting hours.

Looking forward then, for metropolitan areas already prone to severe congestion, additional automobile and truck travel could lead to the further spatial and temporal spread of congestion delays. For rapidly growing suburban and exurban areas in which traffic delays are still minor, congestion could become more problematic in future years based on additional vehicle travel. In contrast, congestion may never become a problem for rural areas not subject to significant growth pressure. Where congestion does arise or become more severe, however, the costs may be considerable. Beyond deterioration in quality of life, congestion imposes major economic costs

Table 6.1. Growth in VMT and congestion delays, 1982–2010.

Metric	1982	2010	Growth
Annual vehicle miles of travel	1.595 trillion	2.966 trillion	86%
Annual delays per peak-hour automotive commuter	13 hours	38 hours	192%

Source: Travel data from ORNL (2012, Table 3.7); delay data from Schrank, Eisele, and Lomax (2012, Table 9).

Table 6.2. Expanding congestion in select cities, 1982–2011.

Urban Area	Percentage of System Lane Miles Subject to Peak-Hour Congestion Delays			Daily Length of Congested Rush-Hour Periods
	1982	2011	Growth	2011
Atlanta	33%	59%	79%	5 hours
Chicago	36%	70%	94%	5.25 hours
Los Angeles	38%	61%	61%	8 hours
New York	41%	52%	27%	6.75 hours
Washington, D.C.	44%	69%	57%	7 hours

Source: TTI (undated a, b, c, d, and e).

related to wasted time and fuel and less efficient goods movement. Schrank, Eisele, and Lomax (2012) estimated the annual costs of congestion across 498 urban areas in the United States at $122 billion for 2011; of this amount, 22%, or $27 billion, represented delay costs for trucking operations.

An excerpt from the interviews:

> *"People will continue to drive, and DOTs will continue to have to accommodate them."*

6.2.4 Increasing Crashes and Fatalities

Another concern that arose during the state DOT interviews was that continuing growth in auto and truck travel could also increase total vehicle crashes and fatalities, undermining current state and federal efforts aimed at working toward zero deaths on the road network. It was not suggested that the crash or fatality rate (e.g., fatalities per million miles of vehicle travel) would rise, but rather that the total number of crashes could scale with total travel. Additionally, some participants speculated that higher fuel prices or increasing interest in climate mitigation could stimulate some drivers to purchase smaller vehicles, whereas efficiency measures in the trucking industry—where efficiency is measured on a ton-mile rather than a vehicle-mile basis—could lead to larger truck configurations. This could increase the severity of any crashes between trucks and passenger vehicles, negatively affecting both the rate and total number of fatalities and serious injuries on the road.

Some additional commentary on both of these issues is merited since there are subtle caveats that apply to each. Beginning with the concern relating to the potential for smaller vehicles, recent analysis indicates that it is vehicle size, rather than vehicle weight, that correlates most strongly with adverse crash outcomes (Kahane 2012). For this reason, as originally mandated in the Energy Independence and Security Act of 2007, the most recent CAFE standards (now harmonized with federal and California greenhouse gas emission standards) do not include just one standard for passenger cars and another for light trucks as in earlier decades. Rather, the standards now factor in the footprint of a vehicle as well, with higher fuel economy targets for vehicles with smaller footprints and lower targets for vehicles with larger footprints. The net effect of this shift is that auto manufacturers no longer have an incentive to build vehicles that are smaller, on average, in order to comply with the standards, as a shift to smaller vehicles triggers even more-stringent fuel economy targets. Instead, auto manufacturers will need to employ such strategies as lighter-weight materials, improved aerodynamics, engine efficiency technologies, and hybrid designs to improve the fuel economy for whatever mix of vehicle types and sizes they choose to produce.

In short, the more-stringent federal fuel economy standards scheduled through 2025 should not induce auto manufacturers to shift the composition of their offerings toward vehicles that are smaller on average simply for compliance reasons. On the other hand, it is possible that consumers—perhaps due to higher fuel prices or increased concern with climate change—could begin to choose to purchase smaller vehicles for additional fuel savings. Thus an aggregate shift toward smaller light-duty vehicles in future years remains a plausible outcome, though one that would be driven by consumer demand rather than by regulation.

Another issue that arose during the course of the study with important implications for safety is the possibility that autonomous vehicles could be developed and achieve broad adoption by 2050. Though a careful analysis of the prospects for autonomous vehicles was not included within the scope of the study, it appears that the technology, if successful, could lead to dramatic reductions in crash rates. Thus the emergence of greater highway safety challenges, though a possibility, must be viewed as quite uncertain.

An excerpt from the interviews:

> *"Cars will be more fuel-efficient but smaller, while trucks will be bigger, heavier, and longer."*

6.2.5 Difficulty Meeting Air Quality Standards

As public health scientists have learned more about the harmful effects of various air pollutants, the EPA has issued gradually more-stringent ambient air quality standards under the Clean Air Act. Lead and ozone standards, for example, were most recently updated in 2008, nitrogen dioxide and sulfur dioxide standards were updated in 2010, carbon monoxide standards were updated in 2011, and particulate matter standards were updated in 2012 (EPA 2012). This is already making it more challenging for many states to achieve attainment for certain criteria pollutants such as ozone and fine particulate matter, and the EPA could issue even more-stringent standards in the future. Some of the plausible futures outlined in this report could compound the challenges faced by states as they seek to improve air quality. Potentially contributing factors include continued reliance on petroleum for transportation fuels, a shift to certain alternative fuels (e.g., coal-generated electricity and some biofuels) that do not perform well for certain pollutants, and overall growth in passenger and truck travel. Diesel-fueled trucks are especially problematic with respect to particulate matter, and thus many goods-movement projects now appropriately include elements to help mitigate local air quality issues.

An excerpt from the interviews:

> *". . . states will play more of a role in providing for efficient goods movement and trade corridors."*

6.2.6 Increasing Pressure to Reduce Greenhouse Gas Emissions

Many states have already taken actions to reduce carbon emissions and promote the emergence of lower-carbon alternative fuels. [For a helpful enumeration of state laws and incentives relating to alternative fuels and vehicle technologies, see the EERE Alternative Fuels Data Center website (EERE 2013).] While most state actions have involved relatively uncontroversial policy mechanisms such as subsidies (e.g., rebates for electric vehicle purchases) or voluntary programs (e.g., coordinating stakeholder efforts to promote hydrogen fuel), a few states have also established more rigorous approaches such as regulatory mandates (e.g., renewable fuel standards or zero-emission vehicle mandates) and carbon cap-and-trade programs. Proposals to mitigate climate change remain controversial throughout many regions in the country, however. Taken as a whole, the collective efforts of states to date, while certainly promising, can be characterized as rather modest in comparison to the potential scale of the challenge.

Looking forward, it is plausible—perhaps due to shifting political attitudes or to a continuing increase in the frequency and severity of extreme weather events and their associated economic and environmental costs—that greater consensus around the need to take effective action to reduce greenhouse gas emissions could emerge. Should this occur, state DOTs could be asked to play an integral role in climate mitigation efforts. According to the EPA (2013), the transportation sector accounts for about 28% of greenhouse gas emissions in the United States. Any effort to achieve meaningful carbon reduction will therefore need to encompass transportation.

Greater pressure on state DOTs to mitigate climate change, should it arise, would be more intense in futures where the transportation sector has remained relatively carbon intensive. Examples include continued reliance on petroleum in combination with lower-than-anticipated fuel economy improvements, a shift to alternative fuels and feedstocks offering negligible carbon benefits, and rapid increases in passenger vehicle and truck travel. Additionally, a continuing absence of more aggressive federal policy to reduce greenhouse gas emissions (such as a national cap-and-trade program) could motivate concerned voters to press for more action at the state level.

An excerpt from the interviews:

> *". . . it is entirely appropriate for state agencies to promote and enable a shift away from gasoline . . ."*

6.2.7 Rising Demand for Alternative Travel Modes

Significant growth in demand for transit and other non-automotive modes is one of the plausible futures outlined in Chapter 5, but it can also be viewed as having a potential impact on state DOTs. While there is slack capacity in many transit systems today, very few systems could accommodate much higher levels of ridership, especially during peak commute hours. Additionally, many transit agencies are already facing considerable operating deficits and would therefore find it difficult to greatly expand service levels on an ongoing and sustainable basis. Assuming that other factors—increasing fuel costs, rising income disparities, denser land-use patterns, and more concerted steps to reduce GHG emissions, for example—combine to stimulate a significant shift to transit, biking, and walking, state DOTs may be asked to play a growing role in supporting this shift. Though these non-automotive modes have traditionally fallen within the purview of local governments, a major expansion of transit capacity and other alternatives to the automobile would almost certainly benefit from, and might require, more active planning and funding support at the state level.

An excerpt from the interviews:

> *". . . there is new interest in different modes in what has been a very highway-centric state."*

References

EERE. 2013. Federal and State Laws and Incentives. Alternative Fuels Data Center. http://www.afdc.energy.gov/laws/ (accessed April 25, 2013).

EIA. 2013. *Annual Energy Outlook 2013.*

EPA. 2012. National Ambient Air Quality Standards. http://www.epa.gov/air/criteria.html (accessed April 24, 2013).

EPA. 2013. National Greenhouse Gas Emissions Data. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html (accessed April 24, 2013).

FHWA. 2007. *Growth in Highway Construction and Maintenance Costs.* CR-2007-079.

Kahane, C. J. 2012. *Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTV – Final Report.* DOT HS 811 665. National Highway Traffic Safety Administration.

OHPI. 2011. Table FE-210: Status of the Highway Trust Fund 1957–2010. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/fe210.cfm (accessed April 22, 2013).

OHPI. 2012. Table SF-1: Revenues Used by State for Highways. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/sf1.cfm (accessed March 12, 2013).

ORNL. 2012. *Transportation Energy Data Book*, Edition 31. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Schrank, D., B. Eisele, and T. Lomax. 2012. *Urban Mobility Report 2012.* Texas Transportation Institute, the Texas A&M University System.

Sorensen, P., M. Wachs, E. Y. Min, A. Kofner, L. Ecola, M. Hanson, A. Yoh, T. Light, and J. Griffin. 2008. *Moving Los Angeles: Short-Term Policy Options for Improving Transportation.* RAND Corporation, Santa Monica, CA.

TTI. Undated a. Performance Measure Summary – Atlanta. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/ums/congestion-data/atlan.pdf (accessed April 23, 2013).

TTI. Undated b. Performance Measure Summary – Chicago IL-IN. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/ums/congestion-data/chica.pdf (accessed April 23, 2013).

TTI. Undated c. Performance Measure Summary – Los Angeles-Long Beach-Santa Ana. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/ums/congestion-data/losan.pdf (accessed April 23, 2013).

TTI. Undated d. Performance Measure Summary – New York-Newark NY-NJ-CT. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/ums/congestion-data/newyo.pdf (accessed April 23, 2013).

TTI. Undated e. Performance Measure Summary – Washington DC-VA-MD. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/ums/congestion-data/washi.pdf (accessed April 23, 2013).

CHAPTER 7

Potential Strategic Directions for State DOTs

With a clear understanding of how the plausible transportation energy scenarios could affect state DOTs (as described in the previous chapter), it becomes possible to consider different strategies that could assist states in preparing for or responding to potential changes in transportation energy use. The main goals in this chapter are to enumerate a set of potentially helpful state strategies and summarize their strengths and weaknesses in addressing transportation energy concerns. (Detailed assessments of the strategies are presented in Appendices I, J, K, L, and M.) This information provides the basis for developing, in the next chapter, a framework to help states craft robust long-range plans to address an uncertain energy future.

The chapter begins by introducing the concept of a strategic direction, which is used to group policies with broadly similar aims and approaches. The second section then enumerates, describes, and categorizes the set of strategic directions included in the analysis. The third section introduces an evaluation framework for assessing the potential benefits, risks, barriers, and costs associated with a given strategic direction, while the final section presents a series of tables that summarize the assessments for all of the strategic directions.

7.1 Defining Strategic Directions

If one were to enumerate all of the individual policies that states might consider to either (a) mitigate potential impacts on state DOTs that could arise with certain energy futures, or (b) seek to influence evolving energy sources and technologies with the aim of promoting a more sustainable energy future, the list would number in the hundreds. To make the analysis more manageable and to focus on higher-level strategies (as opposed to specific tactics) in the context of a study intended to support effective long-range planning across states facing different contextual challenges, the researchers took the approach of grouping discrete policy options (e.g., support for telecommuting) into broader strategic directions, which are also referred to as strategies (e.g., implementing more comprehensive transportation demand management programs). Each strategic direction includes a set of policies that share generally similar aims and approaches, and states interested in pursuing a given strategic direction could choose from the component policies to match their own context-specific needs.

7.1.1 Approach to Developing Strategic Directions

The first step in developing the strategic directions was to assemble the larger set of policies that states might consider. The set of potential policies included suggestions and ideas offered during the interviews with state DOT staff along with additional options identified by the research team based on its review of the relevant literature. Note that the researchers have included both policies that could be implemented directly by a state DOT (e.g., practices to foster greater cost-efficiency in DOT operations) and policies that could require enabling state legislation or the support of multiple state agencies (e.g., pricing carbon emissions to encourage a shift to lower-carbon alternative fuels).

The next step was to group the policies into broader strategic directions. In making the transition from a larger set of potential policies to a smaller set of strategic directions, the researchers sought to group policies that are broadly similar in terms of (a) the objectives that they seek to address (e.g., raising revenue) and (b) the approaches employed to support those objectives (e.g., charging system users, charging other system beneficiaries, or relying on general revenue mechanisms). The goal of applying these criteria in the process of grouping policies into strategic directions was to make it easier to evaluate the anticipated strengths and limitations of each strategic direction, with its component policies, in a more consistent fashion. That is, policies aimed at the same objectives that rely on generally similar approaches are likely to present roughly comparable strengths and limitations.

7.1.2 Assumptions for Evaluating Strategic Directions

While the policies grouped under each strategic direction were selected based on broad similarities, they are not expected to perform identically in terms of effectiveness, cost, and other criteria. Given the potential for variation in the expected performance of different policies within each strategic direction, the researchers found it helpful to establish a clear set of assumptions about the specific combination of policies that a state would choose to implement if it wished to pursue the strategic direction. For the strategic direction involving congestion pricing, for example, the analysis assumes that a state would endeavor to implement one or two priced lanes on all congested freeways and highways, in some cases requiring the conversion of general-purpose lanes to priced lanes. By laying out such assumptions, it then became possible to evaluate the expected strengths and limitations of each strategic direction in less ambiguous terms.

In establishing the assumed policies for assessing each of the strategic directions, the research team sought to integrate three considerations:

1. **Policies falling within state purview.** In determining the assumed combination of policies that a state would implement for a particular strategic direction, the team first focused on policies that could logically be implemented at the state level, or at least be strongly influenced through state funding decisions or collaborative planning efforts. For example, in the strategic direction related to land use, it was not assumed that a state would implement specific zoning policies since that falls within the general purview of local government. Rather, the assumption was that the DOT would seek a greater degree of collaboration with local agencies in achieving more integrated transportation and land use decisions, and the state would further create a system of incentives to encourage local jurisdictions to make zoning decisions consistent with regionally integrated transportation and land use plans.
2. **Cost-effective policies.** In selecting from a larger set of potential policies within each strategic direction, the research team also sought to focus on those that, based on available evidence, could be expected to provide benefits that exceed costs and would thus be viewed as worthwhile.
3. **Ambitious policies.** Finally, in cases where different policies within a strategic direction would likely vary considerably in the magnitude of their effects, it was assumed that a state would pursue a relatively ambitious subset of policies likely to offer the greatest benefits—even in cases where those policies might cost more to implement, for example, or entail greater public acceptance challenges. In other words, the assumed policies were chosen in part to help illustrate the best possible results that could be attained by a state choosing to aggressively pursue a given strategic direction.

7.1.3 Categories of Strategic Directions

After defining the strategic directions to be evaluated, they are grouped into several broader categories. The categorization has no bearing on the underlying analysis but is simply intended to help organize the presentation of the material. (Detailed discussion of the strategies is presented in Appendices I, J, K, L, and M; each of these appendices corresponds to a different category.) The five categories under which the strategic directions have been grouped are:

1. Strategies to sustain or increase revenue,
2. Strategies to reduce costs,
3. Strategies to improve automobile and truck travel,
4. Strategies to improve alternative modes of travel, and
5. Strategies to shape future energy use and technology adoption.

7.2 Strategies Considered

The strategic directions and their component policy elements for each of the five categories listed are now briefly discussed.

7.2.1 Strategies to Sustain or Increase Revenue

The first group of strategies, focused on sustaining or increasing transportation revenue, includes direct user fees, indirect marginal-cost user fees, indirect fixed-cost user fees, beneficiary fees, general revenue sources, and private capital. (The first three of these are sometimes referred to as tolls or mileage-based user fees, fuel taxes, and registration fees in the remainder of this report.) Although all of these could be effective in increasing available revenue, they differ considerably in terms of their respective advantages and disadvantages.

Direct user fees (tolls or mileage-based user fees). This strategy involves raising revenue by charging drivers for their actual use of the roadways, for example via tolls. In assessing this strategy, it is assumed that a state would implement either electronic tolling on all major routes or mileage-based user fees for passenger vehicles and would in addition establish weight-distance truck fees to collect revenue from heavy-duty commercial vehicles.

Indirect marginal-cost user fees (fuel taxes). Current excise taxes on gasoline and diesel represent the main option for collecting indirect road-use fees that vary in proportion to travel. The assumed approach under this strategy would be to implement a significant increase in per-gallon tax rates (e.g., roughly doubling the current rates). States with major port facilities might also consider levying container fees to help fund goods movement projects in the surrounding region.

Indirect fixed-cost user fees (registration fees). This approach also involves charging the users of the transportation system, but in this case the fee is a fixed amount levied on an annual basis or with the purchase of a new vehicle. The assumption under this strategy is that a state would increase existing annual vehicle registration fees. To better align the fees with anticipated system use characteristics, the fees would be structured to account for vehicle age, weight (or axle weight for trucks), and value.

Beneficiary fees. This strategic direction involves raising transportation revenue through taxes or fees levied on developers or property owners who benefit, through improved access, from investments in the transportation network. In assessing this option, it is assumed that states would seek to expand the use of tax increment financing, special assessment districts, developer impact fees, and utility fees to expand the pool of available transportation funding.

General revenue. This strategy entails raising additional transportation funds via general revenue mechanisms not directly linked to use of the transportation system. Here it is assumed that a state, depending on the general revenue mechanisms that it already employs, would seek to increase income taxes, sales taxes, or property taxes, with the incremental amount dedicated for transportation investments.

Private capital. The final revenue strategy includes options for greater reliance on private capital in funding the transportation system, with private investment to be repaid over time through the collection of tolls. The evaluation assumes the use of public–private partnerships in developing new capacity, along with the potential for privatizing existing public facilities. In the latter case, private firms would pay an up-front fee to the public sector for the right to manage and collect tolls for use of the facility over some specified period of time. It is not assumed that a state would seek to privatize the entire network of state highways, although that would also be possible in theory. Note that public–private partnerships likely have a greater role to play in financing—as opposed to funding—transportation investments, but in some cases they can be structured to bring additional revenue into the system.

7.2.2 Strategies to Reduce Costs

This grouping of strategic directions focuses on ways that state DOTs could reduce costs. The two main approaches are striving for greater efficiency and reducing the scope of DOT responsibilities. While the first of these is a laudable goal under any circumstance, the second could become essential if a state fails to find other sources of funding to offset declining fuel-tax revenue.

Greater efficiency. This strategic direction encompasses a variety of approaches that state DOTs could pursue to increase the efficiency of their investments and operations—that is, to focus on investments that will yield the greatest benefits and to reduce the life-cycle costs associated with certain construction, maintenance, and administrative activities. The assessment assumes that a state would adopt materials (e.g., synthetic building products with longer service lives) and technologies (e.g., infrastructure management systems) to lower operating costs, would contract out services to the private sector in cases where that would provide savings, and would employ such approaches as performance-based planning and performance-based budgeting to ensure that investments are achieving maximum results.

Reduced scope of responsibility. This strategy considers the possibility of a state DOT reducing its role or scope in response to a diminishing budget. It was assumed that state legislators, if faced with this requirement, would direct DOT staff to pare back programmatic responsibilities to focus mainly on highway maintenance and operations and to devolve ownership of lesser-used state routes to local jurisdictions. Very little investment in new capacity, even where justified by demand patterns, would be possible.

7.2.3 Strategies to Improve Automobile and Truck Travel

The next set of strategic directions centers on approaches to improving auto and truck travel. All of the strategies in this category aim to mitigate traffic congestion or improve safety, and many offer additional benefits related to air quality, GHG emissions, and revenue generation. By virtue of relieving traffic congestion, some of these strategies could help improve bus transit as well. The strategic directions in this category are road building, goods movement investments, congestion pricing, ITSs, transportation system management and operations (TSM&O), and traffic safety measures.

Road building. Under this strategy, a state would seek to provide new capacity as a core strategy in mitigating traffic congestion. To pursue such a strategy, most states would need to first increase available revenue. In assessing this approach, it is assumed that a state would construct additional lanes on existing routes in congested urban and suburban areas and might also construct new routes in rapidly growing exurban areas. In either case, however, the investments would only be pursued in cases where analysis indicated a favorable benefit–cost ratio.

Goods movement investments. This strategic direction includes road investments to relieve bottlenecks and increase connectivity to multimodal terminals and industrial areas, public–private investments in increased rail capacity and grade separation to facilitate an increased freight mode shift, public support for technology systems to better monitor and manage goods movement, and policies such as idle-free zones to reduce the environmental impacts of goods movement. In assessing this strategy, the researchers assumed that a state would expand its role in freight planning, engage in new partnerships and institutional arrangements, and place greater priority on freight funding. As with the previous strategy, a state would likely need to increase transportation revenue in order to pursue this strategy in a significant way.

Congestion pricing. Congestion pricing options, in which vehicles are charged higher fees during peak-hour periods to help reduce congestion, include HOT or express lanes, full-facility congestion tolls, cordon congestion tolls, network-wide congestion pricing, and variable parking pricing. The assessment assumes that states would continue the trend toward developing HOT or express lanes in the near term but ultimately would work toward the goal of providing one or two priced lanes on all congested highways, even in cases where this would require the conversion of general-purpose lanes to priced lanes. States would also provide technical assistance to local governments, as requested, in setting up other forms of congestion pricing, such as cordon tolls or variable parking prices.

Intelligent transportation systems. This strategy encompasses advanced technology applications involving vehicle-to-vehicle (V-V) and vehicle-to-infrastructure (V-I) communications to improve safety, mobility, and efficiency, as envisioned under the Research and Innovative Technology Administration's (RITA) IntelliDrive and Connected Vehicle programs. The assessment for this strategy assumes that a state would take an active role (e.g., by investing in more intelligent embedded infrastructure technologies) in promoting the emergence of V-V and V-I applications. Note that rapid private-sector innovations in autonomous vehicle technology could, with little input from the public sector beyond establishing appropriate legal and regulatory frameworks, achieve a substantial portion of the benefits envisioned for ITSs (specifically, any that would not rely on V-I communications). This creates significant uncertainty around the utility of major public investments in this area.

Transportation system management and operations. This strategy involves technical applications as well, but in this case the focus is on proven technologies such as ramp metering, signal synchronization, real-time travel information systems, variable speed limits, and incident management systems. The assessment assumes that a state would invest in upgrading older versions of these technologies where they are already being used and would invest in deploying such systems where they are not yet in use.

Traffic safety. This strategy focuses on safety improvements for vehicle travel as well as biking and walking. It encompasses roadway departure reduction measures, intersection improvements, and pedestrian and cyclist protections. Under their efforts to support the national goal of moving toward zero crash-related deaths, states already prioritize such improvements within the constraints of available revenue. In assessing this strategy, the possibility that a state would increase its current level of investment in such strategies to further accelerate deployment was considered, although this would likely require that the state first augment transportation revenue sources. It is also assumed that states would continue to implement programs to reduce distracted or impaired driving.

7.2.4 Strategies to Improve Alternative Modes of Travel

The focus of this category is on strategies to improve public transportation and other non-automotive modes of travel. Options are transportation demand management (TDM), public transportation improvements, and integrated transportation and land use.

Transportation demand management. TDM policies focus on reducing solo driving, especially for commuting, typically through support for alternatives. Policies often discussed under the category of TDM include support for ridesharing and vanpools, 4-day workweeks, telecommuting programs, bicycle and pedestrian improvements, and pay-as-you-drive insurance. In assessing this strategy, the researchers assumed that states would work with local governments and large employers to subsidize or incentivize all of these, and would also pass any needed legislation to allow insurers to offer pay-as-you-drive products.

Public transportation improvements. This strategy involves a number of policies and investments to improve the quality and quantity of both intra- and inter-urban public transportation, including revised fare structures and regional integration of payment systems, bus transit improvements, fixed-guideway (e.g., rail) transit improvements, intercity transit improvements (including high-speed rail), and greater state DOT involvement in transit planning. The assessment assumes that a state would provide technical and financial support for all of these, as appropriate and where warranted by demand, but would not generally be involved in the direct operation of transit systems (except for states in which this is already the case).

Integrated transportation and land use. This strategy aims to better align land use patterns with transportation systems. Options include prioritizing transportation funding for existing communities, creating more flexible guidelines for state roads, building infrastructure for walking and biking (encompassing the concept of complete streets), and seeking to partner with local governments in land use planning. The assessment assumes that a state would work with local jurisdictions to promote all of these options, with the general intent of achieving more compact development patterns amenable to a wider array of travel options.

7.2.5 Strategies to Shape Future Energy Use and Technology Adoption

This final category contains five strategies that states might employ with the aim of promoting greater energy efficiency and the adoption of alternative fuels within the transportation sector: pricing vehicles, pricing fuel or emissions, alternative-fuel mandates and programs, state involvement in the production and distribution of alternative fuels, and efforts to improve energy efficiency and increase the use of alternative fuels within agencies.

Pricing vehicles (vehicle feebates). Potential policy options under this strategy include offering subsidies for the purchase of high fuel-economy or alternative-fuel vehicles, assessing fees on the purchase of low fuel-economy vehicles, and implementing feebate programs under which fees on less environmentally desirable vehicles are used to fund rebates on more environmentally desirable vehicles. It was assumed that states pursuing this strategy would implement feebates that are both effective and revenue neutral.

Pricing fuel or emissions (carbon pricing). This strategy includes the options of offering subsidies for alternative fuels or charging fees on carbon emissions to create a strong financial incentive to adopt lower-carbon alternatives. It is also possible that states could adopt a feebate structure to price fuels for carbon content, although this concept has received less attention in the academic literature and policy debates. In assessing this strategy, it was assumed that a state would price carbon emissions based on either a carbon tax or a carbon cap-and-trade system.

Alternative-fuel mandates and programs. This strategy includes RFSs, LCFSs, renewable portfolio standards (RPSs) for electric power, and voluntary promotion and information campaigns. The assessment assumes that a state pursuing this strategy would implement either an RFS or an LCFS, complemented by an RPS if electric vehicles begin to gain significant market share. Voluntary campaigns to promote alternative-fuel use would also be included.

State involvement in the production and distribution of alternative fuels. Options under this strategy include the production of renewable electricity or fuels on state rights-of-way (growing biomass or installing solar photovoltaic panels along highways, for example) and the provision of financial incentives for private-sector investment in alternative refueling infrastructure. The assessment assumes that a state would pursue both of these options, preceded by a statewide renewable energy feasibility study to determine the most promising alternative energy sources on which to focus.

Improve energy efficiency and increase alternative-fuel use within agencies. Potential policies under this strategy include building or retrofitting facilities for greater energy efficiency, adopting alternative-fuel vehicles in state fleets, making use of less energy- and carbon-intensive construction materials and practices, and setting up programs to reduce travel for state employees. The assessment assumes that a state interested in this strategy would adopt all of these policies across all state agencies, as applicable.

7.3 Framework for Assessing Strategies

After defining the strategic directions, it was necessary to construct a framework for evaluating their strengths and limitations. To support robust decision making in a study intended to inform long-range planning across diverse states, the framework needed to provide insight on how effectively the strategy could address its core aims, which might be to mitigate the negative impacts on state DOTs that could result from certain plausible energy futures or to enhance the prospects for transitioning to a more sustainable energy future. The framework also needed to provide insights on the potential advantages or disadvantages of pursuing a strategy if it proved to not be needed, on the amount of lead time required to implement a strategy and realize its benefits, and on the applicability of the strategy across states within differing contexts.

To address such questions, the research team organized a specific set of criteria using six categories: the effects on mitigating specific impacts associated with certain transportation energy futures; the effects on promoting a more sustainable transportation energy future; broader effects on the economy, on the environment and public health, and on equity; potential implementation barriers; required lead time; and qualifications relating to the applicability of strategies in different states. The research team also constructed a qualitative rating system to characterize the expected performance of a given strategy for each of the relevant criteria. For example, a strategy might be rated as highly effective at reducing DOT costs or as moderately negative in terms of expected effects on equity concerns.

While the ratings for each of the strategies draw upon available evidence from the research literature, they are ultimately subjective in nature and in some cases must rely on principled reasoning. Therefore, multiple members of the research team reviewed all of the ratings for all of the strategies with the intent of ensuring that the rating system was being reasonably and consistently applied by the individual authors who drafted each strategy assessment. In cases where there was insufficient or conflicting evidence in the literature, or if the expected results could vary by implementation choices or local context, the ratings have been characterized as uncertain.

The remainder of this section discusses the specific criteria included within each of the groupings in the evaluation framework, the motivation for including the criteria, and the possible ratings applied to the criteria within each grouping.

Mitigation effects. The first grouping of performance criteria focuses on the ability of strategies to mitigate the potential challenges for state DOTs associated with certain energy futures. Following the discussion of potential impacts presented in Chapter 6, the specific mitigation goals were stabilizing or increasing transportation revenue, reducing state DOT costs, reducing traffic congestion, improving safety, improving air quality, reducing greenhouse gas emissions, and improving alternative travel modes. Possible ratings were "highly effective," "moderately effective," and "not applicable." (Note that in the detailed assessments presented in Appendices I, J, K, L, and M as well as in the summary tables at the end of this chapter, the absence of a rating for a given strategy and criterion implies a rating of not applicable.)

Shaping effects. The next grouping focuses on the potential effects of a strategy in shaping or promoting a more sustainable energy future for states interested in this aim. Three criteria are considered: reducing oil consumption, promoting the adoption of lower-carbon alternative fuels, and reducing the energy cost of travel. These align, roughly, with the policy goals of enhancing energy security, mitigating climate change, and ensuring affordable travel options. For each of these criteria, strategies can again be rated as highly effective, moderately effective, or not applicable.

Effects on the economy, the environment and public health, and equity. To gain a richer understanding of the potential benefits and liabilities of each strategy, the research team also considered their expected performance in the context of broader social goals, including effects on promoting economic efficiency and growth, improving the environment and public health, and supporting greater equity. Note that environment and public health were grouped as a single criterion given the significant overlap in mutually relevant outcomes. For example, air quality improvements are beneficial to public health and to a healthier environment; likewise, strategies that reduce vehicle travel and promote an increase in biking and walking should have benefits for both the environment (reduced GHG emissions) and public health (more exercise, and assuming that appropriate care is devoted to ensuring safe conditions for walking and biking). In contrast to the ratings for shaping and mitigation effects, which are either positive in nature or not applicable, the ratings for the criteria in this grouping can be either positive or negative. In other words, they could represent additional benefits of pursuing a given strategy beyond the intended mitigation or shaping effects, or they could represent potential reasons not to pursue a strategy despite the potential shaping or mitigation effects. The specific ratings are "highly positive," "moderately positive," "neutral," "moderately negative," and "highly negative."

Potential barriers. The next grouping of criteria focuses on potential impediments that might deter states from pursuing a given strategy. These include public acceptance, financial cost, technical risk, the possible need for enabling legislation, and the possible need for institutional restructuring. Note that these criteria (with the possible exception of financial cost and technical risk) do not necessarily represent strong policy reasons for not pursuing a strategy; rather, as a group they are mainly intended to reflect the degree of difficulty in successfully implementing the strategy. There are three possible ratings for these criteria: significant barrier, moderate barrier, and not applicable. Note that with respect to the question of enabling legislation, any strategy likely to require federal legislative action is rated as facing a significant barrier. If state legislation would be sufficient, then the barrier is simply rated as moderate. (There may still be significant public acceptance barriers to overcome before state legislation would be possible, but that is reflected separately in the public acceptance criterion.)

Required lead time. This criterion indicates the expected time required, once political agreement has been achieved, to implement the strategy and realize intended benefits. Estimating the lead time is useful in determining whether a strategy might be deployed adaptively in later years on an as-needed basis (i.e., whether it would be possible to wait until there is clearer information about how the future is unfolding and then trigger the strategy only when it becomes clear that it will indeed be helpful). Possible ratings for lead time are "immediate" (interpreted as within a single year), 1 to 5 years, 5 to 10 years, 10 to 20 years, and more than 20 years.

Qualifications. This last criterion simply offers the opportunity to note whether the strategy in question would be more applicable in some states than in others. Congestion pricing, for example, would not be particularly helpful in largely rural states in which traffic congestion is not expected to be a major issue of concern any time soon. Some of the more common differentiations considered for this criterion include largely rural states versus states with major metropolitan areas, states with rapidly growing populations versus states with stagnant population growth, and states with major ports or trade corridors versus states with comparatively less goods-movement activity.

As indicated in the preceding discussion, the criteria included in the evaluation framework can serve several different roles in the analysis. These include characterizing the potential advantages of pursuing a strategy, highlighting the drawbacks or hurdles associated with a strategy, understanding whether a strategy might be deferred until there is better evidence that it will be useful, and clarifying the potential applicability of a strategy in different state contexts. These are summarized in Table 7.1.

7.4 Summary of Strategy Assessments

Tables 7.2 through 7.7 summarize the ratings for all of the strategies and evaluation criteria considered. Mitigation effects are presented in Tables 7.2 and 7.3; shaping effects

Table 7.1. Elements of the framework for evaluating strategies.

Evaluation Criteria	Reasons to Pursue Strategy	Reasons Not to Pursue Strategy	Possible to Defer Decision	Applicability of Strategy Across States
Mitigation effects	●			
Shaping effects	●			
Effects on the economy, the environment and public health, and equity	●	●		
Potential barriers		●		
Required lead time			●	
Qualifications				●

Table 7.2. Assessment of strategic directions: possible mitigation effects (part 1).

Strategic Direction	Providing More Revenue	Reducing DOT Costs	Reducing Traffic Congestion	Improving Safety Outcomes
Strategies to Sustain or Increase Revenue				
Tolls or mileage-based user fees	↑↑	↑↑	↑	↑
Fuel taxes	▨	↑	↑	↑
Registration fees	↑↑	↑	▨	▨
Beneficiary fees	▨			
General revenue sources	↑↑			
Increased use of private capital	▨	▨	▨	
Strategies to Reduce Costs				
Greater efficiency		↑		
Reduced scope of responsibility		↑↑		
Strategies to Improve Auto and Truck Travel				
Road expansion			↑	
Goods movement			↑	↑
Congestion pricing	↑↑	↑↑	↑↑	▨
ITSs			↑	↑↑
TSM&O			↑	↑
Traffic safety			↑	↑↑
Strategies to Improve Alternative Travel Modes				
TDM			↑	▨
Public transportation			↑	↑
Land use		↑↑		▨
Strategies to Promote Energy Efficiency and Alternative Fuels				
Vehicle feebates				
Carbon pricing	▨	↑	↑	↑
Fuel mandates and programs				
Fuel production and distribution	▨	▨		
Agency energy use		↑		

Key: ↑↑ = Highly Effective ↑ = Moderately Effective
Blank = Not Applicable ▨ Shaded = Uncertain

Table 7.3. Assessment of strategic directions: possible mitigation effects (part 2).

Strategic Direction	Improving Air Quality	Reducing GHG Emissions	Enhancing Non-Automotive Travel Options
Strategies to Sustain or Increase Revenue			
Tolls or mileage-based user fees			
Fuel taxes	↑	↑↑	
Registration fees			
Beneficiary fees			
General revenue sources			
Increased use of private capital			
Strategies to Reduce Costs			
Greater efficiency			
Reduced scope of responsibility			
Strategies to Improve Auto and Truck Travel			
Road expansion			
Goods movement	↑		
Congestion pricing	▨ ↑	▨ ↑	▨ ↑↑
ITSs	▨ ↑	▨ ↑	↑
TSM&O	▨ ↑	▨ ↑	↑
Traffic safety			↑
Strategies to Improve Alternative Travel Modes			
TDM	↑	↑	↑↑
Public transportation	↑	↑	↑↑
Land use	▨ ↑	▨ ↑	↑↑
Strategies to Promote Energy Efficiency and Alternative Fuels			
Vehicle feebates	▨ ↑	↑↑	
Carbon pricing	▨ ↑↑	↑↑	
Fuel mandates and programs	▨ ↑	▨ ↑↑	
Fuel production and distribution	▨ ↑	▨ ↑	
Agency energy use	↑	↑	

Key:

↑↑ = Highly Effective	↑ = Moderately Effective
Blank = Not Applicable	▨ Shaded = Uncertain

Table 7.4. Assessment of strategic directions: possible shaping effects.

Strategic Direction	Reducing Oil Consumption	Increasing Use of Lower-Carbon Alternative Fuels	Reducing Energy Cost of Travel
Strategies to Sustain or Increase Revenue			
Tolls or mileage-based user fees			
Fuel taxes	↑	▨ ↑	
Registration fees			
Beneficiary fees			
General revenue sources			
Increased use of private capital			
Strategies to Reduce Costs			
Greater efficiency			
Reduced scope of responsibility			
Strategies to Improve Auto and Truck Travel			
Road expansion			
Goods movement			
Congestion pricing	▨ ↑		↑
ITSs	▨ ↑		↑
TSM&O	▨ ↑		↑
Traffic safety			
Strategies to Improve Alternative Travel Modes			
TDM	↑		
Public transportation	↑		
Land use	▨ ↑		
Strategies to Promote Energy Efficiency and Alternative Fuels			
Vehicle feebates	↑↑	▨ ↑↑	↑↑
Carbon pricing	↑	▨ ↑	
Fuel mandates and programs	▨ ↑↑	▨ ↑↑	
Fuel production and distribution	▨ ↑	▨ ↑	
Agency energy use	↑	↑	

Key:

↑↑ = Highly Effective	↑ = Moderately Effective
Blank = Not Applicable	▨ Shaded = Uncertain

Table 7.5. Assessment of strategic directions: other general effects.

Strategic Direction	Economy	Environment and Public Health	Equity
Strategies to Sustain or Increase Revenue			
Tolls or mileage-based user fees	↑↑	▨ ↑	↑↑
Fuel taxes	↑↑	↑↑	▨ ↑
Registration fees	↑	▨ ○	↑
Beneficiary fees	↑↑	▨ ○	↑
General revenue sources	▨ ↓	↓	↓
Increased use of private capital	▨ ↑	○	▨ ○
Strategies to Reduce Costs			
Greater efficiency	▨ ↑	▨ ○	↓
Reduced scope of responsibility	▨ ↓	▨ ○	↓
Strategies to Improve Auto and Truck Travel			
Road expansion	↑	↓	↓
Goods movement	↑↑	▨ ↑	▨ ○
Congestion pricing	↑↑	▨ ↑	↑
ITSs	↑↑	↑	▨ ○
TSM&O	↑	▨ ↑	○
Traffic safety	↑↑	↑↑	▨ ↑
Strategies to Improve Alternative Travel Modes			
TDM	○	↑↑	↑
Public transportation	▨ ○	↑	↑↑
Land use	▨ ○	↑↑	▨ ○
Strategies to Promote Energy Efficiency and Alternative Fuels			
Vehicle feebates	▨ ↑	▨ ↑	↑
Carbon pricing	▨ ↑	▨ ↑↑	▨ ↓
Fuel mandates and programs	▨ ○	▨ ↑	▨ ↓
Fuel production and distribution	▨ ↑	▨ ↑	○
Agency energy use	○	↑	○

Key:			
	↑↑ = Highly Positive	↑ = Moderately Positive	○ = Neutral
	↓↓ = Highly Negative	↓ = Moderately Negative	▨ Shaded = Uncertain

Table 7.6. Assessment of strategic directions: potential barriers.

Strategic Direction	Public Support	Financial Cost	Technical Risk	Enabling Legislation	Institutional Restructuring
Strategies to Sustain or Increase Revenue					
Tolls or mileage-based user fees	↓↓		↓	↓↓	
Fuel taxes	▨ ↓			↓	
Registration fees	▨ ↓			↓	
Beneficiary fees			↓	↓	↓
General revenue sources	↓			↓	
Increased use of private capital	▨ ↓		▨ ↓	▨ ↓	▨ ↓
Strategies to Reduce Costs					
Greater efficiency		↓		▨ ↓	▨ ↓
Reduced scope of responsibility	▨ ↓↓			▨ ↓	↓
Strategies to Improve Auto and Truck Travel					
Road expansion	↓	↓↓			
Goods movement		↓↓			↓
Congestion pricing	↓↓		▨ ↓	↓↓	▨ ↓
ITSs	↓	↓↓	↓↓	▨ ↓↓	↓↓
TSM&O		↓	↓	↓	↓
Traffic safety		↓			
Strategies to Improve Alternative Travel Modes					
TDM		↓		▨ ↓	▨ ↓
Public transportation		↓↓		▨ ↓	▨ ↓
Land use	↓			▨ ↓	▨ ↓
Strategies to Promote Energy Efficiency and Alternative Fuels					
Vehicle feebates	↓			↓	
Carbon pricing	↓↓			↓	
Fuel mandates and programs	↓	↓	↓↓	↓	
Fuel production and distribution		↓	↓	▨ ↓	↓
Agency energy use		↓	↓		

Key:

↓↓ = Significant Barrier	↓ = Moderate Barrier
Blank = Not Applicable	▨ Shaded = Uncertain

Table 7.7. Assessment of strategic directions: lead time and qualifications.

Strategic Direction	Lead Time	Qualifications
Strategies to Sustain or Increase Revenue		
Tolls or mileage-based user fees	5–10 years	
Fuel taxes	Immediate	
Registration fees	Immediate	
Beneficiary fees	5–10 years	Best in states with strong growth
General revenue sources	Immediate	
Increased use of private capital	5–10 years	Best in states with strong growth
Strategies to Reduce Costs		
Greater efficiency	5–10 years	
Reduced scope of responsibility	5–10 years	
Strategies to Improve Auto and Truck Travel		
Road expansion	10–20 years	Best in states with strong growth
Goods movement	10–20 years	Best in states with large ports or trade corridors
Congestion pricing	1–5 years	Best in states with large urban areas
ITSs	>20 years	
TSM&O	1–5 years	Best in states with large urban areas
Traffic safety	1–5 years	
Strategies to Improve Alternative Travel Modes		
TDM	1–5 years	
Public transportation	5–10 years	Best in states with large urban areas
Land use	>20 years	Best in states with strong growth
Strategies to Promote Energy Efficiency and Alternative Fuels		
Vehicle feebates	1–5 years	
Carbon pricing	1–5 years	
Fuel mandates and programs	1–5 years	Form of mandate varies by state
Fuel production and distribution	5–10 years	Best fuel choice could vary by state
Agency energy use	5–10 years	

are presented in Table 7.4; anticipated effects on economy, environment and public health, and equity are presented in Table 7.5; barriers are summarized in Table 7.6; and required lead time and any caveats are presented in Table 7.7. In the tables, black upward arrows indicate a strength or benefit (with a double arrow indicating a stronger effect), gray downward arrows indicate a liability or obstacle, a hollow circle indicates a neutral rating, the absence of an entry indicates not applicable, and light gray shading in the background indicates some uncertainty regarding the rating. Discussions of the analysis supporting the strategy ratings are presented in Appendices I, J, K, L, and M.

CHAPTER 8

Framework for Robust Long-Term Plans

Based on the background research conducted for this study, Chapter 5 described plausible transportation energy futures for the 2040 to 2060 time frame. Chapter 6 then discussed potential challenges for state DOTs that could emerge or intensify with some of the plausible futures. This led to the identification and development of a series of strategies, presented in Chapter 7, that could help states mitigate specific impacts associated with certain plausible transportation energy futures or promote a more sustainable energy future. Chapter 7 also summarized strengths and limitations of the strategies based on more detailed analysis in Appendices I, J, K, L, and M.

The preceding analysis sets the stage for developing, in this chapter, a framework to help state DOTs craft robust long-term plans to address an uncertain energy future. Given that some of the challenges for state DOTs identified in Chapter 6 could occur with certain plausible futures but not others, the framework begins by considering the broad question of whether and when to pursue strategies with the aim of mitigating potential impacts or shaping a more desirable energy future. The logic rests on the principles of robust decision making, a methodology for effective long-term planning in the face of deep uncertainty (Lempert, Popper, and Bankes 2003). RDM recognizes that it can be helpful, where possible, to defer certain policy decisions until more information about how the future is unfolding becomes available.

The framework also examines which strategies appear to offer the greatest prospects for mitigating certain impacts or for influencing evolving transportation energy use patterns. This component of the analysis involves comparing the relative strengths and limitations of the various strategies for different objectives of interest and considering how some of the strategies might complement one another or instead be largely redundant.

The next section of this chapter describes in greater detail the methodology employed by the research team in creating a framework to help state DOTs develop robust long-term plans. The next six sections then consider, in sequence, potential roles and timing for different strategies to stabilize or enhance revenue and reduce costs, to reduce traffic congestion, to improve traffic safety, to mitigate air pollutants and GHG emissions, to respond to increased demand for non-automotive travel modes, and to shape a more sustainable energy future. The final section integrates the results across the mitigation and shaping goals for a more comprehensive view of the robust planning framework. After outlining the general framework, Chapter 9 offers suggestions for how states might tailor some of the included strategies to meet their own specific needs.

8.1 Developing the Framework for Robust Long-Term Plans

This section begins by discussing how the principles of RDM can provide insight into whether and when to pursue strategies with the aim of mitigating potential impacts or shaping future energy-use patterns. In the context of an uncertain future, the basic intent of RDM analysis is to minimize the prospects for regret—that is, the chances of investing in a strategy that proves not to be needed given how the future unfolds, or alternatively, of failing to implement a strategy that would have been very helpful. The discussion then outlines the logic for determining the most promising set of strategies, from among a broader set of potential options, to use to address each of the mitigation and shaping objectives. This analysis draws on the assessment of strategy strengths and limitations summarized in the preceding chapter.

8.1.1 Determining the Time Frame for Implementing Strategies

Planning approaches that involve identifying the most likely future trends and then optimizing policy choices accordingly may perform poorly if the future evolves in an unexpected direction. To avoid this pitfall, RDM considers a wide array of plausible futures and then shifts the focus from developing optimal plans to identifying robust plans—that is, policy choices that can be expected to perform at least reasonably well regardless of how the future unfolds. Key RDM constructs aimed at facilitating more robust plans are:

- **Shaping strategies.** Actions intended to increase or decrease the likelihood of certain plausible futures unfolding.
- **Mitigation strategies.** Actions intended to mitigate the negative impacts that could result from certain plausible futures.
- **Adaptive strategies.** Actions that can be triggered by, or evolve in response to, new information about how the future is unfolding.
- **Hedging strategies.** Actions that, to be effective, must be implemented in the near term, even though there is some uncertainty as to whether the future will unfold in such a way that the actions prove to be valuable.
- **Signposts.** New information showing that a given future is either more or less likely, which may trigger the activation of an adaptive strategy.

As suggested by this terminology, RDM is concerned with both the appropriate timing for policies and the degree of risk associated with taking action. A primary objective is to distinguish between actions that are worth pursuing in the near term and actions that can safely be deferred until more information about the future becomes available. The intent is to prepare adequately for the future while preserving as much flexibility as possible for planners in the future.

In assessing candidate strategies aimed at mitigating some of the negative impacts associated with certain futures, the first question to consider is whether a strategy performs well, or at least benignly, across the full range of plausible futures. If so, then the strategy can be described as robust and appropriate for near-term action with little chance of regret.

If the strategy would be advantageous in some futures but a source of regret in others (for example, if the strategy required significant investment but proved to be largely unnecessary), then the next question to consider is whether it would be possible to defer action until more information about how the future is unfolding becomes available. Actions in this category, described as deferred or adaptive strategies, are triggered when signposts indicate an increasing likelihood that they will be helpful or necessary. In order to safely defer an action with little risk of regret, two criteria must be met. First, there must be one or more signposts capable of providing reliable indication that the future is indeed unfolding in such a manner that the strategy is likely to prove valuable. Second, the signpost(s) must offer sufficient lead time so that the action can be implemented and yield the intended effects within an acceptable time frame.

In practice, these conditions are not always met. While a given strategy may be helpful in some futures and unnecessary or even counterproductive in others, a lack of reliable signposts or a particularly long required lead time could prevent the ability to safely defer action. Such conditions make it necessary to choose whether to implement the strategy in the near term as a hedge against certain futures that may or may not unfold. This choice entails irreducible risk, posing a trade-off between the benefits of the strategy if the future unfolds in one direction and the costs or regrets associated with the strategy if the future unfolds in a different direction.

Shaping strategies—that is, strategies intended to increase the likelihood of desirable futures or reduce the likelihood of undesirable futures—also entail a higher degree of risk and discretionary judgment. To begin with, implementing a shaping action may fail to achieve the intended outcomes. For example, early state investment in alternative-fuel fleet vehicles could fail to stimulate adoption among the broader population. At the other end of the spectrum, it is possible that the desired future conditions would have been achieved even if the shaping strategy had not been implemented. Breakthroughs in battery technology, for instance, might set the stage for broad adoption of electric vehicles even without state support for publicly accessible charging infrastructure. In short, shaping strategies carry the risk of being either ineffective or superfluous. Additionally, shaping actions aimed at promoting a more sustainable energy future may well accelerate other challenges for state DOTs, such as reduced fuel-tax revenue.

Figure 8.1 presents the logic flow for applying RDM principles to distinguish between robust mitigation strategies that can be advised for near-term implementation with a low degree of risk, mitigation strategies that can be safely deferred and triggered adaptively in response to signposts with a low degree of risk, and hedging and shaping strategies that should be implemented in the near term if they are to be helpful at all, though doing so entails greater risk.

8.1.2 Prioritizing Strategies for Specific Objectives

For any of the possible mitigation or shaping objectives, there are multiple strategies that DOTs might consider pursuing. To address traffic congestion, for example, options include new road capacity, improvements focused on more efficient goods movement, congestion pricing, intelligent transportation systems investment, transportation system management and operations practices, transportation demand management, and transit investment. In addition to considering the appropriate timing of strategies for different objectives based on RDM principles, as described previously, the analysis also examined the question of which combination of strategies offers the greatest promise for each of the objectives. Drawing

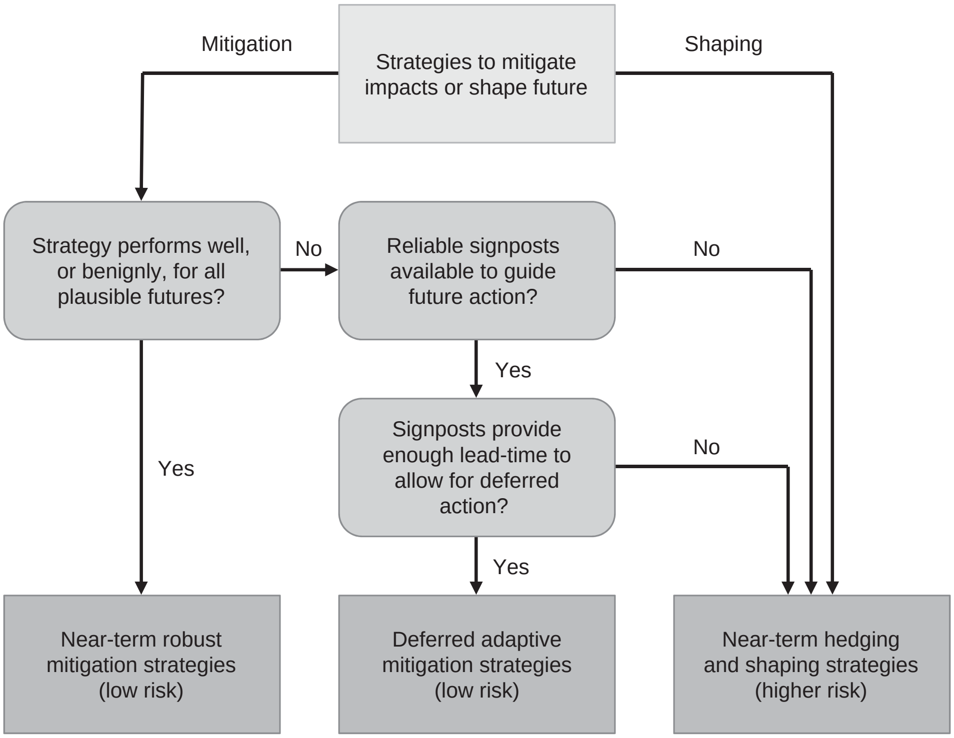


Figure 8.1. Logic for application of RDM principles.

on the assessment of the specific strengths and limitations of the possible strategies, as summarized in the preceding chapter, this stage of the analysis involved two steps: (1) identifying candidate strategies for each objective, and (2) ranking the strategies for each objective.

Identifying candidate strategies for each objective. As described in the previous chapter, the strategies examined in this study have been grouped into categories for organizational convenience—specifically, stabilizing or raising revenue, reducing DOT costs, improving auto and truck travel, improving alternative modes of transportation, and promoting energy efficiency and alternative fuels. Many of the strategies, however, could play a role in addressing multiple mitigation or shaping objectives. For instance, congestion pricing could help reduce traffic congestion, reduce emissions, raise revenue, and reduce DOT costs (by allowing greater throughput on existing lanes and, in turn, reducing the need for new capacity investment). It was therefore helpful to begin by identifying the specific set of candidate strategies that states might consider for each of the possible objectives. In making this determination, the research team focused on strategies that could play a role in addressing a given objective and would also be viewed by states as logical choices for the objective in question.

- **Relevance of strategies for each objective.** In the assessment of the individual strategies considered in this study, among the factors included was the potential effectiveness in addressing each of the mitigation and shaping objectives. Possible ratings, as shown in the summary tables in the previous chapter, included highly effective, moderately effective, and not applicable. As the first pass in identifying the set of candidate strategies for each of the objectives, the research team included only those strategies rated as moderately effective or highly effective for the objective in question; strategies rated as not applicable for the objective were omitted from further consideration.
- **Determining logical candidate strategies for each objective.** To further pare the number of candidate strategies for each of the objectives, the research team next considered whether a given objective—for example, raising revenue or reducing traffic—would be viewed by states as one of the primary motivating factors for implementing each of the potentially relevant strategies. As an example, increasing fuel-tax rates, by increasing the overall cost of travel, should have a modest effect on reducing travel and in turn traffic congestion. If a state chose to increase fuel-tax rates, however, the main motivation would almost certainly be to increase transportation funding; absent revenue shortfalls, states would be unlikely to increase fuel taxes for the purpose of reducing traffic. Within this analysis, then, the strategy of increasing or indexing fuel-tax rates would be viewed as a candidate for stabilizing or increasing revenue but would not be selected as a candidate strategy for reducing traffic.

Ranking the strategies for each objective. After identifying candidate strategies for the different mitigation and shaping objectives, the research team sought to determine the most promising combination of strategies for each objective from among the broader set of options offering at least some merit. This involved the development and application of a relative ranking system based on the assessed strengths and drawbacks for each of the candidate strategies.

As suggested in the discussion of the strategy assessments in the prior chapter, strengths include effectiveness in addressing the specific objective of interest—for example, improving traffic safety outcomes—along with general benefits relating to the economy, environment and public health, and equity. Drawbacks typically involve barriers related to public acceptance, financial cost, technical risk, required legislation, and the possible need for institutional restructuring. Through comparison of strengths and limitations, candidate strategies for each objective were grouped into three relative priority rankings:

1. **Most-promising strategies.** This ranking includes at least one strategy assessed as highly effective in addressing the specific objective in question, though the strategy may face high barriers as well. Congestion pricing, for example, is ranked as a most-promising strategy for reducing traffic congestion even though low public support remains a major barrier. Also included in this grouping are strategies that present a favorable relationship between assessed strengths and drawbacks (i.e., significant strengths—possibly relating to broader effects on the economy, environment and public health, and equity—and only modest barriers) that should complement the most effective strategies. For the goal of stabilizing or increasing revenue, for example, beneficiary fees could complement user fees—fuel taxes, tolls, mileage-based user fees, or registration fees—by broadening the tax base in an equitable manner to include additional parties who benefit from transportation investments.
2. **Optional strategies.** This next ranking applies to strategies that could also be helpful in addressing the objective but present less clear-cut trade-offs between strengths and weaknesses. Some offer significant strengths but also face major drawbacks; others present more moderate barriers but offer only modest benefits in return. Given these trade-offs, a decision to pursue any of the optional strategies will require a greater degree of discretionary judgment from policy makers. In the analysis that follows, the strategies with this ranking are divided into two groups: higher-impact optional strategies (higher benefits and barriers) and lower-impact optional strategies (lower benefits and barriers).
3. **Fallback strategies.** This final ranking applies to strategies that are generally redundant to the most-promising strategies and do not perform as well for most policy goals of interest. For example, funding highways from general revenue is rated as a fallback alternative to various forms of user fees. Note that some of the strategies ranked in this grouping may not be viewed as desirable outcomes but rather would be the logical result of failing to take other policy action. Failure to increase sources of transportation funding, for example, could make it necessary for states to reduce the scope of DOT roles and responsibilities.

Sequence of analysis. In the remainder of this chapter, strategy ratings are discussed for addressing the various mitigation and shaping goals of interest. Because of the strong degree of overlap in relevant strategies, the analyses for some of the objectives are folded together (combining, for example, strategies to address revenue and cost concerns). The sequence of analysis for the various objectives is as follows:

1. Mitigation strategies for increasing revenue and reducing costs.
2. Mitigation strategies for reducing traffic congestion.
3. Mitigation strategies for improving safety outcomes.
4. Mitigation strategies for reducing air pollutant and greenhouse gas emissions.
5. Mitigation strategies for improving alternative travel modes.
6. Shaping strategies for future energy use and technology adoption.

Note, finally, that the ratings applied to a given strategy may be different depending on the objective in question. For example, increasing fuel taxes could be rated as advisable in the near term to increase transportation revenue and as a potentially deferred strategy for reducing greenhouse gas emissions in states where that goal is not currently prioritized but could become so in the future. A state that chooses not to implement a particular strategy for one objective might subsequently choose to do so for another. After rating strategies in the context of specific objectives, it is possible to combine the results to form an integrative, robust planning framework for addressing the multiple mitigation and shaping goals of interest in this study. This integration is presented at the end of the chapter.

8.2 Strategies to Mitigate Revenue and Cost Impacts

First, potential strategies are considered for stabilizing or increasing revenue and reducing DOT costs. Declining fuel-tax revenue is viewed as highly problematic under all of the plausible futures outlined in this report, whether resulting from significant improvements in fuel economy for conventional vehicles or from a shift to alternative fuels. In contrast, increasing DOT costs based on higher oil prices is a less certain outcome. Even if oil prices do not rise significantly, it seems unlikely that state DOTs would regret having taken action to reduce costs, especially those actions focused on increased efficiency. Strategies aimed at stabilizing or increasing revenue and reducing costs can thus be characterized as robust strategies for near-term action with considerable benefits and little risk. The main analysis tasks, then, are to identify an appropriate set of candidate strategies and, based on their strengths and limitations, distinguish between most promising, optional, and fallback strategies.

Strategies considered in this study that could have some effect on raising revenue or reducing costs were direct user fees (tolling or MBUFs), indirect marginal-cost user fees (fuel taxes), indirect fixed-cost user fees (registration fees), beneficiary fees, general revenue, private capital, increased cost-efficiency, reduced scope of DOT responsibility, congestion pricing, land use, pricing fuel or emissions (carbon pricing), state production and distribution of alternative fuels, and agency energy efficiency and adoption of alternative fuels. Of these, the production and distribution of alternative fuels by states were judged as being not highly relevant for revenue and cost concerns; this strategy, if adopted, would likely have different objectives.

Table 8.1 summarizes the potential strengths and limitations of the remaining candidate strategies under consideration for raising revenue and reducing costs, along with the relative rankings for these goals. The organization of this table, and of similar tables for other objectives presented later, is that strategies are listed in the left column and grouped by ranking—most promising, optional with higher benefits and higher barriers, optional with lower benefits and lower barriers, and fallback. The logic for the rankings is described later in the discussion of the tables.

The next two columns indicate whether the strategy should have strong effects in the specific objectives of interest—in this case, raising revenue or reducing costs. Any strategy that is rated as highly effective for one of these goals is marked with a bullet in the corresponding column. Strategies without a bullet are at most moderately effective in addressing these goals.

The next column, "Strong E/EPH/E Effects," indicates expected performance on the more general goals of economy, environment and public health, and equity. Here a bullet indicates that the strategy has a highly positive effect for at least one of these goals, while the absence of a bullet indicates at best moderately positive performance.

The final column concerns the barriers associated with each of the strategies, including financial cost, low public support, technical risk, required legislation, and institutional restructuring. In this column, a bullet indicates that there are no significant barriers for the strategy. The absence of a bullet, in contrast, indicates that the strategy faces one or more major barriers.

In summary, bullets across the columns denote the most desirable attributes—strong effects for applicable policy goals

Table 8.1. Ranking strategies to raise revenue and reduce costs.

Strategies	Strong Revenue Effects	Strong Cost Effects	Strong E/EPH/E Effects	Low Barriers
Most-promising strategies				
Fuel taxes	●		●	●
Tolling or MBUFs	●	●	●	
Registration fees	●			●
Beneficiary fees			●	●
Greater efficiency				●
Land use		●	●	●
Higher-impact optional strategies				
Congestion pricing	●	●	●	
Carbon pricing			●	
Lower-impact optional strategies				
Private capital				●
Agency energy use				●
Fallback strategies				
General revenue sources	●			●
Reduced scope of responsibility		●		

Note: E/EPH/E = economy, environment and public health, and equity.

and low barriers—and the presence or absence of these bullets can be used to clarify the relative attractiveness of the options. Strategies that have bullets across all of the columns can be viewed as highly desirable. Strategies that only have bullets under the effects columns, in contrast, could offer significant benefits but also face higher barriers. Next, strategies that only have bullets in the last column would present relatively little downside, but also would offer only modest potential rewards. Finally, strategies without any bullets in any of the columns are not generally advised because they face high barriers but offer limited positive effects in return. This does not happen to be the case for any of the revenue and cost strategies discussed here, but it does occur for some strategies aimed at other objectives in later sections of the analysis.

Based on the summary ratings in Table 8.1 and drawing upon more detailed findings from the strategy assessments in Appendices I through M, the logic for the relative rankings of these strategies is as follows:

- **Most-promising strategies.** User fees are highly desirable in terms of promoting efficient use of the transportation system and apportioning cost in a fair manner. Fuel taxes perform reasonably well in this regard and will remain a viable funding mechanism as long as cars and trucks rely primarily on liquid fuels—gasoline, diesel, ethanol, renewable diesel, and the like—distributed by wholesalers and dispensed at refueling stations. In the near term, then, a promising approach would be to increase or index existing fuel taxes to keep pace with inflation and improved vehicle fuel economy, adding in taxes for alternative liquid fuels as needed. At the same time, states might begin to plan for a potential transition to tolling or MBUFs, including weight-distance truck tolls, over the longer term. Such direct user fees are able to apportion the tax burden based on road use with even greater precision, and they would offer a more stable revenue source should other alternative fuels such as electricity, hydrogen, or natural gas (all of which potentially allow for at-home refueling) begin to gain significant market share. As an alternative to tolls or mileage fees, states could consider higher registration fees to account for alternative-fuel vehicles, although this approach does not perform quite as well in terms of promoting efficient system use.

  Fuel taxes, tolls, mileage fees, or registration fees could be augmented by container fees in states with major ports to fund multimodal freight investments, although it would be advisable to first conduct an analysis to determine whether such fees would induce shippers to shift to competing ports in other states. (Container fees are not listed in Table 8.1 but are included in the same strategy—indirect, marginal-cost user fees—as fuel taxes.) Beneficiary fees, which would spread the revenue base among other stakeholders who derive value from transportation improvements in an equitable manner, offer another complementary strategy. Policies to improve the efficiency of state DOT operations are likewise generally advisable, though care should be taken to mitigate any equity concerns associated with certain efficiency options (most notably the loss of employee benefits that can occur with some outsourcing decisions). Better integration between land use and transportation could also help reduce costs over the long term.
- **Higher-impact optional strategies.** Congestion pricing is rated as highly effective for raising revenue and reducing costs, and it also offers strong performance for the broader social goal of economic efficiency. At the same time, it faces significant public acceptance challenges. Given the availability of other effective strategies aimed more specifically at revenue and costs, congestion pricing is ranked as an optional strategy with higher benefits and barriers rather than as a most-promising strategy. Carbon pricing is rated as highly effective for the broader social goal of improved environment and public health, and it could also provide some revenue for DOTs. (An economy-wide carbon pricing program would produce significant revenue, but the funding would likely be apportioned across many sectors.) Like congestion pricing, carbon pricing also faces major public acceptance barriers.
- **Lower-impact optional strategies.** Private capital could offer modest benefits for reducing costs and increasing the overall flow of funding into the transportation system and faces only moderate barriers. It is characterized as an optional rather than a complementary strategy because the choice to pursue a greater private role in funding transportation may vary with state philosophical attitudes about the appropriate roles for the public and private sector. Efforts to improve agency energy efficiency also offer the potential for modest cost savings over time with relatively low barriers.
- **Fallback strategies.** This final category contains general revenue and reduced scope of responsibility for DOTs. While greater reliance on general revenue would be adequate to address funding needs, it does not perform nearly as well as the various forms of user fees for the general policy goals of efficiency and equity. Reducing the scope of DOT responsibility is likewise not viewed as a highly desirable option in most cases, but it could represent the default option for states that fail to offset declining fuel-tax revenue.

8.3 Strategies to Reduce Traffic Congestion

Increasing traffic congestion is viewed as highly likely in many of the plausible futures identified in this report, although this concern is not equally applicable across all states. Traffic is already a serious problem in many states with large metropolitan regions, it could possibly become a serious problem in other rapidly growing states, and it may never be an issue in largely rural states not subject to growth pressures. As described in the future scenarios laid out in Chapter 5, it is also conceivable that some states might lose population in future decades, with corresponding declines in vehicle traffic. Given such uncertainties, congestion mitigation strategies are framed for the possibility of deferred action, although states that are already heavily congested may wish to pursue such strategies in the near term given the likelihood that the problem will only worsen in the coming decades.

With the possibility for deferred action, it becomes important to consider the signposts that might be used to trigger action at a later date as well as whether certain potentially helpful strategies have such long lead times that they would need to be implemented in the near term, under imperfect information, in order to contribute later. With respect to signposts, the following list suggests the types of indicators that could provide some early warning that traffic congestion appears likely to worsen; states may, of course, wish to develop their own indicators that are more relevant to local context.

- Data—for example, based on new housing permits or from population forecasts—suggest that a state's population can be expected to grow in the coming years.
- VMT, after declining late in the first decade of this century, begins to rise again as the recession recedes.
- Freight flows begin to rise again as the economy recovers.
- Fuel prices remain stable even as vehicles, due to CAFE standards, achieve higher fuel economy, resulting in lower driving costs.
- Alternate fuel and vehicle technologies that offer low energy cost for driving, such as electric vehicles or natural gas, achieve significant market share.

Of the strategies considered in this report, the following are rated as having at least a moderate effect on reducing traffic congestion: direct user fees (tolling or MBUFs), indirect marginal-cost user fees (fuel taxes), indirect fixed-cost user fees (registration fees), private capital, road expansion, goods movement improvements, congestion pricing, ITSs, TSM&O, traffic safety, TDM, public transportation improvements, and pricing fuel or emissions (carbon pricing). Among these, tolling or MBUFs, fuel taxes, registration fees, private capital, traffic safety, and carbon pricing can be viewed as less relevant in the sense that they would more likely be adopted for other policy objectives instead. Table 8.2 summarizes the rankings, along with the benefits and barriers, for the remaining strategies.

Drawing on the summary information on strengths and barriers along with more detailed analysis from the individual strategy assessments presented in Appendices I though M, the logic for the relative rankings of these options is as follows:

- **Most-promising strategies.** Congestion pricing is by far the most potent available strategy for reducing traffic congestion, and it provides the additional benefits of raising

Table 8.2. Ranking strategies to reduce traffic congestion.

Strategies	Strong Congestion Effects	Strong E/EPH/E Effects	Low Barriers
Most-promising strategies			
Congestion pricing	●	●	
Goods movement		●	
TDM		●	●
Public transportation		●	
Higher-impact optional strategies			
ITSs		●	
Lower-impact optional strategies			
TSM&O			●
Fallback strategies			
Road expansion			

Note: E/EPH/E = economy, environment and public health, and equity, ITSs = intelligent transportation systems, TDM = transportation demand management, TSM&O = transportation system management and operations.

revenue and using existing capacity much more efficiently. In areas where there is considerable congestion related to goods movement activities—for instance, traffic backups due to at-grade rail crossings—congestion pricing could be complemented by goods movement strategies. And because congestion pricing could pose equity concerns, it would be sensible to include public transportation improvements and TDM programs as well. Fortunately, the revenue raised through congestion pricing could help fund these complementary strategies.

- **Higher-impact optional strategies.** ITSs could be very helpful in reducing congestion through improved system efficiency and supporting other transportation goals over the long term, although they face considerable barriers in relation to financial cost and technical risk.
- **Lower-impact optional strategies.** TSM&O represents an option that could offer moderate benefits in reducing traffic congestion with relatively little downside. Note that TSM&O applications are generally quite effective but have already been applied in many of the congested urban areas where they would be most helpful. Additional investments in TSM&O—either to upgrade existing technologies or to deploy the technologies in new areas—are thus expected to provide moderate rather than significant benefits at the margin.
- **Fallback strategies.** Road building entails significant financial cost but would be expected to provide only moderate traffic reduction benefits—owing to latent and induced demand—and is thus ranked as a fallback rather than as a most-promising or optional strategy. Note that this ranking is not intended to imply that no new capacity should be built since certain individual projects will no doubt have highly favorable benefit–cost ratios. Rather, the idea is that providing new capacity as the first response to traffic congestion would not be expected to perform as well across a range of relevant policy considerations as other available options such as congestion pricing that would facilitate much more efficient use of existing capacity.

States already facing significant congestion problems may of course wish to pursue these strategies in the near term. For states in which traffic congestion is not yet a major concern, many of the strategies can be safely deferred until signposts provide a clearer indication that traffic is likely to worsen considerably. However, three of the strategies discussed previously—road building, goods movement improvements (a large share of which involve capital improvements), and ITSs—are likely to require long lead times. These must, therefore, be categorized as near-term discretionary hedging actions. That is, they must be initiated sooner rather than later if they are to be helpful in future decades, even if it is not yet certain they will be needed.

8.4 Strategies to Improve Traffic Safety

Travel in the United States is safer than in many countries, but the numbers of crashes and fatalities on the nation's road network are still dismayingly large. Aggressive steps to improve traffic safety are already underway. All states have adopted strategic highway safety plans and are working in concert with the FHWA to support a "Towards Zero Deaths" national strategy on highway safety. Thus, safety can fairly be viewed as an issue that states are already prioritizing.

In the context of the scenarios developed for this study, the main concern is not that the rates (e.g., per passenger mile) of crashes or fatalities appear likely to increase; indeed, safety rates should be improving in response to current state safety initiatives. Rather, it is that the total number of crashes and fatalities could rise based on the projected gains in passenger vehicle and truck travel in some of the plausible futures outlined. In other words, even if ongoing state efforts are successful at improving traffic safety rates, this could be more than offset by the effects of greater traffic volumes.

It could also be the case, although this is more speculative, that a shift to smaller passenger vehicles and larger trucks would lead to an increased rate in crash-related fatalities. (Note, though, that with CAFE standards now based on vehicle footprint, any shift to smaller passenger vehicles would reflect consumer choice rather than government regulation.) Another safety-related uncertainty is the future of autonomous vehicles. Although this study did not encompass analysis of the prospects for this technology, it appears that autonomous vehicles, if successful, could eliminate a significant share of the crashes that occur today.

The question is how states might address the potential, though highly uncertain, risk of adverse safety outcomes stemming from significant increases in vehicle travel. While states are already prioritizing safety improvements, in many cases they are doing so within the context of highly constrained budgets. The potential action considered, then, is to further increase the pace of investment in safety strategies, recognizing that such a course might require that states first increase transportation revenue in order to provide more funds. Of course, it is not certain that traffic volumes will increase in all states or that increased traffic would necessarily result in increasing the total number of crashes and fatalities. Faced with such uncertainty, states could reasonably defer a decision to accelerate investment in safety improvements until more information about the future emerges, although some states might still choose to take more immediate steps.

Because crashes and fatalities, like traffic congestion, are likely to increase with greater vehicle travel, the same set of signposts used to trigger congestion-reduction strategies would also be appropriate for triggering safety strategies. Additionally, states

Table 8.3. Ranking strategies to improve traffic safety.

Strategies	Strong Safety Effects	Strong E/EPH/E Effects	Low Barriers
Most-promising strategies			
Traffic safety	●	●	●
ITSs	●	●	
Goods movement		●	
TSM&O			●

Note: E/EPH/E = economy, environment and public health, and equity, ITSs = intelligent transportation systems, TSM&O = transportation system management and operations.

might simply choose to monitor total crash and fatality statistics and make the determination to increase safety investments if these numbers begin to rise.

Among the strategies considered in this report, those rated as likely to offer at least modest safety benefits were direct user fees (tolls and MBUFs), indirect marginal-cost user fees (fuel taxes), indirect fixed-cost user fees (registration fees), goods movement improvements, congestion pricing, ITSs, TSM&O, TDM, traffic safety, investments in public transportation, land use, and pricing fuel and emissions (carbon pricing). Of these, the vast majority would improve safety outcomes simply by reducing total vehicle and truck travel. The researchers view these as not being primary choices for safety since they would more likely be pursued for other reasons. Instead, the assessment focuses on four strategies that could help reduce the actual rate of crashes and fatalities: goods movement improvements, ITSs, TSM&O, and traffic safety policies. The strengths and limitations of these strategies are summarized in Table 8.3.

Of these, the traffic safety and ITS strategies offer the greatest potential safety benefits. Goods movement and TSM&O offer complementary safety benefits spanning trucks, rail crossings, passenger vehicle travel, and non-automotive passenger travel and thus are also included in the most promising category. Note that ITSs and goods movement both entail long lead times and, as such, fall into the category of near-term discretionary hedging strategies; only the traffic safety and TSM&O strategies can be safely deferred.

8.5 Strategies to Reduce Harmful Emissions

The strategies that states might consider to mitigate future challenges related to air quality and greenhouse gas emissions are similar to those that might be employed in the near term with the intent of shaping a more sustainable energy future, as discussed later in this chapter. For states not seeking to pursue such measures now, there could be increased pressure to do so in the future. The EPA could promulgate more-stringent air quality standards, for example, making it more difficult for states to achieve compliance. Alternatively, shifting attitudes on climate—possibly in response to new information or events such as greater frequency of severe storms, floods, fires, or droughts with mounting economic costs—could stimulate efforts to mitigate carbon emissions in states where this policy goal is not currently prioritized. Such outcomes, however, are not certain. Accordingly, strategies to reduce emissions, if not employed in the near term to promote a more sustainable energy future, could be deferred pending additional information or events.

Examples of the types of signposts that states might rely on as indicators to trigger the implementation of strategies for reducing local air pollutant and greenhouse gas emissions are:

- EPA air quality standards are further tightened, with the result that states find it more difficult to achieve compliance in some of their air basins.
- Petroleum remains the dominant fuel source, while increases in total vehicle travel outpace gains in fuel economy; emissions from highway travel thus continue to rise.
- Irrefutable and alarming evidence of severe climate change emerges (e.g., collapse of the West Antarctic Ice Sheet, leading to significant sea level rise).
- Public polling within a state indicates majority support for more aggressive action to mitigate climate change.

Of the strategies considered in this report, the following could have a positive effect in reducing air pollutant or greenhouse gas emissions: indirect marginal-cost user fees (fuel taxes), goods movement improvements, congestion pricing, ITSs, TSM&O, TDM, investments in public transportation, land use, pricing vehicles (feebates), pricing fuel or emissions (carbon pricing), alternative-fuel mandates and programs, state production and distribution of alternative fuels, and greater energy efficiency and alternative-fuel use within agencies. Of these, it is assumed that fuel taxes, congestion pricing, ITSs, and TSM&O, if implemented, would be principally motivated by other objectives; therefore, the ratings focus on

Table 8.4. Ranking strategies to reduce emissions.

Strategies	Strong Air Quality Effects	Strong GHG Reduction Effects	Strong E/EPH/E Effects	Low Barriers
Most-promising strategies				
Feebates		●		●
Carbon pricing	●	●	●	
Goods movement			●	
TDM			●	●
Land use			●	●
Higher-impact optional strategies				
Fuel mandates and programs		●		
Public transportation			●	
Lower-impact optional strategies				
Fuel production and distribution				●
Agency energy use				●

Note: E/EPH/E = economy, environment and public health, and equity, TDM = transportation demand management.

the remaining alternatives. The expected performance of the strategies is summarized in Table 8.4.

Drawing on the strategy assessment information within the table along with the more detailed analyses in Appendices I through M, the ratings and corresponding logic for the potential strategies to mitigate air quality and reduce greenhouse gas emissions are as follows:

- **Most-promising strategies.** Feebates and carbon pricing offer the strongest effects for improving air quality and reducing greenhouse gas emissions. Feebates would create a strong incentive for consumers to adopt vehicles with higher fuel economy, while carbon pricing would encourage lower-carbon fuels on an ongoing basis. For example, plug-in hybrid owners would have an incentive to rely on electricity rather than petroleum for as much of their travel as possible, while owners of flex-fuel, diesel, natural gas, and hydrogen vehicles would have a greater incentive to shift to renewable or lower-carbon sources of the respective fuels. Because a carbon tax would likely be applied across multiple sectors, it could also offer major air-quality benefits by motivating the replacement of legacy coal-fired power plants with natural gas plants or wind, solar, or other sources of renewable power.

  Feebates and carbon taxes could be well complemented by goods movement improvements, TDM investments, and land use reforms to promote more compact, mixed-use development patterns. While many of the policies included within the goods movement strategy would entail considerable expense, one of the core aims of the strategy—beyond improved efficiency—is to reduce air pollution around ports and major trade corridors as a matter of environmental justice. TDM, in turn, offers a reasonably low-cost approach to facilitating a shift from solo-occupancy driving to lower-carbon travel options such as ridesharing, vanpooling, and telecommuting. Finally, land use reforms would promote denser development more supportive of public transportation, walking, and bicycling as alternatives to vehicle travel.
- **Higher-impact optional strategies.** The two strategies with this ranking are alternative or low-carbon fuel mandates and programs and investments in public transportation. Fuel mandates—such as the federal RFS and California's LCFS—represent an alternative to carbon pricing in the sense that both aim to promote a transition to lower-carbon renewable fuels. Whereas carbon pricing harnesses market forces to identify the most efficient ways to reduce emissions, fuel mandates instead rely on government regulations that may be structured to specify the production of certain quantities of certain types of fuel. Fuel mandates do not guarantee the most efficient outcomes, but to date they have proven to be more politically feasible than carbon pricing. For a state that chooses to implement carbon pricing, however, fuel mandates could be viewed as redundant. With its carbon cap-and-trade and LCFS programs, however, California has chosen to employ both strategies in parallel. With that precedent in mind, fuel mandates are ranked as a higher-impact optional strategy rather than as a fallback strategy.

  Public transportation improvements could help reduce petroleum consumption and emissions by encouraging a shift from driving to transit and other modes. The cost of making significant public transportation improvements is rated as high, however, and it is unclear that such improvements, on their own, would be enough to stimulate proportional shifts in travel choices. This motivates a ranking of optional rather than most promising.

- **Lower-impact optional strategies.** This category includes state production and distribution of alternative fuels and energy efficiency and use of alternative fuels by agencies. Both of these face relatively low barriers but also can be expected to yield only modest emissions-reduction benefits in return.

Among these most promising and optional strategies, goods movement and land use require long lead times. Therefore, they should be implemented in the near term, if needed, as discretionary hedging actions to play a helpful role in reducing emissions in the coming decades.

8.6 Strategies to Improve Alternative Travel Modes

The final potential mitigation goal involves improving alternative modes of travel. This would be applicable if the demand for non-automotive alternatives were to rise rapidly in the coming years in response to much higher energy costs for travel or perhaps as part of concerted societal effort to adopt lower-carbon modes of transportation. It is also possible that significant worsening of traffic congestion could lead many travelers to seek alternatives to sitting in traffic. Because such outcomes are not certain, it should be safe to frame the possible policy options as adaptive strategies that could be triggered in response to information indicating that they are likely be needed. Examples of the types of signposts that states might rely on to trigger efforts to improve alternative travel options are:

- Increases in the price of oil outpace fuel economy gains, and lower-cost alternative fuels and vehicle technologies fail to emerge, leading to higher energy costs for vehicle travel.
- Greater consensus on the importance of reducing GHG emissions emerges, leading more households to seek alternatives to automotive travel.
- Traffic congestion increases significantly once the economy fully recovers.

The strategies considered in this report that could play a potential role in improving alternative travel options are congestion pricing, ITSs, TSM&O, traffic safety, TDM, public transportation, and land use. Note that this list includes some strategies, such as congestion pricing, that would mainly improve bus transit options by virtue of reducing traffic congestion and in turn speeding bus travel. Other alternatives listed could affect a broader range of alternative travel modes in additional ways, and all are viewed as potentially helpful and applicable. The strengths, barriers, and rankings of these strategies are summarized in Table 8.5.

Based on the high-level strengths and barriers of the strategies summarized in the table, along with the more detailed strategy analyses in Appendices I through M, the logic for the strategy rankings is as follows:

- **Most-promising strategies.** Public transportation investments, TDM, and land use are all expected to offer strong benefits for improving alternative modes of travel. Although

Table 8.5. Ranking strategies to improve alternative travel modes.

Strategies	Strong Effects on Improving Alternate Modes	Strong E/EPH/E Effects	Low Barriers
Most-promising strategies			
Public transportation	•	•	
TDM	•	•	•
Land use	•	•	•
Traffic safety		•	•
Higher-impact optional strategies			
Congestion pricing	•	•	
ITSs		•	
Lower-impact optional strategies			
TSM&O			•

Note: E/EPH/E = economy, environment and public health, and equity, ITSs = Intelligent transportation systems, TDM = transportation demand management, TSM&O = transportation system management and operations.

public transportation investments face a high barrier in relation to financial cost, the strategy could result in significant transit system improvements. TDM, in turn, can be very effective in supporting alternative commuting options, while land use reforms aimed at denser mixed-use development patterns would help make transit, biking, and walking more attractive and viable. These strategies could be complemented by additional investments in traffic safety policies, many of which would improve safety for cyclists and pedestrians in addition to vehicle occupants.

- **Higher-impact optional strategies.** Congestion pricing and ITSs could also offer strong benefits—specifically, by improving the flow of traffic and in turn enhancing bus transit—though they also face greater barriers in terms of public opposition, financial cost, and technical risk. Note that congestion pricing would also raise significant revenue, some of which might be invested in transit improvements.
- **Lower-impact optional strategies.** TSM&O would also offer important benefits, such as enabling signal prioritization to improve bus service. Because TSM&O has already been implemented in many urban regions, however, the marginal effects of further investment are expected to be more moderate; fortunately, the barriers for TSM&O are lower as well.

Note that of the strategies included in this section, both land use and ITSs are rated as requiring long lead times. They would thus need to be implemented as near-term hedging strategies to have much effect in improving alternative travel modes over the next several decades. This entails some degree of risk since greater demand for alternative travel modes is associated with some plausible futures but not others.

8.7 Strategies for Shaping Future Energy Outcomes

The preceding sections focused on strategies for mitigating potential impacts associated with certain plausible transportation energy futures. In this section, the discussion shifts to strategies that states might pursue with the intent of shaping a more sustainable energy future.

As background, robust decision making generally begins, as it does in this study, with the identification of potentially adverse consequences associated with certain plausible futures. Based on an understanding of such consequences, decision makers can then consider the application of shaping actions intended to increase the likelihood of desirable futures or decrease the likelihood of more unfavorable futures. Assuming that such actions are possible and highly likely to be effective, it is then reasonable to reduce the set of potentially negative future outcomes that might need to be addressed through mitigative actions.

In this study, however, the utility of shaping actions is more complicated. To begin with, the role of a single state in shaping future energy use and technology adoption—factors that will be influenced by major national and international policy frameworks, private and public investment choices, and unpredictable technology advances—is likely limited. If multiple states were to act collectively, then their combined level of influence would be greater, but decision makers within one state may not be certain, in advance, of the intended actions of other states. In short, the ability of state shaping actions to achieve their intended objections is far from ensured.

It is also possible that the desired transition to a more sustainable energy future might occur regardless of the actions taken by a state. In this case, any cost and effort invested in shaping actions could be viewed as superfluous. Finally, assuming that state shaping actions prove helpful and do succeed in their aims, the development of affordable and lower-carbon alternative fuels could exacerbate other challenges faced by DOTs such as diminishing fuel-tax revenue. (On balance, this may not be viewed as a negative since it should correspond to a range of improved social and environmental outcomes and states will likely need to address revenue challenges in any event, but it is still worth noting.)

For all of these reasons, energy shaping strategies are characterized in this study as entailing a higher degree of risk. In states with a strong interest in promoting environmental sustainability, near-term implementation of energy shaping strategies would be a sensible choice. In states where the relative prioritization of environmental goals is lower, choosing not to pursue energy shaping strategies could also be a rational choice for decision makers.

Some potential objectives of shaping future transportation energy outcomes are reducing aggregate petroleum consumption, promoting the development and adoption of lower-carbon alternative fuels, and supporting more affordable energy costs for travel. Of the strategies examined for this study, the following are likely to have either a moderate or a strong effect for one or more of these objectives: pricing vehicles (feebates), pricing fuels or emissions (carbon pricing), alternative-fuel mandates and programs, state production and distribution of alternative fuels, energy efficiency and use of alternative fuels by agencies, indirect marginal-cost user fees (fuel taxes), congestion pricing, ITSs, TSM&O, TDM, public transportation investments, and integrated land use. Of these, however, congestion pricing, ITSs, TSM&O, and TDM were judged to be not highly relevant in the consideration of energy shaping approaches; if implemented at all, these strategies would more likely be aimed at different objectives, such as reducing traffic. Table 8.6 summarizes the potential benefits, barriers, and rankings associated with the remaining strategy options.

Based on the relative strengths and barriers summarized in the table along with the more detailed strategy assessments

Table 8.6. Ranking strategies to shape future energy outcomes.

Strategies	Strong Energy-Shaping Effects	Strong E/EPH/E Effects	Low Barriers
Most-promising strategies			
Feebates	●		●
Fuel taxes		●	●
Land use		●	●
Higher-impact optional strategies			
Carbon pricing		●	
Fuel mandates and programs	●		
Public transportation		●	
Lower-impact optional strategies			
Fuel production and distribution			●
Agency energy use			●

Note: E/EPH/E = economy, environment and public health, and equity.

in Appendices I through M, the logic for the rankings is as follows:

- **Most-promising strategies.** As discussed previously, energy shaping strategies pose an inherently higher degree of risk for states. To reduce the risk as much as possible, the most promising energy-shaping strategies are those that offer significant benefits but only face modest barriers, such as feebates, fuel taxes, and land use. Assuming that fees on vehicles with lower fuel economy and rebates on vehicles with higher fuel economy are increased over time, feebate programs could accelerate a shift to vehicles with higher fuel economy, helping to reduce total petroleum consumption and reduce the energy cost of travel. Fuel taxes would also stimulate a reduction in petroleum use and could create more opportunity for alternative fuels to succeed. As an additional benefit, higher fuel taxes would also help to address revenue shortfalls. (Note, though, that fuel taxes would not support the objective of lowering the energy cost of travel.) Finally, land use reforms aimed at denser mixed-use development patterns should translate to a reduction in per-capita vehicle miles of travel and, in turn, aggregate petroleum consumption.
- **Higher-impact optional strategies.** Higher-impact optional strategies are carbon pricing, alternative-fuel mandates and programs, and investments in public transportation. While these offer a range of potential energy-shaping benefits, they also face greater barriers in terms of public acceptance, technical risk, and financial cost, respectively.
- **Optional strategies with lower benefits and lower barriers.** State production and distribution of alternative fuels and agency efforts to improve energy efficiency and adopt alternative fuels are rated as offering only modest benefits in promoting a more sustainable energy future, though the barriers are correspondingly low.

8.8 Integration of Robust Strategies

The preceding sections presented and ranked strategies for a series of mitigation and shaping objectives. It is now possible to integrate the results across objectives to provide a more comprehensive framework to assist state DOTs in developing robust long-term plans in the context of an uncertain energy future. This framework is shown in Table 8.7. The framework encompasses:

- Near-term strategies for addressing highly probable impacts (declining revenue with a possibility of higher DOT costs),
- Deferred adaptive strategies and near-term hedging strategies to address less-certain impacts (increased traffic congestion, more crashes and fatalities, greater difficulty in meeting air quality standards, more pressure to reduce greenhouse gas emissions, and increased demand for alternative transportation modes), and
- Near-term shaping strategies to influence future transportation energy outcomes.

Note that some strategies appear in multiple categories, reflecting the fact that a strategy can be helpful in addressing more than one objective. In the table, the strategies for each objective are grouped into the categories of most promising, optional high impact, and optional low impact. (Fallback strategies are not shown here.) As discussed earlier, near-term mitigation strategies to address highly probable impacts along with deferred adaptive strategies to mitigate uncertain impacts on an as-needed basis can be characterized

Table 8.7. Framework for robust long-term planning.

Objective	Most Promising	Optional High Impact	Optional Low Impact
Near-term strategies to address highly probable impacts			
Revenue and DOT costs	• Fuel taxes • Tolling or MBUFs • Registration fees • Beneficiary fees • DOT efficiency • Land use	• Carbon pricing • Congestion pricing	• Private capital • Agency energy use
Deferred adaptive strategies and *near-term hedging strategies* to address uncertain impacts			
Traffic congestion	• Congestion pricing • *Goods movement* • TDM • Public transportation	• *ITSs*	• TSM&O
Safety	• Traffic safety • *ITSs* • *Goods movement* • TSM&O		
Air quality or greenhouse gas emissions	• Vehicle feebates • Carbon pricing • *Goods movement* • TDM • *Land use*	• Fuel mandates and programs • Public transportation	• Fuel production and distribution • Agency energy use
Demand for alternative travel modes	• Public transportation • TDM • *Land use* • Traffic safety	• Congestion pricing • *ITSs*	• TSM&O
Shaping strategies to influence future transportation energy outcomes			
Shaping future transportation energy outcomes	• *Vehicle feebates* • *Fuel taxes* • *Land use*	• *Carbon pricing* • *Fuel mandates and programs* • *Public transportation*	• *Fuel production and distribution* • *Agency energy use*

Note: ITSs = intelligent transportation systems, MBUFs = mileage-based user fees, TDM = transportation demand management, TSM&O = transportation system management and operations. Italicized text denotes higher-risk hedging and shaping strategies.

as posing relatively low risk. In contrast, the longer-term benefits of near-term hedging and shaping strategies are more uncertain, translating to a greater degree of risk. To highlight the differentiation between lower- and higher-risk strategies, hedging and shaping strategies are shown in the table in italicized text.

Although the general framework presented in Table 8.7 is intended to be broadly applicable across the nation, individual states may wish customize the selection and prioritization of strategies to better meet their own needs. The next chapter considers a variety of ways in which states can adapt the framework as part of the planning process.

Reference

Lempert, R. J., S. W. Popper, and S. C. Bankes. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Policy Analysis*, RAND Pardee Center, Santa Monica.

CHAPTER 9

Developing State-Specific Plans

There were two main challenges to this project. The first was to conduct an analysis to provide states with general guidance on developing robust strategies to address uncertain but possibly significant shifts in transportation energy sources and vehicle technologies in the coming decades. The second was to structure the findings such that they could be adapted to the distinct needs of each state.

Up to this point in the report, the focus has been mainly on the first of these challenges. Steps in the analysis were to develop plausible transportation and energy futures; to discern how these futures might affect state DOTs given their roles, mandates, funding, and operations; to identify and assess strategies that states might pursue to mitigate adverse impacts associated with certain plausible futures or to proactively shape a more sustainable energy future; and to develop a framework for robust long-range planning that encompasses:

- Near-term strategies to mitigate highly probable impacts,
- Deferred strategies to mitigate uncertain impacts that can be triggered by signposts,
- Near-term hedging strategies with long lead times to mitigate uncertain impacts, and
- Near-term shaping strategies aimed at promoting a more sustainable future.

In setting up the analysis, the researchers included elements that would subsequently assist states in tailoring the general planning framework to meet their own contextual needs. It is to this latter question that the discussion now turns.

From the perspective of identifying suitable strategies for a given state, such factors as whether a state is home to major metropolitan areas, whether it includes major ports or trade corridors, and whether it is subject to significant population growth pressure may in some cases be highly relevant. Another important consideration is how voters within a state prioritize potentially competing policy objectives. Some strategies aimed at environmental goals, for example, could entail near-term economic costs. Whether a state would choose to pursue such actions hinges on the electorate's relative prioritization of these goals. A final question relates to the state's ability to overcome certain barriers associated with the various strategies. Some strategies involve significant financial costs, for example, and would be more challenging to pursue in a state already facing budget shortfalls. The detailed strategy assessments—developed in Appendices I, J, K, L, and M and summarized in the tables in Chapter 7—have been structured to provide insight on such questions.

The remainder of this chapter is divided into four sections. The first of these outlines a general sequence of steps or decisions that a state could follow in order to assemble a state-specific strategic long-range plan based on the robust planning framework outlined in the last chapter. In short, this process entails selecting a set of strategies for near-term action, a set of strategies that can be safely deferred, and a set of signposts to be monitored in order to trigger deferred strategies when and if needed.

The second section then enumerates various options for states to tailor plans to meet their own contextual needs and policy preferences. These include choosing from different strategies to address a specific objective, choosing to omit certain strategies that would be less relevant within a given state (e.g., congestion pricing would be less useful in a largely rural state), choosing whether to defer strategies aimed at uncertain impacts, choosing whether to pursue higher-risk hedging and shaping strategies, and choosing to alter the assumed set of specific policies that would be implemented in order to pursue a given strategy.

The third section outlines steps that state DOT planners could follow, if viewed as helpful, to expand the analysis and consider other future outcomes of interest that were beyond the scope of this study. For example, planners might wish to consider how the potential introduction and adoption of autonomous vehicles, alongside changes in fuels and vehicle technologies, could affect DOTs in the coming decades. The outlined steps also offer a general template for how states might incorporate the principles of robust decision making in other long-range planning exercises.

The final section observes that many of the strategies discussed in this study, including a large share of those described as "most promising," may require enabling legislation, typically at the state level but in some cases at the federal level. This suggests that DOTs may find it useful to develop contingency plans in case certain preferred strategies fail to gain legislative support.

9.1 Translating the Framework into a Strategic Long-Range Plan

As noted previously, the framework developed in the previous chapter was designed to help state DOTs craft robust long-range strategic plans that include: (a) strategies to pursue in the near term, (b) strategies that can be safely deferred until more information about how the future is unfolding becomes available, and (c) signposts that can be monitored in future years to determine if certain plausible futures are becoming more or less likely, which can in turn trigger the implementation of deferred strategies. A logical sequence of steps that state DOTs can follow to develop a plan with these elements is as follows:

1. Determine the preferred set of strategies for addressing revenue shortfalls and reducing DOT costs. (Revenue challenges are seen as likely in all of the plausible futures considered in this study, while finding efficient ways to reduce DOT costs should be generally beneficial regardless of how the future unfolds.) Add selected strategies to the plan for near-term action.
2. For each of the less certain impacts identified in the study—including worsening traffic congestion, more vehicle crashes and fatalities, greater difficulty meeting air quality standards, increased pressure to mitigate greenhouse gas emissions, and greater demand for non-automotive travel modes—select the preferred strategies for mitigating the impact. Additionally, consider whether the issue is already viewed as a problem within the state that merits near-term action or if instead it is possible to wait and see whether the problem will emerge or worsen in future years.
   a. For any of the uncertain impacts that are already viewed as problems that merit attention within the state, add the corresponding strategies to the set of near-term actions.
   b. For any of the uncertain impacts that are not yet viewed as problems within the state, add any of the preferred strategies that have relatively short lead times to the set of actions that can be safely deferred. Additionally, specify the signposts that should be monitored in future years to determine if and when to implement the deferred strategies for a given mitigation objective (see the prior chapter for examples of the types of signposts that states might choose).
3. Consider whether to implement any of the mitigation strategies with longer lead times—notably road expansion, goods movement investments, land use reforms, and investments in intelligent transportation systems—as a hedge against uncertain future impacts. Add selected strategies from this group to the set of planned near-term actions.
4. Consider whether to implement any of the strategies aimed at shaping future energy outcomes—such as pricing vehicles, pricing fuels, alternative-fuel mandates, state production and distribution of alternative fuels, and agency energy efficiency and use of alternative fuels—with the aim of promoting a sustainable energy future. Add any selected strategies from this group to the set of planned near-term actions.

9.2 Tailoring a Plan for State-Specific Needs

Proceeding through the steps just outlined, there are many opportunities for state DOTs to tailor the resulting plans to meet their own needs. Options include selecting strategies to address specific mitigation or shaping objectives, omitting certain strategies that would be less relevant in a given state, deferring strategies intended to address uncertain impacts, adopting higher-risk hedging and shaping strategies, and altering the policies chosen to implement a given strategy.

9.2.1 Selecting Strategies to Address an Objective

As discussed in the preceding chapter, the research team developed a logic for ranking the strategies that could be employed to address a given mitigation or shaping goal in up to four categories: most-promising strategies, higher-impact optional strategies, lower-impact optional strategies, and fallback strategies. Based on the analysis conducted for this study, a strategic plan would ideally include at least a subset of the most-promising strategies, and could be further complemented with some of the higher- or lower-impact optional strategies. Fallback strategies, as a general rule, do not perform as well for most policy goals of interest but could still be preferable to taking no action at all.

In sorting through the potential strategies for addressing a particular objective within a state, several elements of the detailed strategy assessments—developed in Appendices I through M and summarized in Chapter 7—should be especially helpful:

- **Effectiveness in supporting the specific mitigation or shaping objective.** The strategy assessments conducted for this study considered whether a given strategy could be expected to exert a significantly positive effect, a moderately positive effect, or no appreciable effect in addressing each of the mitigation and shaping objectives of interest. In selecting strategies to address a given objective, states would ideally choose at least one strategy rated as having a significantly positive effect (though such strategies may also face higher barriers).

- **Broader effects on the economy, environment and public health, and equity.** The assessments also examined how strategies could affect—positively or negatively—the broader social goals of economic growth and efficiency, environment and public health, and equity. While some strategies can be expected to perform well for all of these goals, others present more mixed results. For example, carbon pricing is rated as being significantly positive for environment and public health but could possibly, depending on implementation details, have negative implications for equity. In such cases, planners may find it helpful to compare the expected performance of different strategies for these broad social objectives against the relative policy preferences of a state's population and elected officials. Some states, for example, might focus on strategies that perform particularly well for the economy; others might prefer to emphasize strategies with stronger environmental or equity effects.
- **Implementation barriers.** Finally, the strategy assessments considered the nature and degree of potential implementation barriers for each of the strategies, including financial cost, public support, technical risk, the need for enabling legislation, and the need for institutional restructuring. Such barriers could certainly influence the feasibility of pursuing different strategies in different states. For example, states with major funding shortfalls would find it more challenging to adopt strategies entailing high financial costs, while states with a pronounced philosophical preference among the electorate for smaller government could find it difficult to pursue strategies that pose high public acceptance barriers, many of which involve significant government intervention.

9.2.2 Omitting Strategies Based on State Context

In addition to the factors just discussed, the strategy assessments developed for this study also considered whether a strategy would be generally applicable in any state or would instead be most helpful only in certain contexts. During the course of assessing the strategies, three contextual factors that might limit the utility of certain strategies emerged. Specifically, some strategies would mainly be applicable in states with large metropolitan areas, some would be most helpful in states experiencing rapid growth, and some would offer the greatest benefits in states with major port complexes or trade corridors. Table 9.1 lists all of the strategies that are likely to be more helpful in some states than others based on these contextual factors.

In Table 9.1, strategies with a bullet in a given column promise greater benefits in states that have the corresponding contextual trait. As a corollary, the expected benefits of implementing one of these strategies in a state that does not have the trait are likely to be lower. So, for example, public transit investments would likely yield greater returns in states with large metropolitan areas than in states that are largely rural.

Based on this reasoning, states that do not have one or more of the contextual traits listed previously might understandably choose not to include strategies with a bullet in the corresponding columns within their long-range strategic plans. Two caveats, though, should be noted. First, the traits are not binary in nature but rather involve a continuum. All states, for example, have at least some urbanized areas and some level of goods movement. There is thus a role for the subjective judgment of decision makers in determining whether these strategies would be valuable to pursue within their states depending on where they fall along the relevant continuums. Second, many of these strategies could still provide benefits even in states that do not have the corresponding contextual

Table 9.1. Strategies offering greater benefits in certain contexts.

Strategies	*Most Helpful in States With:*		
	Major Metro Areas	Rapid Growth	Major Ports or Trade Corridors
Beneficiary fees		•	
Increased use of private capital		•	
Goods movement			•
Congestion pricing	•		
TSM&O	•		
Public transportation	•		
Land use		•	

Note: TSM&O = transportation system management and operations. Contextual qualifications are based on the strategy assessments developed in Appendices I through M and summarized in Table 7.7.

traits. Therefore, a state that is already motivated to pursue a given strategy need not abort the plan simply because it does not have major metropolitan areas, is not growing rapidly, or does not have as much goods movement activity as some other states. Decision makers should be aware, though, that the benefits of the strategy may be fewer in comparison to other states that do have the indicated contextual traits.

9.2.3 Deferring Strategies to Mitigate Uncertain Impacts

As already noted, several of the potential impacts for state DOTs identified in this report are associated with some plausible futures but not with others. States might therefore choose to defer efforts to address these impacts until it becomes clearer—based on the monitoring of signposts—that they will emerge as problems that need to be addressed. That said, some of the uncertain future impacts may already be viewed as problems meriting near-term action in some states. For example, while some of the plausible futures could lead to worsening traffic congestion, the problem is already quite severe in most states with large metropolitan areas. Likewise, voters in some states may already be pressuring their elected officials and state agencies to take meaningful action to mitigate greenhouse gas emissions.

Based on their own situations, then, states may choose to either defer strategies intended to address potential impacts characterized as uncertain or take action in the near term if the underlying issues are already viewed as problematic. In cases where states choose to defer action, two caveats bear repeating. First, states will only be able to defer strategies with relatively short lead times. (Strategies with longer lead times would need to be implemented in the near term as hedging actions, as discussed next.) Second, to ensure that the ability exists to implement deferred strategies when it becomes apparent that they will be needed, states should develop signposts to be monitored on an ongoing basis.

9.2.4 Pursuing Higher-Risk Hedging and Shaping Strategies

As described in the previous chapter, strategies implemented in the near term to increase DOT revenue or reduce DOT costs along with deferred strategies to address uncertain future impacts can be characterized as posing a relatively low chance of regret. In contrast, both hedging strategies (that is, strategies with long lead times implemented in the near term to address uncertain future impacts) and strategies aimed at shaping a sustainable energy future entail a higher degree of risk. Hedging strategies, due to their long lead times, must be implemented before it is clear that they will be helpful, while shaping strategies may prove to be unsuccessful or superfluous.

In considering whether to adopt higher-risk hedging and shaping strategies, planners may find it helpful to contrast the potential regret of failing to implement a strategy that would have been very useful with the potential regret of implementing a strategy that proves to be either unnecessary or unsuccessful. Relevant factors in this deliberation include the anticipated effects of a strategy in addressing specific mitigation or shaping objectives; the expected performance of a strategy for broader social goals related to the economy, environment and public health, and equity; and the type and degree of barriers associated with a strategy.

For greater insight into the potential regret associated with failing to implement a strategy that would have proven helpful, it is useful to examine the foregone benefits that the strategy could have offered in the context of mitigating uncertain impacts or supporting different energy-shaping objectives. Table 9.2 lists all of the strategies from the study that might be implemented in the context of hedging against uncertain future impacts or shaping future energy outcomes and summarizes their anticipated effects for relevant mitigation and shaping objectives.

Note that in the context of this discussion, the anticipated effects on mitigation goals are most relevant for the potential hedging strategies, while the shaping goals are most relevant for the potential shaping strategies. As indicated in the table, however, both sets of strategies could address mitigation as well as shaping objectives. This suggests that there could be important ancillary benefits from choosing to implement any of the hedging or shaping strategies.

In terms of the potential regret associated with implementing a hedging or shaping strategy that proves to be either unneeded or unsuccessful, it is useful to consider in turn the expected performance with respect to the broader social goals of economy, environment and public health, and equity along with the anticipated barriers to implementation, as summarized in Table 9.3. Much of the regret in this case will relate to the required effort and financial investment directed to the strategy, as reflected in the assessment of barriers. The level of regret may be mitigated to some extent, however, if the strategy performs well for the broader social goals of interest.

9.2.5 Selecting Alternate Policies in Pursuing a Strategic Direction

The strategies examined in this study, as discussed in Chapter 7, have been constructed from small sets of policies that share similar aims and approaches. In order to evaluate each of the strategies, the research team needed to make certain assumptions about which of the component policies a state would implement in pursuing the strategy. As a general rule, the team assumed that states would be fairly aggressive in selecting specific policies to maximize the benefits of the

Table 9.2. Effectiveness of hedging and shaping strategies for specific objectives.

Strategies	Mitigating Uncertain Impacts					Shaping Goals		
	TC	TS	AQ	GHG	ATM	OC	LCF	CT
Near-term hedging strategies to mitigate uncertain impacts								
Road expansion	↑							
Goods movement	↑	↑	↑					
ITSs	↑↑	↑↑	↑ ▨	↑ ▨	↑	↑ ▨		↑
Land use		↑ ▨	↑ ▨	↑ ▨	↑↑	↑ ▨		
Near-term shaping strategies to promote a sustainable energy future								
Fuel taxes	↑	↑	↑	↑↑		↑	↑ ▨	
Public transportation	↑	↑	↑	↑	↑↑	↑		
Land use			*As above*				*As above*	
Vehicle feebates			↑ ▨	↑↑		↑↑	↑↑ ▨	↑↑
Carbon pricing	↑	↑	↑↑ ▨	↑↑		↑	↑ ▨	
Fuel mandates and programs			↑ ▨	↑↑ ▨		↑↑ ▨	↑↑ ▨	
Fuel production and distribution			↑ ▨	↑ ▨		↑ ▨	↑ ▨	
Agency energy use			↑	↑		↑	↑	

Note: TC = mitigating traffic congestion, TS = improving traffic safety, AQ = improving air quality, GHG = mitigating greenhouse gas emissions, ATM = improving alternative transportation modes, OC = reducing oil consumption, LCF = promoting the adoption of lower-carbon alternative fuels, CT = reducing the energy cost of travel, and ITSs = intelligent transportation systems. The list of potential hedging and shaping strategies is based on information presented in Table 8.7; ratings are based on the assessments developed in Appendices I through M and summarized in Tables 7.2, 7.3, and 7.4.

Key:
↑↑ = Highly Effective
↑ = Moderately Effective
Blank = Not Applicable
▨ Shaded = Uncertain

Table 9.3. General performance and barriers for hedging and shaping strategies.

Strategies	*Broad Policy Goals*			*Implementation Barriers*				
	Econ	E/PH	Equity	PS	FC	TR	EL	IR
Near-term hedging strategies to address uncertain impacts								
Road expansion	↑	↓	↓	↓	↓↓			
Goods movement	↑↑	↑ ▨	○ ▨		↓↓			↓
ITSs	↑↑	↑	○ ▨	↓	↓↓	↓↓	↓↓ ▨	↓↓
Land use	○ ▨	↑↑	○ ▨	↓			↓ ▨	↓ ▨
Near-term shaping strategies to promote a sustainable energy future								
Fuel taxes	↑↑	↑↑	↑ ▨	↓ ▨			↓	
Public transportation	○ ▨	↑	↑↑		↓↓		↓ ▨	↓ ▨
Land use		*As above*				*As above*		
Vehicle feebates	↑ ▨	↑ ▨	↑	↓			↓	
Carbon pricing	↑ ▨	↑↑ ▨	↓ ▨	↓↓			↓	
Fuel mandates and programs	○ ▨	↑ ▨	↓ ▨	↓	↓	↓↓	↓	
Fuel production and distribution	↑ ▨	↑ ▨	○		↓	↓	↓ ▨	↓
Agency energy use	○	↑	○		↓	↓		

Note: Econ = economic growth, E/PH = environment and public health, PS = public support, FC = financial cost, TR = technical risk, EL = enabling legislation, IR = institutional restructuring , and ITSs = intelligent transportation systems. The list of potential hedging and shaping strategies is based on information presented in Table 8.7; ratings are based on the assessments developed in Appendices I through M and summarized in Tables 7.5 and 7.6.

Key:
↑↑ = Highly Positive
↓↓ = Highly Negative / Major Barrier
○ = Neutral
↑ = Moderately Positive
↓ = Moderately Negative / Modest Barrier
▨ Shaded = Uncertain

broader strategy, even if the choices faced higher barriers. In other words, the idea was to develop a clearer understanding of the maximum benefits for states that fully embrace the strategic direction. In tailoring the results of this study, however, decision makers might alter the mix of policies within a strategy given the needs of and constraints within their own states. It should be stressed, however, that changing the mix of policies within a strategy could alter the profile of benefits and barriers associated with that strategy.

This can be illustrated with a more concrete example. The strategy of congestion pricing encompasses HOT or express lanes, congestion-priced facilities, cordon congestion tolls, network-wide congestion pricing, and variable parking pricing. From these options, the team assumed that a state would pursue the goal of establishing one or two priced lanes on all congested freeways, even in cases where this would require the conversion of general-purpose lanes to priced lanes—a concept that would surely face significant public acceptance challenges. As an alternative to this assumption, a state might instead choose to apply congestion pricing only on newly built lanes or on converted HOV lanes, as is often done now. This would reduce public acceptance challenges, but would also greatly limit the share of facilities that could feature congestion-priced lanes. As such, the aggregate congestion-reduction benefits as well as the resulting revenue stream would be much reduced in comparison to the assumed policy of developing priced lanes on all congested facilities.

In short, decision makers may find it appropriate to modify the assumed mix of policies for some of strategies to better meet their state's needs, but they should be aware that the strategy assessments conducted for this study may no longer be valid as a result of such modifications.

9.3 Considering Additional Future Outcomes of Interest

In the course of this study, the research team endeavored to develop a reasonably comprehensive spectrum of plausible long-range scenarios for energy use within the transportation sector—the principal focus area for the study—along with future travel trends and evolving federal policies on energy, climate, and transportation funding. However, given the many interactions between transportation, energy, the built environment, the economy, social and demographic trends, technological innovation, and shifting policy attitudes and perspectives, along with the ever-present potential for wholly unanticipated events or developments, it would be quite challenging to encompass all plausible futures.

In wrestling with this concern, the researchers chose to adopt two guiding criteria in developing the scenarios. First, given the scope of the report, the scenarios focused on factors—such as the price of oil, growth in the market share for alternative fuels, growth in passenger vehicle travel, and future federal energy and climate policy—that are either directly or indirectly linked to transportation fuels and vehicle technologies. Second, the research team developed a range of plausible future outcomes for these factors that can be viewed as at least reasonably probable based on current trends and expected interactions with other variables. In contrast, the team did not as a general rule include extreme or catastrophic scenarios that, while possible, are not generally viewed as likely for planning purposes. So, for example, the future travel scenarios did not include an outcome in which a future pandemic causes a major loss of population, triggering in turn significant reductions in overall travel, even though such an outcome could occur.

Still, it is possible that the scenarios developed for this report omit potential future outcomes of a less dire nature that states might wish to consider in developing long-range strategies. Alternatively, states might wish to expand the analysis to encompass future scenarios involving factors that are not directly or indirectly linked to evolving energy use. For example, the possible emergence of autonomous vehicles in future years could have a profound effect on travel choices but was not considered to be within the scope of this study. To identify and incorporate additional future scenarios within the context of the robust decision-making framework employed here, an appropriate sequence of analysis would be as follows:

1. **Specify scenarios.** Briefly identify and describe the additional factors and scenarios to include in the analysis.
2. **Identify impacts.** Consider whether these scenarios would create any additional negative impacts for state DOTs and whether the impacts are likely in all futures or just in certain futures.
3. **Identify and assess relevant strategies.** Examine whether the additional impacts would motivate the adoption of additional strategic directions not included in this study. If so, develop and assess the strategies using the criteria identified in Chapter 7.
4. **Identify additional near-term actions.** Evaluate whether the inclusion of additional scenarios suggests the need for near-term action. This could include strategies aimed at addressing newly identified impacts that appear likely across all futures. It could also include strategies with long lead times that might be useful as a hedge against potential impacts that may unfold.
5. **Identify actions that can be deferred until better information becomes available.** For newly identified impacts that only occur with certain futures, specify the set of strategies that would be employed to address the impact should the need arise. Also, identify signposts—that is, evidence that the impact appears highly likely—that would be used to trigger the strategies.

Note that this same general sequence of steps—specifying plausible futures, identifying impacts, identifying and assessing relevant strategies, identifying near-term actions, and identifying actions that can be deferred—can be fruitfully applied to other long-range DOT planning efforts. Although labor intensive, the overall process is relatively straightforward, and the application of robust decision-making principles can be very helpful in developing plans that will perform well however the future unfolds.

9.4 Developing Contingency Plans

While there are many strategies that could be highly effective in helping state DOTs address the mitigation and shaping objectives identified in this study, a large share could require state, or even federal, legislation. This is especially true of strategies rated as most promising for one or more objectives, as shown in Table 9.4

In this table, all of the strategies rated as most promising for one or more of the mitigation and shaping objectives are listed in the left column. The center column denotes the objectives for which a strategy is rated as most promising, while the right column indicates whether the strategy could require enabling state or federal legislation. (Entries shaded in light gray correspond to greater uncertainty.)

As shown, only two of the 15 strategies listed in the table are viewed as unlikely to require either state or federal legislation. Note, though, that for some of the strategies, the potential need for legislation may not apply to all of the component policies. Many of the TDM policies, for example, such as support for vanpools or the development of HOV lanes, might be implemented by state DOTs within their existing authority. However, the TDM strategy also assumes that a state would allow pay-as-you-drive insurance, and this could require enabling legislation in states that do not yet permit this type of auto insurance product.

Even with that caveat, it is clear that without enabling legislation, state DOTs will not be able to rely on many of the most-promising strategies for overcoming challenges that they could face in the coming decades. Importantly, this holds for all of the strategies aimed at stabilizing or increasing revenue, and it also applies to some of the more powerful strategies—congestion pricing, vehicle feebates, and carbon pricing, for instance—aimed at other objectives. Thus, while state DOT planners can employ the logic developed in this study to map out a long-range plan that identifies potential

Table 9.4. Potential legislative requirements for most-promising strategies.

Strategies	Most Promising For:	Required Legislation
Tolls or mileage-based user fees	RC	Federal/state
Fuel taxes	RC/SE	State
Registration fees	RC	State
Beneficiary fees	RC	State
Greater efficiency	RC	State
Goods movement	TC/TS/RE	
Congestion pricing	TC	Federal/state
ITSs	TS	Federal/state
TSM&O	TS	State
Traffic safety	TS/AT	
TDM	TC/RE/AT	State
Public transportation	TC/AT	State
Land use	RC/RE/AT/SE	State
Vehicle feebates	RE/SE	State
Carbon pricing	RE	State

Note: RC = increasing revenue and reducing cost, SE = shaping the energy future, TC = reducing traffic congestion, TS = improving traffic safety, RE = reducing emissions, AT = improving alternative transportation modes, ITSs = intelligent transportation systems, TSM&O = transportation system management and operations, and TDM = transportation demand management. The compiled list of most-promising strategies for different objectives is based on information presented in Table 8.7. The expectations for legislative requirements are based on the strategy assessments developed in Appendices I through M and summarized in Table 7.6, with entries shaded in light gray corresponding to a higher degree of uncertainty.

challenges, promising sets of strategies to address the challenges, and appropriate time frames for pursuing the strategies, the success of the plan will ultimately be contingent on the actions of legislators.

Therefore, it would be judicious for state DOTs to develop backup plans for responding to challenges in the event that legislation to enable the most-promising strategies is not enacted. Two different options in this vein are possible. As noted previously, most of the strategies encompass multiple policies, not all of which are likely to require legislation. Thus, one backup option would be for a state DOT to implement a strategy by pursuing just the subset of policies for which it already has the necessary authority. Of the most-promising strategies listed previously that are judged as potentially requiring state or federal legislation, quite a few—for example, greater efficiency, ITSs, TSM&O, TDM, public transportation, and land use—include at least some policies that state DOTs could implement on their own.

Another option would be to select backup strategies that could serve in place of preferred strategies if enabling legislation is not passed. If DOTs are asked to help reduce greenhouse gas emissions in the transportation sector but the legislature has not enacted policies involving vehicle feebates, carbon pricing, or low-carbon fuel standards, for example, DOTs might instead concentrate on improved energy efficiency and increased use of alternative fuels within agency operations and also explore the option of producing and distributing alternative fuels within existing rights-of-way. While the backup strategies may not be as effective as the most-promising strategies, they still may be preferable to taking no action at all.

CHAPTER 10

Promising Directions for Future Research

The objectives of this study were to develop a range of plausible transportation energy scenarios for the 2050 time frame, examine potential challenges that different futures could pose for state departments of transportation, and identify robust policy options to assist state DOTs in preparing for an uncertain energy future. To support this effort, the research team conducted extensive background research. This included a thorough review of recent progress and future prospects for conventional and alternative fuels and vehicle technologies, an exploration of important socio-demographic factors and ongoing policy debates likely to influence future energy and transportation outcomes, and an examination of ongoing trends in the evolution of state DOT activities and responsibilities.

Though extensive, the research and analysis conducted for this study cannot be viewed as exhaustive. Transportation and energy systems intersect with each other and virtually all other aspects of our society, economy, and environment through a series of direct and indirect positive and negative feedback mechanisms that are not always well understood. The pace of technological innovation appears to be accelerating as well, increasing the likelihood of surprise developments leading to transformative shifts in transportation and energy use in future decades. Even with the research team's best efforts, it seems quite likely that this study will have omitted certain factors and trends that in future decades will prove to be extremely influential for energy use in the transportation sector.

In short, while the findings and results of this study should be very helpful in assisting state DOTs to develop more robust long-range plans, there are ample opportunities to extend and complement the results through additional research. Over the course of the study, members of the project panel and other experts and observers have suggested a series of specific issues that could benefit from further analysis. In this final chapter of the report, opportunities for follow-on research are briefly described that, from the perspective of the research team, appear most promising.

Autonomous vehicles. Nascent autonomous- and connected-vehicle technology, if commercially successful, could transform passenger travel and goods movement in profound ways in the coming decades. The technology could affect, for example, the cost of driving, total travel, on-road fuel economy, traffic safety, effective throughput capacity on existing roadways, the cost and efficiency of moving goods by truck, travel options for those unable to drive on their own, available forms of transit service, models of shared auto ownership, requirements for parking capacity in dense urban areas, and patterns of low-density development in suburbs and exurbs. To date, however, there remains much uncertainty regarding the time frame over which autonomous- and connected-vehicle technologies might be deployed. Additionally, current thinking on the potential effects for many of the factors listed previously is largely speculative. To assist transportation agencies in better preparing for the potentially transformative effects of autonomous- and connected-vehicle technology, it could be helpful to conduct additional research that could be structured similarly to this study. Specifically, the effort could include identifying a range of plausible futures for the development and adoption of autonomous- or connected-vehicle technology, examining the types of challenges or opportunities that the plausible futures could pose for transportation agencies, and examining appropriate policy responses.

Future travel preferences. The future scenarios developed in this study assume that past predictors of vehicle travel will generally hold in the coming years—for example, that expected growth in population and the economy should lead to an increase in aggregate vehicle miles of travel. In the early 2000s, however, the rate of growth in vehicle travel slowed to some degree, and total vehicle travel actually declined in the latter part of the first decade of this century. While much of the decline can be attributed to spiking fuel prices followed by the most severe recession in a generation, some have suggested that shifting travel preferences among younger generations—for example, delays in applying for a driver's license and greater reliance on social media as a possible alternative to physical travel—may also be playing a role. Additional research to better understand whether fundamental shifts in travel preferences are occurring and, if so, what implications such shifts might have for transportation agencies, could be very helpful.

Signposts to trigger deferred strategies for uncertain future impacts. In developing the framework to assist state DOTs in crafting robust long-term plans in the context of an uncertain energy future, the team outlined a number of possible signposts that DOTs might monitor to determine when it would be appropriate to pursue strategies aimed at uncertain future impacts. Assuming that many state DOTs would choose to develop their own signposts, the study did not craft a set of highly detailed signpost metrics, which could involve identifying required data and methods for computing metrics and specifying threshold values for triggering the implementation of strategies. Additional analysis to address such technical details—either for specific states or for the nation as a whole—would certainly be valuable.

Evaluation of novel strategies. While many of the strategies discussed in this study, such as the use of fuel taxes to raise transportation revenue or the application of transportation demand management policies to provide alternative commuting options, have been in use for many decades, others are relatively novel and in some cases have not yet been implemented anywhere in the United States. Examples in the latter category include mileage-based user fees, vehicle feebates, and state production and distribution of alternative fuels. In reviewing an early version of this report, one of the project panel members suggested that it would be helpful to track and evaluate the early exploration of novel strategies by states to better understand their practical effects and to identify best practices as they emerge. The research team concurs that such evaluation and information sharing could serve as a helpful resource for state DOTs.

General guide on long-range planning for an uncertain future. Several of the state DOT staff with whom the research team interacted over the course of the study suggested that the general approach to developing robust plans in preparation for an uncertain energy future employed in the analysis would be broadly applicable for other DOT planning efforts as well. While it is possible to abstract the basic steps for such analysis through a careful review of this study, a shorter and more accessible document that outlines the methodology and considers how robust decision-making principles could be more broadly integrated in DOT planning processes would likely be a valuable contribution.

APPENDIX A

Conventional Fuels and Vehicles

This appendix reviews the current status of vehicles that run on conventional fuels as well as potential developments that could affect their cost and performance in the future.

- **Conventional fuels.** These include gasoline and diesel fuel, both of which are refined from crude oil. Increasingly, conventional fuels are blended with small amounts of biofuels—for example, "E10" refers to gasoline with 10% ethanol as an oxygenate. Gasoline or diesel with modest blends of biofuels, given their common use today, are considered as conventional fuels for the sake of this discussion; blends with much higher biofuel content, such as "E85," are discussed separately in Appendix C, which focuses on biofuels.
- **Conventional vehicles.** These are defined as relying on an ICE to burn liquid fuels, including spark-ignition engines for gasoline and compression-ignition engines for diesel. Also included in this category are most current hybrid-electric vehicles—those that are unable to plug in to receive additional grid power—since all of their power ultimately derives from the combustion of conventional fuels. Plug-in hybrids and battery electric vehicles, which in contrast receive some or all of their power from the grid, are discussed in Appendix D, which focuses on electric vehicles.

By these definitions, nearly all passenger vehicles and light-duty trucks on the road today can be classified as conventional vehicles that run on conventional fuels. Relative to alternative fuels and vehicle technologies, conventional vehicles have traditionally offered travel at lower cost and accommodated longer ranges between refueling stops. The markets for conventional fuel distribution, new vehicles, and vehicle maintenance have been well established for many decades.

Stricter federal fuel economy standards through 2025, which should act to reduce the per-mile energy cost of driving, and the possibility of a long-run trend toward moderate oil prices could reinforce continued reliance on conventional vehicles in the decades to come. On the other hand, there are several factors that could promote a shift away from conventional vehicles more rapidly than expected:

- **The future price of petroleum.** Higher prices for petroleum-based fuels could arise through market forces tied to increases in demand relative to supplies or through tax policies (i.e., fuel-tax increases) that increase the cost of petroleum relative to other transportation fuels.
- **Increasing concern over climate change, air quality, and energy security.** Efforts at the federal, state, and local levels to address climate change and energy security concerns may involve regulatory actions to promote a transition to lower-carbon fuel sources.
- **Advancements in alternative fuels and vehicle technologies.** As other fuel and vehicle technologies develop and reduce costs, conventional options may become less attractive to consumers in comparison.

A.1 Production, Distribution, and Refueling

Gasoline and diesel fuel are generally derived from conventional and unconventional crude oil, although synthetic alternatives—such as from coal-to-liquid and gas-to-liquid technologies—are also possible. Reserves of crude oil are distributed around the globe. While the United States currently produces a considerable amount of oil from domestic wells, oil must still be imported to meet domestic demand. Once extracted from a reserve, crude oil is transported to refineries where it is processed into gasoline, diesel, and other refined petroleum products. After refining occurs, the fuel is transported, primarily via pipelines and then trucks, to refueling stations.

A.1.1 Crude Oil Production

Crude oil is a mixture of hydrocarbons produced through geologic processes acting on organic matter. Crude oil also contains such trace elements as sulfur, nitrogen, salts, and heavy metals. Concentrations of sulfur can vary from close to zero to several percent. Low-sulfur oils are termed "sweet," and high-sulfur oils are termed "sour" crudes. In general, sweet crudes have a sulfur content below 0.5% by mass and are more easily converted to gasoline (Young 2006).

Global production of oil and liquid hydrocarbons was 89.1 million barrels per day (mbd) in 2012. Of that amount, the United States produced 11.1 mbd, or 12% of the world total. Members of the Organization of the Petroleum Exporting Countries (OPEC), comprising Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela, accounted for 41% of production worldwide. Output from former Soviet republics—primarily Russia, Azerbaijan, and Kazakhstan—accounted for another 15%, exceeding the supply from Saudi Arabia, the largest OPEC producer. Other important sources are the North Sea, Canada, Mexico, and China. Between 1985 and 2006, U.S. output gradually declined as consumption rose, requiring increased imports of crude oil and finished products. In contrast, Russia and the other former Soviet republics have boosted output above past peaks during this period. Between 2006 and 2012, however, aided by new technologies for exploiting tight oil resources, U.S. production increased by almost 34%, helping to reduce the need for imports (EIA 2013b).

The EIA now projects that U.S. crude oil production will continue to rise through 2020, spurred by increased demand and enabled by enhanced oil recovery techniques and more production from offshore and tight oil resources. After 2020, however, output is projected to decline back toward 2012 production levels, which stood at about 6.3 mbd (EIA 2013a).

Outside the United States, increases in production are projected to come from OPEC, especially the states bordering the Persian Gulf, from Russia and other former Soviet republics, and from new producers in Africa and Latin America. These suppliers are expected to provide the increase in oil output needed to satisfy the anticipated rise in global consumption through 2040 (EIA 2013a).

A.1.2 Additional Sources of Crude Oil and Crude Oil Substitutes

Most of the oil extracted by humans to date has been drawn from readily accessible reservoirs using well-established drilling and extraction technologies. While these will remain important in the coming decades, there will also be a greater role for emerging sources of crude oil and synthetic substitutes to meet rising global demand. Several options are possible. Producers might employ enhanced recovery techniques such as CO_2 injection to extract more oil from existing wells, or they might drill for oil in harder-to-reach locations, such as ultra-deepwater and Arctic resources. Another option would be to expand production of petroleum from oil sands and tight oil resources. Oil shale could also be developed. Finally, there are processes by which other energy feedstocks, including coal and natural gas, might be converted to liquid fuels (IEA 2012).

The emergence and successful application of technologies to extract petroleum from such sources has been an important development in recent years, stimulating upward revisions in oil reserve estimates. In a recent analysis, the International Energy Agency estimated that global proven oil reserves, defined as the amount of oil that could likely be produced under current economic conditions with available technology, stood at 1.7 billion barrels in 2011 (IEA 2012). This corresponds to a proven reserves-to-production ratio, one indicator of future production potential, of about 55; that is, proven reserves should allow for continued production at current rates for about 55 years.

In the same analysis, IEA estimated the quantity of technically recoverable reserves, defined as the amount of oil that could likely be recovered with existing technology irrespective of price, at about 5.9 trillion barrels, for a reserves-to-production ratio of almost 200 years. This estimate includes 2.7 trillion barrels of technically recoverable conventional oil along with 3.2 trillion barrels from unconventional sources such as tight oil, kerogen, and extra-heavy oil and bitumen. Synthetic petroleum from coal-to-liquid or gas-to liquid technologies could further expand the potential supply (IEA 2012).

To put these numbers in perspective, cumulative oil production in the industrial era has been a little over 1 trillion barrels (IEA 2008). As such, there appears to be no imminent danger of running out of oil anytime soon. On the other hand, there are reasons, such as concerns over climate change, why society might not develop all of the remaining fossil-based resources. Additionally, the per-barrel production costs for some unconventional petroleum resources and substitutes are expected to be considerably higher than for conventional oil. As the production cost curve rises, this could create an opportunity for renewable energy to substitute for fossil-based fuels on a cost-competitive basis. Still, emerging fossil-fuel sources remain the subject of considerable attention within the energy industry, and in the remainder of this section a closer look is taken at four existing or potential options that are highly relevant in the U.S. context.

In addition to conventional on- and offshore petroleum reserves, North America has vast reserves of four important fossil-fuel resources that can be exploited or processed to produce crude or synthetic crude substitutes. These are tight oil, oil sands, oil shale, and coal. (The United States also has significant reserves of natural gas, which can be processed into liquid fuels; natural gas is discussed in Appendix B.) Tight oil and Canadian oil sands already represent important sources of active production in North America, whereas oil shale and coal-to-liquid technology will require significant investment and sustained high oil prices to be considered viable substitutes.

Tight oil. "Tight oil" refers to light crude oil trapped in low-permeability rock formations, often shale or tight sandstone. Advances in drilling technologies, including hydraulic fracturing and horizontal drilling, have had a major effect on the production and recoverable supply of tight oil in recent years. While there are tight oil resources scattered around the globe, the United States boasts significant reserves. Important sources include the Bakken Shale in parts of Montana, South Dakota, Saskatchewan, and Manitoba; the Niobrara Formation underlying much of the Great Plains of the United States and Canada; and the Barnett Shale and Eagle Ford Formations in Texas.

Tight oil production in the United States rose from nearly zero in 1999 to about 1.2 million barrels per day in 2011. From 2012 to 2040, EIA estimates that more than 25 billion barrels of tight oil will be produced (EIA 2013a).

Oil sands. Oil sands are deposits of bitumen in sand or porous rock. Bitumen is a mixture of hydrocarbons that is solid or semi-solid at normal temperatures and pressures. Bitumen can be mined and brought to a central processing facility for upgrading, or it can be extracted in situ by injecting steam into the deposit, heating the bitumen, and coaxing it to flow to a well. (The in situ process uses about a barrel of water per barrel of crude, with much less impact on the land, but also emits more greenhouse gases due to the production of steam.) The bitumen may need to be upgraded before it can substitute for conventional crude oil. Upgraded bitumen is often referred to as synthetic crude oil.

The world's most significant deposits of oil sands are in Canada. The United States also has appreciable deposits of bitumen in Utah, with measured reserves of 8 to 12 billion barrels. Recently, the United States has leased several tracts in Utah for exploration and testing of extraction techniques. While oil sands are prevalent in North America, the extraction of oil sands has raised concerns with regard to groundwater contamination and land reclamation (Toman et al. 2008).

Oil shale. Sedimentary rock containing solid bituminous materials is known as oil shale (Bartis et al. 2005). These materials may be heated and extracted from the rock and then subsequently upgraded into a substitute for crude oil. Like oil sands, oil shale may be surface mined or extracted in situ. Most recent activity has been focused on developing technologies for in situ extraction, none of which have yet been tested at commercial scale. Advancement of these technologies could result in oil shale being competitive with conventional petroleum.

The largest oil shale deposits are in the United States, principally in the Green River Formation covering portions of Colorado, Utah, and Wyoming. The resources in the Green River Formation are equivalent to as much as 2 trillion barrels of oil. Recoverable resources would be considerably less, likely in the range of 500 billion to 1 trillion barrels (Bartis et al. 2005). Interest in oil shale development began in the early 1980s but then subsided, temporarily, with lower world oil prices during the 1990s. The rise in oil prices over the past decade, however, has stimulated renewed interest in developing the resource.

The principal uncertainties surrounding the development of oil shale are land use and ecological impacts, air quality, greenhouse gas emissions, water quality, water consumption, and production costs. The most serious environmental impacts of oil shale development appear to be disturbance of the land (Bartis et al. 2005) and the climate concerns applicable to fossil fuels more generally.

Coal-to-liquid technology. It is also possible to produce liquid fuels from coal. The most mature technique for doing so is indirect liquefaction, in which the coal is gasified to produce synthesis gas, which in turn is converted to hydrocarbons in a reactor. The best known method for this is Fischer-Tropsch (FT) synthesis, developed in the 1920s. The only commercial coal FT plant in the world, operated by Sasol in South Africa, produces approximately 160,000 barrels per day of synthetic fuels and chemicals (Bartis, Camm, and Ortiz 2008).

Coal-to-liquid production appears to be economically feasible at crude oil prices above $55 to $65 per barrel. With the vast coal resources that exist in the United States, liquid fuels produced from coal could displace 10% to 15% of conventional fuel demand and provide significant economic and national security benefits (Bartis, Camm, and Ortiz 2008).

There are three principal uncertainties complicating the development of coal-to-liquid fuel. First is the production cost, which remains uncertain because of the relative lack of experience with modern technologies for producing liquid fuels from coal. Second, the commercial viability of coal-to-liquid fuel depends directly on the world price of crude oil, which is highly uncertain over the time frame required to recover the investment in a production facility. Third, absent systems for capturing and sequestering carbon dioxide, coal-derived fuels would have roughly double the life-cycle greenhouse gas emissions of conventional fuels (Bartis, Camm, and Ortiz 2008), which is highly problematic from a climate perspective.

A.1.3 Refining and Production of Conventional Fuels

Gasoline and diesel, among other products, are refined from petroleum. Refineries perform three standard processes: separation, conversion, and blending (Young 2006). The fundamental refining process is fractional distillation, which involves separating petroleum into different products based on their boiling temperatures. Common conversion processes include cracking, in which longer hydrocarbons are broken down into smaller hydrocarbons; hydroprocessing, in which hydrogen is added to molecules; and isomerization, in which the structure of the hydrocarbon molecules is modified. In the final process, blending, intermediate products at the refinery are mixed into retail products, including gasoline, diesel, jet fuel, lubricating oils, asphalt cement, and petroleum coke.

To address air quality issues, refiners face certain formulation requirements for gasoline and diesel. Gasoline may have to meet specifications regarding the quantity of aromatic compounds, which do not burn completely and in turn affect air quality adversely, or include oxygenates such as ethanol. These specifications vary by state and by season. U.S. refiners are also required to produce fuels with low levels of sulfur: 30 parts per million (ppm) for gasoline and 15 ppm for on-road diesel fuel (Young 2006, Hileman et al. 2009). There were 139 operating refineries in the United States as of 2013, with a total production capacity of 16.8 mbd (EIA 2013c). At that time, the most recent U.S. refinery was activated in 2008, but the majority of U.S. refinery capacity is several decades old.

A.1.4 Distribution and Refueling

Once refined, conventional fuels must be distributed to demand centers. Major movements of petroleum products occur by pipeline, ocean tanker, and barge. Distribution of processed fuels typically occurs by rail freight and tanker truck. The distribution system for gasoline and diesel fuel in the United States is well established relative to other fuels discussed in this report. For example, API reports that the number of gasoline and diesel stations in the United States exceeds 150,000 (API 2013).

A.1.5 Oil Consumption

U.S. oil consumption is closely related to the state of the economy. Consumption declined considerably, for example, in the recession of the early 1980s, declined modestly in the recession of the late 1980s and early 1990s, and experienced a steep decline in 2008 and 2009 with the recent severe recession. U.S. consumption has since begun to climb again, though it remains below its 2007 peak.

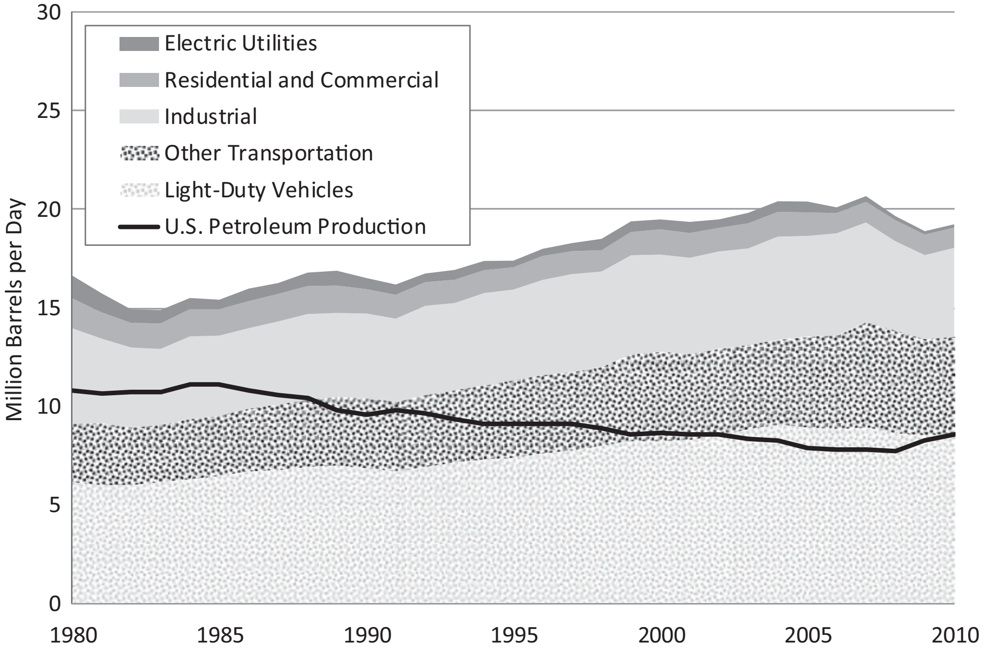
Despite a dip in the mid-1980s, global oil demand rose from 63.1 mbd in 1980 to a peak of 85.9 mbd in 2007. It subsequently declined to 84.7 mbd in 2009 as a result of the global economic slowdown, then climbed to more than 88 mbd in 2011. The United States remains the largest oil consumer in the world, accounting for 21% of global demand in 2012. The share of global consumption attributed to the United States and other developed nations, however, has been falling. China, the largest consumer of oil among the developing nations, has increased consumption at an average annual rate of 5.5% since 1980, accounting for 12% of global demand, or 10.2 mbd, in 2012 (EIA 2013b).

Much of the rise in U.S. oil consumption in the past decades can be attributed to passenger vehicles. The transportation sector accounts for more than two-thirds of oil use in the United States, and light-duty vehicles (passenger cars and light trucks) consume nearly two-thirds of the transportation total. Whereas total U.S. consumption increased about 16% between 1980 and 2010, use by the light-duty vehicle fleet rose by over 40% (ORNL 2012). Figure A.1 provides an overview of U.S. oil production and consumption by sector since 1980.

As the figure shows, consumption has generally trended up over time, albeit with some declines during recessionary periods. Production, in contrast, declined at a fairly steady pace between the mid-1980s and latter part of the first decade of this century, at which point the advent of tight oil and enhanced oil recovery techniques along with higher oil prices enabled and stimulated greater production. As recently as 1988, the United States produced enough oil to meet its transportation needs but not enough to meet total U.S. consumption. By 2002, it no longer produced enough oil to meet the needs of just the light-duty vehicle fleet (passenger cars and light trucks), let alone other modes of transport. However, this trend is now reversing due to increased U.S. production and a modest falloff in oil consumption by the light-duty vehicle fleet (ORNL 2012).

To bridge the difference between production and consumption, the United States must import petroleum. In 2011, according to EIA (2012), the United States imported 11.4 mbd of crude oil and petroleum products, with 40% coming from OPEC nations, 24% from Canada, 11% from Mexico, and the remaining 25% from other countries. U.S. reliance on imported oil has declined in recent years due to both increased production and reduced consumption. This trend could persist in future years if U.S. production continues to rise through 2020 as projected by EIA (2013a).

Major energy forecasting institutions project continued increases in global oil demand. In their reference-case scenario, for example, EIA (2013a) expects that the total world demand for liquid fuels will rise from 86.75 mbd in 2010 to 111.93 mbd in 2040. More than 97% of this increase will



Source: Based on data from ORNL (2012, Figure 1.6 and Table 1.15).

Figure A.1. U.S. oil production and consumption, 1980–2010.

come from developing countries (specifically, from those countries that are not members of the Organisation for Economic Co-operation and Development at present). Much of the focus in developed nations is on using oil and other resources more efficiently, thereby accommodating modest rates of growth with little effect on petroleum consumption. Among developing nations, in contrast, more significant economic growth and income gains are projected to lead to increased expenditures on automobiles, air travel, and other goods that involve consumption of refined oil products.

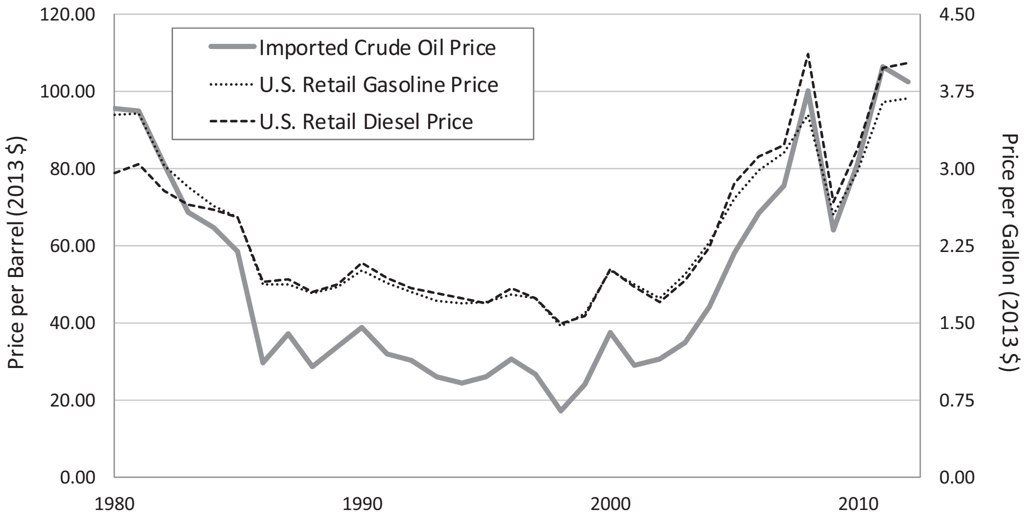
A.1.6 Oil, Gasoline, and Diesel Prices

The price of conventional fuels depends on the underlying price of oil and the costs of refining, blending, distributing, and marketing fuel to consumers, along with any applicable taxes. Of these, the cost of oil is the most significant component. As of May 2013, according to EIA (2013e) data, the price of oil accounted for about 67% of the average retail price of gasoline in the United States with taxes included, at $3.62 per gallon, and for about 62% of the average retail price of diesel, at $3.87 per gallon. As a general rule, and not surprisingly, the share of gasoline and diesel prices attributed to the underlying cost of oil increases with higher oil prices and decreases with lower oil prices.

Figure A.2 shows how world oil prices (on the left axis) and the average retail price for gasoline and diesel in the United States (on the right axis, inclusive of applicable taxes), both in 2013 dollars, have fluctuated together over the past 30 years. As suggested in the figure, oil and fuel prices are subject to significant volatility—much more so than for other manufactured goods and services—due to the inelastic nature of short-run oil supply and demand. Households find it difficult to forgo many trips—most notably, those to work and school and to purchase necessities. Faced with higher fuel prices for extended periods of time, however, consumers do change behavior. They purchase more fuel-efficient vehicles, take public transportation, and shorten trips. They may even move or change jobs so as to be closer to work. Such changes were witnessed during 2008 in the United States, just prior to the recession, as consumers faced historically high gasoline prices of $4.00 per gallon and higher.

While not shown in this figure, the 1970s were also characterized by extreme volatility in world oil markets. Two major crises—the Arab oil embargo of 1973 and the Iranian Revolution in 1979—led to rapidly escalating oil costs. Following this turbulence, the price of oil declined considerably and remained relatively stable for much of the next 25 years. Recent years, however, have witnessed a return of high and volatile oil prices. Owing in part to surging demand in developing nations such as China and India, world oil prices reached historic highs in the 2007 through 2008 period, only to decline precipitously again with the ensuing recession.

The future prices of oil, gasoline, and diesel are uncertain. Factors affecting supply and demand for petroleum are global economic conditions, geopolitical events, the response of demand to prices, OPEC decisions regarding production targets, and advances in certain extraction technologies, among



Source: Based on data from EIA (2013d).

Figure A.2. Imported oil prices and U.S. gasoline and diesel prices, 1980–2012.

others. Since it is difficult to resolve these uncertainties, efforts to forecast the supply and demand for petroleum and refined products typically involve the use of discrete scenarios of petroleum prices. In essence, a forecasting agency projects alternate prices of petroleum and employs an econometric model to simulate worldwide supply and demand under the different scenarios (Hileman et al. 2009).

The EIA's *Annual Energy Outlook* presents three price scenarios: a reference case representing an extrapolation of current trends, a low-price case in which non-OPEC petroleum resources are developed to ease the pressure on prices, and a high-price case that involves worldwide restrictions on the production of conventional petroleum liquids. Table A.1 shows how the price of imported oil and the retail price of gasoline, in constant 2011 dollars, is expected to change between 2010 and 2040 under these three scenarios.

A.2 Vehicle Technologies

While many expect oil prices to rise in future years, conventional vehicles are likely to achieve much higher levels of fuel economy as well. Barring dramatic advances in alternative fuels and vehicle technologies, this could enable petroleum-fueled vehicles to maintain their current cost advantage, even with potentially higher gasoline and diesel costs.

Over time, automobiles purchased by U.S. consumers have improved greatly in terms of their power, size, and safety. As documented by Knittel (2011) and others, however, the fuel economy of the U.S. fleet achieved only modest gains from the mid-1980s to the early 2000s, due in part to such factors as low and reasonably stable fuel prices and relatively stagnant federal CAFE standards. Over this period, technology innovations for vehicles focused primarily on attributes other than fuel economy, such as performance and utility (EPA 2013).

The average fuel economy of the U.S. new automobile fleet increased by less than 15% from 1980 to 2004. Over this same period, the average horsepower of new passenger cars increased by 80% and the average curb weight increased by 12%. These increases have been even more pronounced for light-duty trucks (SUVs, vans, and pickups), with average horsepower increasing by 99% and average weight increasing by 26% from 1984 to 2004. Concurrently, consumers began to purchase a greater number of light-duty trucks in relation to passenger cars, with the former's market share increasing

Table A.1. Future oil and gasoline price projections for 2040.

Year/Scenario	Price of Imported Crude Oil (2011 $ per Barrel)	Price of Gasoline (2011 $ per Gallon, with Taxes)
2010	77.49	2.88
2040 – Low oil price scenario	70.93	2.64
2040 – Reference scenario	154.96	4.32
2040 – High oil price scenario	228.39	5.86

Source: EIA (2013a).

from 20% of all light-duty vehicle sales in 1980 to 51% in 2004 (Knittel 2011). These past U.S. trends contrast sharply with the experience in European nations, where much higher fuel taxes, and in turn retail fuel prices, have motivated consumers to favor vehicles with greater fuel economy than those purchased in the United States.

Knittel (2011) analyzed vehicle model-level data and found that if weight, horsepower, and torque were held at their 1980 levels, fuel economy for both passenger cars and light trucks could have increased by nearly 50% between 1980 and 2006. But because vehicle advancements were used to improve other aspects of vehicles, such as power and acceleration, fuel economy only increased by 15% over that period.

Beginning in 2005, the combined fuel economy for cars and light trucks began to rise more steadily, increasing from 19.9 mpg in 2005 to 23.8 mpg in 2012 (EPA 2013). Several factors contributed to this trend. The production of light-duty trucks as a share of all light-duty vehicles peaked in 2004 at 48% and has since declined to 42% in 2011. In a related development, fuel prices increased rapidly and grew more volatile from the early 2000s up until the recession in 2008, and this led some consumers to choose vehicles with greater fuel economy. Most recently, federal fuel economy standards for light-duty trucks and automobiles have been set at more-stringent levels. As of 2012, the estimated fuel economy of cars was 27.3 mpg, while the estimated fuel economy of trucks was 19.4 mpg (EPA 2013).

Most of the light-duty vehicles currently marketed in the United States have a conventional powertrain incorporating an ICE running on either gasoline or, less commonly, diesel. HEVs are also being marketed by an increasing number of auto manufacturers. HEVs incorporate an ICE supplemented with an electric propulsion system, the latter powered by electricity captured through regenerative braking. The net effect is to increase the overall fuel economy of the vehicle by recycling energy that otherwise would have been lost to the system. Hybrids accounted for 3.7% of the new light-duty vehicle market as of 2012 (EPA 2013).

While previous improvements in automotive technology have, until just the past few years, been largely channeled into greater weight and improved performance rather than greater fuel economy, this will almost certainly change in the coming decades. To begin with, higher fuel prices could create a financial incentive for consumers to choose vehicles capable of more miles per gallon, and some consumers might be motivated by broader social goals related to energy security and climate mitigation. Even absent such motivations, however, the most recent revisions to federal CAFE standards, announced in 2011 and finalized in 2012, require auto manufacturers to steadily increase the fuel economy of their light-duty models, culminating in an average fuel economy rating of 54.5 mpg by 2025—roughly double the current requirement for passenger vehicles (EPA and NHTSA 2012). To meet the higher standards, auto manufacturers will likely pursue a range of strategies, including improved aerodynamics, lightweight materials, advanced engine and transmission technologies, and hybridization. To varying degrees, some of these strategies should be transferrable to alternative-fuel vehicles as well.

Aerodynamic improvements. Over time, vehicles have become more aerodynamic, but further improvements are possible. The development of tires with less rolling resistance may also play a role in improving fuel economy.

Lightweight materials. The integration of new lightweight parts made from aluminum, magnesium, plastics, and other materials in conventional vehicles can also help reduce fuel use. A 10% reduction in vehicle weight, for example, has the potential to improve fuel economy by 4% to 8% (Kobayashi, Plotkin, and Ribeiro 2009). In their recent book *Reinventing Fire*, Amory Lovins and the Rocky Mountain Institute (2011) describe the significant "lightweighting" of vehicles, enabled by carbon fiber materials, as a crucial step for radically improving the fuel economy of conventional vehicles in the near term and enabling their replacement by cost-competitive electric and hydrogen vehicles over the longer term. The logic for the latter is that lighter vehicles would require much less battery or fuel-cell capacity, in turn reducing the costs of these alternatives. And because of the strength of carbon fiber, future vehicles could be both lighter and safer than today's models.

Advanced direct injection engines and transmissions. Direct injection diesel engine vehicles have become common in Europe and yield about 35% greater fuel economy than conventional gasoline engines (Kobayashi, Plotkin, and Ribeiro 2009). Diesel-fueled vehicles have not yet been widely adopted in the United States, in part because it is costly to configure the technology to comply with stringent U.S. emission control regulations. However, gasoline direct injection systems have achieved greater market share in the United States and were installed in nearly a quarter of vehicles in model year 2012 (EPA 2013). Other advances to turbocharged direction injection engines and advanced six- and seven-speed transmissions are being developed, with significant potential for improved fuel economy and performance. Turbochargers were installed on 9% of vehicles in model year 2012, while transmissions with six or more speeds and continuously variable transmissions cumulatively accounted for about a quarter of the market share in model year 2012 (EPA 2013).

Hybrid-electric systems. Hybrid-electric systems, which in addition to the ICE include an electric motor, battery, power electronics (including an inverter), braking-energy recovery systems, and a control system to manage the battery-engine-transmission system, have been available for more than a decade and continue to become more advanced. The fuel economy benefits of hybrid-electric systems are significant. The Toyota

Prius, for example, offers a 40% to 50% fuel economy gain in comparison to otherwise comparable conventional alternatives (Kobayashi, Plotkin, and Ribeiro 2009). Although hybrid vehicles entail a premium cost of several thousand dollars, the development of more hybrid options presents a significant opportunity for auto manufacturers to progress toward the more-stringent CAFE standards unfolding through 2025.

A.3 Cost and Performance

The phasing in of more-stringent federal CAFE standards will result in vehicles that consume less fuel per mile driven, in turn decreasing the cost of driving and reducing emissions of local and global pollutants. At the same time, vehicles with higher fuel economy, other factors held equal, tend to be more costly to produce. As a consequence, the cost of purchasing a new vehicle may rise somewhat in the future as manufacturers comply with tighter CAFE requirements.

A.3.1 Vehicle Cost

In the future, vehicles will likely need to integrate advanced technologies such as lighter-weight materials and hybrid-electric drivetrains to comply with new CAFE standards. Because these technologies generally cost more than existing standard systems, the cost of purchasing new vehicles is expected to increase as a result of the more-stringent CAFE standards. For example, NHTSA estimates that the average cost for a 2025 vehicle that meets CAFE standards will be about $2,000 more than a vehicle capable of meeting the less-demanding 2016 standards (EPA and NHTSA 2012).

A.3.2 Energy Cost of Travel

Congress enacted CAFE standards in 1975 following the 1973–1974 Arab oil embargo. One of the specific motivations, along with the broader goal of energy security, was to help reduce the energy cost of travel for consumers. CAFE standards require that automobile manufacturers' sales-weighted average fuel economy meet or exceed a specified minimum value each year. Manufacturers failing to achieve this requirement must pay fines based on the number of vehicles sold and the extent to which the standard has been missed. These fines are effectively a tax on the fuel economy of the engine. The standards have historically differed for passenger cars and light trucks.

CAFE standards were increased rather aggressively through the late 1970s and early 1980s, but then remained relatively static for the next 20 years. Low and stable oil prices, in combination with debates over the economic merits and resistance from the auto manufacturing industry, derailed a number of efforts to further strengthen the standards in the late 1980s, the 1990s, and the early 2000s. In recent years, however, with mounting concerns over energy security and climate change, CAFE standards have once again been viewed as an attractive policy tool for improving fuel economy, stimulating an ambitious series of legislative and administrative actions. Federal legislation passed in 2007 resulted in a mandate for a 40% gain in fuel economy by 2020, translating to an average of 35.5 mpg for the combined fleet of passenger cars and light-duty trucks. In 2009, the Obama administration moved up the compliance deadline for the new standards to 2016, then subsequently instituted an even more aggressive set of requirements beginning in 2017 and culminating in the target of 54.5 mpg by 2025 (EPA and NHTSA 2012).

Previous standards had a single target for all passenger vehicles and another for all light-duty trucks. Beginning in model year 2008, though, automakers could optionally comply with standards based on vehicle footprint (width multiplied by wheel base), and footprint-based standards became required starting in the 2011 model year (EPA 2013). Thus, smaller passenger cars must on average have higher fuel economy than larger passenger cars. The often-quoted figures of 35.5 mpg in 2016 and 54.5 mpg in 2025 thus represent averages based on expected sales volumes for different sizes of passenger cars and light-duty trucks.

As vehicles with higher fuel economy are integrated into the vehicle mix to meet higher CAFE standards, the cost of driving is expected to decline under stable fuel prices. For example, NHTSA projects that consumers of 2025 new light-duty vehicles will save between $5,200 and $6,600 in fuel expenses over the life of the vehicle compared to fuel costs for a vehicle designed to meet the standard in 2010 (EPA and NHTSA 2012).

It is not clear, of course, that fuel costs will remain stable in the future. If one is interested in the question of how overall expenditures on fuel are likely to evolve over time, it is necessary to consider both changes in fuel economy and changes in fuel price. As noted earlier, the most recent reference-case forecast from EIA (2013a) suggests that the price of gasoline could increase to $4.32 per gallon (in 2011 dollars) by 2040, with low and high oil price scenarios corresponding to $2.64 to $5.86 per gallon, respectively. If fuel costs fall within the higher end of this range, the potential reductions in fuel expenditures stemming from improved fuel economy could be partially offset. Still, drivers would pay much less than they would with higher fuel prices absent fuel economy improvements.

A.3.3 Operational Performance

Petroleum-fueled ICE vehicles, as the established incumbent technology, set the benchmark for operational performance to which drivers have become accustomed. They

Table A.2. Fuel economy assumptions for conventional vehicle comparisons.

Vehicle Technology	2010 mpg	2050 mpg (Base)	2050 mpg (Optimistic)
Gasoline ICE	24.8	72	91
Diesel ICE	30.1	73	108
Gasoline hybrid-electric	34.7	93	121

Source: Computations by authors based on data from ANL (2012) and NRC (2013).

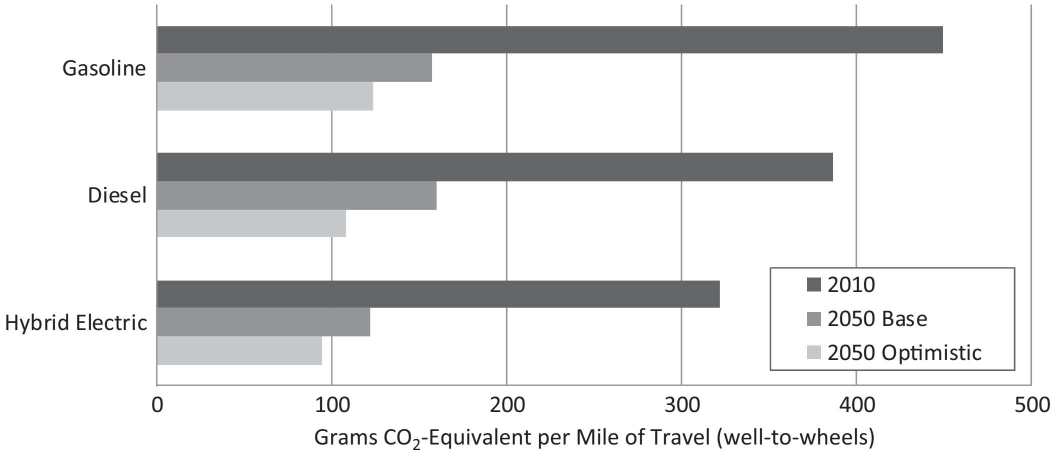
provide good power and acceleration, driving ranges in excess of 300 miles, and refueling times lasting no more than a few minutes.

A.3.4 Greenhouse Gas Emissions

The phasing in of more-stringent CAFE standards is expected to reduce greenhouse gas emissions per vehicle mile of travel, which vary in proportion to fuel consumption. To examine potential reductions in GHGs for conventional vehicles in the 2050 time frame, the research team conducted an exercise relying on emissions factors from ANL's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (ANL 2012). The team first considered the fuel economy for a mid-size passenger vehicle with recent (2010) gasoline, diesel, or hybrid technology. Next, drawing on common expectations reported within the technical literature, the team constructed two scenarios for the potential improvement in fuel economy for each of these technologies by 2050, including a base case and an optimistic case. Projected values, again calibrated for a mid-sized passenger car, were based on recent NRC (2013) and ANL (2011) analyses. The assumed fuel economy levels for recent and future vehicles used in the exercise are listed in Table A.2. Note that the numbers refer to estimates of actual, as opposed to EPA-rated, fuel economy. (EPA ratings assume a particular driving profile and are usually higher than actual mileage under realistic driving conditions.) Following the method used in the NRC (2013) report, future EPA/CAFE fuel economy estimates were reduced by 17% to derive on-road fuel economy estimates.

After specifying the current and hypothetical future conventional vehicles, the team used the GREET emissions factors to estimate the per-mile CO_2-equivalent greenhouse gas emissions for each of the current and future options, which are depicted in Figure A.3. The numbers presented are for well-to-wheels emissions—that is, they include emissions from extracting, refining, transporting, and ultimately combusting the fuel. The numbers do not, in contrast, include GHGs from the production of the vehicle, which would be necessary to incorporate for a full life-cycle emissions analysis.

As indicated in the figure, reasonably anticipated improvements in fuel economy for conventional vehicles should help reduce the carbon intensity of vehicle travel by 2050. Even in the base case, a conventional gasoline-fueled vehicle in 2050 would emit just over a third of the greenhouse gases per mile of travel compared to a typical vehicle on the road today; for a future hybrid vehicle in the optimistic case, the GHG emissions would only be about 20% of that for a current gasoline-



Source: Computations by authors based on data from ANL (2012) and NRC (2013).

Figure A.3. GHG reduction prospects for conventional vehicles in 2050.

fueled ICE vehicle. One scenario under which the greenhouse gas emissions performance of future conventional vehicles could possibly worsen would involve lower than anticipated gains in fuel economy along with a shift from conventional petroleum to coal-to-liquid fuel without carbon capture and sequestration (Mashayekh et al. 2012).

Note that the gasoline test cases are used again in the subsequent examinations of potential greenhouse gas emission reductions for natural gas, biofuels, electric vehicles, and hydrogen (see Appendices B, C, D, and E). The intent is to offer a fair comparison between how a future alternative-fuel vehicle might compare against a future petroleum-powered vehicle, not just how it compares to today's conventional vehicles.

A.3.5 Local Air Pollutant Emissions

Most local air pollutant emissions, such as VOCs, CO, NO_x, fine and very fine PM (PM10 and PM2.5), and SO_x, can be expected to decline with greater fuel economy. Unlike GHG emissions, however, which vary in direct proportion to fuel consumption, local air pollutants can be further reduced through the application of various emission control strategies. Examples are highly efficient combustion systems to minimize exhaust pollution, vapor recovery systems to capture evaporating gasoline, computer technologies to monitor and control engine performance, and effective after-treatment technologies such as catalytic converters and particulate filters (EPA 2012).

Under the authority of the Clean Air Act, the EPA has promulgated increasingly stringent emissions requirements for on- and off-road vehicles over the years, and the California Air Resources Board has the authority to set even stricter requirements for vehicles to be sold in California (EPA 2012). In response, automakers will typically select a combination of control strategies to meet applicable emission requirements in the most cost-effective manner. As such, while conventional vehicles are likely to emit less local air pollutants in future decades, the magnitude of the declines will depend more on regulatory decisions than on fuel economy gains.

A.4 Market Prospects

Petroleum is an entrenched fuel with well-established production, distribution, and refueling infrastructure. Markets for conventional vehicles are mature, and they have enjoyed decades of prominence. Factors that could enhance the prospects for continued reliance on conventional petroleum-fueled vehicles include further fuel economy improvements under the more-stringent upcoming CAFE standards, the possibility of future oil prices stabilizing or declining, and the chance that alternative fuels and vehicle technologies will fail to achieve the necessary breakthroughs to become cost-competitive with conventional vehicles.

A.4.1 Future Market Projections

Many of the fuel and vehicle experts interviewed during the early stages of the project indicated that a major shift away from petroleum over the next several decades would be unlikely to occur unless the price of petroleum increases significantly. Higher prices for petroleum-based fuels could arise through market forces such as rapidly increasing global demand or through tax policies (e.g., fuel-tax increases, a carbon tax) that increase the cost of petroleum relative to other transportation fuels.

Projections in the most recent *Annual Energy Outlook* from EIA (2013a) likewise assume continued dominance for petroleum. EIA's reference-case scenario envisions that about 18.3 million new light-duty vehicles will be sold in 2040. Of these, about 89% are expected to be gasoline- or diesel-fueled ICEs or HEVs. If you include flex-fuel vehicles, which are capable of running on 85% ethanol blends but in practice often rely on conventional gasoline blends instead, the total share comes to about 96%.

A.4.2 Factors Affecting Market Prospects

In Appendices B, C, D, and E are presented market adoption projections for several alternative fuels. Many of these projections are rather optimistic. Significant market success for any of the alternative fuels would obviously be incompatible with the continuing dominance of petroleum. Some of the factors that could diminish the current market share for petroleum in the next 30 to 50 years are policies that strongly favor alternative-fuel vehicles: for example, alternative-fuel vehicle purchasing subsidies, mandates for the production of certain alternative fuels (such as biofuels), and mandates requiring auto manufacturers to produce a certain percentage of alternative-fuel vehicles. Major breakthroughs in the cost and performance of alternative-fuel vehicle technologies could likewise make conventional vehicles relatively less attractive to consumers.

References

ANL. 2011. *Light-Duty Vehicle Fuel Consumption Displacement Potential up to 2045*, ANL/ESD/11-4.

ANL. 2012. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)*, Fuel Cycle Model version 1 2012. U.S. Department of Energy.

API. 2013. Oil & Natural Gas Overview: Service Station FAQs. http://www.api.org/oil-and-natural-gas-overview/consumer-information/service-station-faqs (accessed July 20, 2013).

Bartis, J. T., F. Camm, and D. S. Ortiz. 2008. *Producing Liquid Fuels from Coal: Prospects and Policy Issues.* RAND Corporation, Santa Monica.

Bartis, J. T., T. LaTourrrette, L. Dixon, D. J. Peterson, and G. Cecchine. 2005. *Oil Shale Development in the United States: Prospects and Policy Issues.* RAND Corporation, Santa Monica.

EIA. 2012. Petroleum & Other Liquids: U.S. Imports by Country of Origin. http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_m.htm (accessed September 18, 2012).

EIA. 2013a. *Annual Energy Outlook 2013.*

EIA. 2013b. International Energy Statistics. http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm (accessed June 6, 2013).

EIA. 2013c. *Refinery Capacity Report.*

EIA. 2013d. Short-Term Energy Outlook: Real Prices Viewer. http://www.eia.gov/forecasts/steo/realprices/ (accessed July 20, 2013).

EIA. 2013e. Gasoline and Diesel Fuel Update. http://www.eia.gov/petroleum/gasdiesel/ (accessed July 20, 2013).

EPA. 2012. Emission Standards Reference Guide: Basic Information. http://www.epa.gov/otaq/standards/basicinfo.htm (accessed July 20, 2013).

EPA. 2013. *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2012*, EPA-420-R-13-001.

EPA and NHTSA. 2012. "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule." *Federal Register*, 77(199).

Hileman, J., D. S. Ortiz, J. T. Bartis, H. M. Wong, P. E. Donohoo, M. A. Weiss, and I. A. Waitz. 2009. *Near-term Feasibility of Alternative Jet Fuels.* RAND Corporation, Santa Monica.

IEA. 2008. *World Energy Outlook 2008.*

IEA. 2012. *World Energy Outlook 2012.*

Knittel, C. R. 2011. "Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector." *American Economic Review*, 101 (7): 3368–3399.

Kobayashi, S., S. Plotkin, and S. Ribeiro. 2009 "Energy Efficiency Technologies for Road Vehicles." *Energy Efficiency*, 2: 125–137.

Lovins, A. and Rocky Mountain Institute. 2011. *Reinventing Fire: Bold Business Solutions for the New Energy Era.* Chelsea Green Publishing, White River Junction, Vermont.

Mashayekh, Y., P. Jaramillo, C. Samaras, C. T. Hendrickson, M. Blackhurst, H. L. McLean, and H. S. Matthews. 2012. "Potentials for Sustainable Transportation in Cities to Alleviate Climate Change Impacts." *Environmental Science & Technology*, 46: 2529–2537.

NRC. 2013. *Transitions to Alternative Vehicles and Fuels.* The National Academies Press, Washington, D.C.

ORNL. 2012. *Transportation Energy Data Book*, Edition 31.

Toman, M., A. E. Curtright, D. S. Ortiz, J. Darmstadter, and B. Shannon. 2008. *Unconventional Fossil-Based Fuels: Economic and Environmental Trade-Offs.* RAND Corporation, Santa Monica.

Young, R. E. 2006 (December). "Petroleum Refining Process Control and Real-Time Optimization: Transforming Oil Boiling into Managing Molecules." *IEEE Control Systems*, 26 (6): 73–83.

APPENDIX B

Natural Gas and Liquid Petroleum Gas

Natural gas and liquid petroleum gas have a long history of use as transportation fuels both domestically and internationally. Natural gas is a fossil fuel extracted from onshore or offshore wells, sometimes in conjunction with crude oil. It is composed mostly of methane (70% to 90%) and minor amounts of ethane, propane, butane, and other gases (NRC 2013). The gas must either be pressurized to compressed natural gas or cooled to liquefied natural gas for storage in vehicles. Most light- and medium-duty vehicles (i.e., passenger cars, sport utility vehicles, vans, and small-to-medium trucks) that rely on natural gas use CNG, whereas both CNG and LNG are used for heavy-duty vehicles such as buses and cargo trucks (Yacobucci 2005). Currently less than 3% of the natural gas consumed in the United States is used for transportation (NRC 2013).

Until recently, LPG has dominated the alternative-fuels transportation market in the United States. Produced as a by-product of natural gas processing and petroleum refining, LPG is a mixture of various hydrocarbons, including propane, propylene, butane, and butylene. LPG is also referred to as propane or autogas (EERE 2012c). Because LPG is gaseous at ambient temperature and pressure, it must be liquefied before it is injected into a vehicle (Yacobucci 2005).

Natural gas is viewed as a potentially attractive alternative to conventional petroleum-fueled vehicles for several reasons. First, recent breakthroughs in natural gas extraction technologies—specifically, horizontal drilling combined with hydraulic fracturing (or fracking)—have made it possible to economically recover abundant domestic natural gas resources (IEA 2012). The resulting lower cost of natural gas should help reduce the energy cost of travel, while the domestic supply is important from the perspective of energy security. In comparison to the combustion of gasoline and diesel, natural gas also promises modest reductions in local air pollutants and greenhouse gas emissions.

However, natural gas still results in greenhouse gas emissions, both from combustion and from the upstream supply chain (ANL 2012, Alvarez et al. 2012), and the fuel is a nonrenewable fossil resource. Some, therefore, view natural gas as an intermediate step in a decades-long transition to cleaner, renewable transportation fuels. Additionally, natural gas has competing uses as a cleaner alternative to coal for power generation, as well as in manufacturing. These considerations, and others discussed later in this appendix, make the prospects for a significant shift to natural gas within the transportation sector somewhat uncertain.

Although LPG has been a leader in alternative fossil fuels in the past, the greater supply and reduced prices of natural gas suggest that CNG has greater promise for future success in the light-duty vehicle market. Accordingly, this appendix focuses more attention on natural gas than on LPG.

B.1 Production, Distribution, and Refueling

There is already significant production of natural gas, worldwide and in the United States, along with a well-developed distribution system with an extensive network of pipelines. Yet there are relatively few stations for dispensing natural gas to vehicles, most of which are dedicated for fleet use. Thus the network of dispensing stations would need to be considerably expanded in order to support a significant level of natural gas adoption among the light-duty vehicle fleet.

B.1.1 Natural Gas Reserves

The proven reserves of natural gas in the world—the quantity that appears to be recoverable in the future under existing economic and operating conditions based on available geological and engineering information—have increased steadily over time. From 1991 to 2011, the world's proven reserves of natural gas rose from 131 trillion cubic meters (tcm) to 208 tcm. Nearly 80% of this total—almost 160 tcm—is divided in roughly equal shares between the Middle East and Europe and Eurasia. As of 2011, proven reserves in the United States stood at 8.5 tcm, just over 4% of the world total (BP 2012).

Total world production of natural gas in 2011 was 3,276 billion cubic meters (bcm). At this rate, the world's proven-reserves-to-production ratio—that is, the number of years that it would take to exhaust the proven reserves—is about 64 years. The United States produced about 651 bcm in 2011, corresponding to a proven-reserves-to-production ratio of about 13 years (BP 2012). Estimates suggest, however, that the United States has as much as 50 tcm of technically recoverable natural gas, which includes undiscovered, unproven, and unconventional natural gas resources [NPC 2007, Potential Gas Committee (PGC) 2009]. It is quite possible, therefore, that significant U.S. production levels could extend well beyond the 13-year proven-reserves-to-production time frame.

A recent breakthrough in drilling methods—the combination of horizontal drilling and hydraulic fracturing—has significantly increased the estimates of domestic economically recoverable natural gas reserves. Horizontal drilling allows producers to drill vertically and then horizontally to access multiple permeable zones of vertical geologic faults rich with natural gas. Although more costly than the traditional vertical drilling approach, this technique has allowed for the economical extraction of natural gas from sources once considered unrecoverable or uneconomical, such as the Barnett shale regions of Texas, which could supply gas for over 40 years [Texas Comptroller of Public Accounts (TCPA) 2010]. The high price of petroleum in recent years has also contributed to the emergence of horizontal drilling as an economical option. Between 2000 and 2010, according to estimates from the EIA, the U.S. proven reserves of natural gas increased by about 71% (EIA 2012d).

The production of natural gas from shale has enabled significant growth in overall U.S. natural gas production over the last several years. Shale formations trap natural gas in rocks of low permeability and low porosity. Horizontal drilling enables fracturing of the shale formations to release the natural gas. The overall environmental impact of shale gas, however, remains unclear. The process of extracting the natural gas can result in localized emissions of harmful air pollutants in new areas (Litovitz et al. 2013). On the other hand, the net effects on air quality at the regional level might be positive if the natural gas is substituting for coal in the generation of electric power, a subject being examined in ongoing research. Shale development has also introduced water quality concerns (see, for example, Osborn et al. 2011), which could slow the development of natural gas from shale via hydraulic fracturing. Additional studies are currently underway to better understand the water quality implications of hydraulic fracturing. Additional unconventional sources of natural gas that might be exploited in future years include other tight gas and coal bed resources.

B.1.2 Natural Gas Production

The world's total production of natural gas has increased steadily from 1,100 bcm in 1970 to almost 3,300 bcm in 2011. Dating to the 1980s, the Russian Federation and the United States have consistently accounted for the largest shares of global production. In 2011, the United States produced 651 bcm of natural gas, or almost 20% of the world total (BP 2012). Recent increases in U.S. production stem from unconventional gas supplies such as shale gas (EIA 2013). The states with the highest share of U.S. proven reserves, ranked in descending order, are Texas, Wyoming, Louisiana, Oklahoma, Colorado, New Mexico, Arkansas, and Pennsylvania. Collectively these accounted for more than 80% of total U.S. proven reserves and close to 79% of U.S. production as of the end of 2010. Texas alone has more than a quarter of the nation's proven reserves. Additional producers, alphabetically, are Alaska, Alabama, California, Florida, Kansas, Kentucky, Michigan, Mississippi, Montana, New York, North Dakota, Ohio, Utah, Virginia, and West Virginia (EIA 2012c). Many of these states already have an extensive natural gas network of underground pipelines that could support delivery for transportation uses.

B.1.3 Natural Gas Consumption

As with historical production trends, the world's consumption of natural gas has grown steadily over time. The largest consumers of natural gas, by a sizable margin, are the United States and the Russian Federation. The United States consumed over 690 bcm (21% of global consumption) and the Russian Federation consumed 425 bcm (13%) in 2011. With recent gains in U.S. production, however, the United States has now become a net exporter of natural gas (EIA 2013). It still imports a significant volume of natural gas by pipeline from Canada along with more limited quantities via pipeline from Mexico and liquefied natural gas via tanker from Trinidad and Tobago, Qatar, Yemen, Egypt, Peru, Norway, and Nigeria (BP 2012). It also exports natural gas to other countries, however, and export volumes have grown to exceed import volumes as of 2013.

Natural gas has many uses. It provides a feedstock for electric power generation; it is used to help produce such products as steel, glass, paper, clothing, and bricks; it serves as a raw material in paints, fertilizers, plastics, antifreeze, dyes, photographic film, medicines, and explosives; it heats homes and fuels stoves, water heaters, clothes dryers, and other home appliances; and it propels a small share of the vehicle fleet. As of 2011, the shares of natural gas consumption in the United States across different sectors were as follows: 31% for electric power, 28% for industrial, 19% for residential, 13% for commercial, 6% for oil and gas industry operations, 3% for pipeline and distribution use, and less than 1% for vehicle fuel (EIA 2012b). In considering the future potential for natural gas as a fuel for transportation, it is thus important to consider the competition from other potential applications of natural gas as well (NRC 2013).

B.1.4 Natural Gas and Liquid Petroleum Gas Distribution

The pipeline infrastructure for distributing natural gas in the United States is expansive. In areas without gas pipelines, natural gas is liquefied at the wellhead and transported to the market as LNG in insulated containers. LNG is also imported into U.S. coastal states via LNG tanker ships. After being transferred from the ships, LNG can be delivered via pipeline or stored in cryogenic tanks or underground caverns. At fueling stations, LNG can either be injected into natural-gas vehicles equipped with LNG fuel tanks or gasified for vehicles with CNG tanks (NPC 2012). CNG can be delivered to retailers through pipelines and tanker trucks much like gasoline. Large electric- or gas-driven compressors are used to produce higher-pressure CNG for onboard storage from low-pressure pipeline gas. Most fueling stations have their own compressors.

LPG is more commonly used for home heating and outdoor grilling than for transportation. Currently, most of the LPG pipelines run through the central and southern United States. There are no major LPG pipelines in the western states, so LPG is delivered to these states primarily via rail, truck, and ship transport. It is likely that the supply infrastructure of LPG could expand if demand were to rise (WGA 2008).

B.1.5 Refueling Infrastructure

In contrast to the extensive distribution network for natural gas, available refueling infrastructure is quite limited. To support significant market adoption of natural gas as a transportation fuel, the network of refueling stations would need to be expanded significantly. Because natural gas is delivered to many homes in the United States, the installation of home refueling appliances is also possible.

Refueling stations. Compared to more than 150,000 gasoline stations operating in the United States (API 2013), the number of natural gas and LPG stations available to the public is quite limited. As of August 2012, there were 2,654 LPG stations, 59 LNG stations, and 1,107 CNG stations in the country (EERE 2012e), and many of these were for fleet use only and not open to the public. While there are more refueling stations for LPG than for LNG or CNG, their patronage has been declining in recent years, with the total number of LPG stations having peaked in 1998 with over 5,300 (WGA 2008). In contrast, the number of natural gas refueling stations has been on the rise.

Texas has the largest share of LPG stations in the country, with 18% of the total, followed by California with 9% and Indiana with 7%. California and New York have the most CNG stations, with 22% and 10% of the nation's total, respectively. Interestingly, Texas is home to less than 4% of the CNG refueling stations, even though it leads the nation in natural gas production (EERE 2012e).

Developing a broader market for natural gas as a transportation fuel, then, will likely require a significant build-out of refueling infrastructure, which is a costly undertaking. The amortized cost of building a new dedicated natural gas refueling station can be $0.61 to $0.69 per gge of CNG, corresponding to about 125 cubic feet of natural gas (NPC 2012). The estimated amortized cost of adding integrated, modular CNG refueling infrastructure is higher, at $1.09 to $1.15 per gge, since the annual dispensing capacity is lower than with dedicated stations (NPC 2012).

Home refueling. Because natural gas is already delivered by pipeline to many homes in the United States, home refueling stations are also possible. This can take the form of a garage-mounted appliance that allows a vehicle to connect to the existing natural gas line and refuel overnight. Currently this appliance can be purchased for about $4,500, with an additional cost for installation (O'Dell 2011). Rebates and tax incentives exist to help offset this cost.

B.2 Vehicle Technologies

As of 2011, there were approximately 253 million vehicles operating in the United States. Most (about 234 million) were light-duty vehicles—cars, minivans, pickup trucks, and SUVs (BTS 2013). Approximately one million light-duty AFVs were in use during the same year. This count includes vehicles running on LPG, natural gas, E85 (an 85% ethanol blend; the count does not include the share of flex-fuel vehicles believed to run mainly on gasoline instead of E85), grid electricity, and hydrogen. About 77,000, or 8% of the AFVs, were LPG vehicles, and another 66,000, or 7%, were CNG vehicles (EIA 2012a).

A significant share of both LPG vehicles and CNG vehicles are fleet vehicles. As shown in Table B.1, private fleets and municipal governments are the predominant users of CNG and LPG as transportation fuels (EIA 2012a). In response to incentives and regulations in the federal Energy Policy Act, federal and state agencies have invested considerably in CNG vehicles and LPG vehicles. About 90% of the federally owned fleet of CNG vehicles is made up of light-duty vehicles purchased to fulfill EPA requirements (Yacobucci 2005).

Manufacturers of NG- and LPG-powered vehicles. CNG and LPG vehicles can be supplied to the public through two routes: either an OEM directly assembles or manufactures the vehicle, or a converter modifies a gasoline or diesel vehicle to operate on CNG or LPG.

In 1992, only two OEM light- and medium-duty natural gas-powered vehicles were available in the U.S. market. The

Table B.1. Fleet users of light-duty CNG and LPG vehicles.

User Group (2011)	CNG	LPG
Federal agencies	4,548	75
State agencies	3,733	1,626
Electric power providers	2,313	289
Natural gas fuel providers	1,739	12
Propane fuel providers	16	1,129
Transit agencies	336	101
Other private fleets and municipal governments	53,295	73,415
Total	**65,980**	**76,647**

Source: EIA 2012a.

number of models offered by OEMs subsequently increased, peaking at 18 models in 2002, and then declined rapidly. In the latter part of the first decade of this century, Honda, with its Civic GX, was the only OEM to offer a natural gas-powered light-duty vehicle. Spurred by the enhanced supply and reduced price of natural gas enabled by horizontal drilling technologies, however, an increasing number of OEMs have once again begun to offer natural gas models. As of 2012, five manufacturers—Chevrolet, Ford, GMC, Honda, and the Vehicle Production Group—were offering light-duty CNG vehicles, and Ford was marketing a bi-fueled truck capable of running on natural gas (EERE 2012a).

OEM LPG vehicle production began in 1997 with three different models of Ford trucks. In 2001 and 2002, Chevrolet and GMC also contributed to the mix of light- and medium-duty LPG vehicles available to the public but have since discontinued their productions, leaving Ford as the lone producer of OEM LPG vehicles. Following model year 2009, Ford terminated its LPG vehicle production as well (EERE 2012a). Buyers can now only acquire an LPG vehicle through conversions. In some cases, buyers can place an order with an automaker, which contracts with a vehicle converter to modify the standard OEM vehicle into an LPG vehicle.

In addition to CNG and LPG vehicles relying solely on an internal combustion engine, natural gas–electric hybrid and LPG-electric hybrid vehicles have also been developed. In the United States, only heavy-duty models (i.e., buses and trucks) of these hybrids are available. Although not available in the United States, Hyundai (2009) has released the first light-duty LPG-electric hybrid vehicle—the Hyundai Elantra LPi hybrid.

NG and LPG vehicle technology. CNG light-duty vehicles inject natural gas into spark-ignition engines, much like gasoline engines do. Vehicles can be dedicated—that is, designed to rely solely on natural gas—or provide a bi-fuel configuration. The latter includes both a CNG and gasoline tank and separate fueling systems, enabling the vehicle to operate on either fuel (EERE 2012f).

LPG vehicles also operate similarly to gasoline-powered, spark-ignition vehicles. Because LPG is stored in the vehicle as a lower-pressure liquid, a regulator first vaporizes a controlled amount of LPG. The vapor is passed into a mixer where it is combined with filtered air. This mixture is then introduced into the combustion chamber, where it is spark-ignited and burned to produce power. In the last 15 years, LPG injection engines, which allow the injection of LPG into the combustion chamber as a liquid, have also been developed [Energy Technology System Analysis Program (ETSAP) 2009].

In the United States, onboard CNG storage is typically accommodated with a tank pressurized at between 2,000 psi and 4,000 psi. The CNG tank on the Honda Civic GX holds 8 gge of CNG at 3,600 psi, and the tank reduces available trunk space by half compared to a gasoline-powered Civic. Higher-pressure tanks of up to 10,000 psi are also possible, reducing the amount of space required to store a given amount of fuel but also increasing the cost and energy required to compress the gas (NRC 2013). LPG, which is gaseous at ambient temperature and pressure, is compressed to a liquid and stored in vehicle tanks at around 200 psi.

Vehicle conversion technology. The conversion of conventional vehicles to run on natural gas or LPG is an option for increasing the number of CNG and LPG vehicles on the road. Most gasoline engines can be converted to operate on natural gas with some modifications to the fuel system, including a new fuel tank, new fuel lines, and changes to the electronic control unit (Yacobucci 2008). Because natural gas and LPG engines typically use spark ignition, it is generally easier to convert a gasoline engine, which also relies on spark ignition, to operate on natural gas or LPG.

Light- and medium-duty gasoline vehicles can be retrofitted with a CNG or LPG fuel system using converter kits made by small-volume manufacturers, or SVMs (NGVA 2010).

SVM engine conversion systems may be installed into a new or used vehicle. System installations are usually handled by the SVMs themselves or their qualified system retrofitters. From the 1970s to 1990s, unregulated conversion kits were available from dozens of manufacturers. Since the 1990s, all gaseous fuel engine systems on the market have been engineered and tested to comply with the EPA emissions standards. Hence, all conversion kits are now tightly regulated.

B.3 Cost and Performance

Natural gas offers less-expensive per-mile energy costs compared to conventional vehicles and can potentially reduce greenhouse gases and local air pollutant emissions. Natural gas and LPG vehicles currently entail a significant price premium, however, and natural gas faces challenges with respect to vehicle range and, to a lesser degree, power.

B.3.1 Vehicle Cost

The current cost differential between a natural gas or LPG vehicle and an otherwise comparable conventional vehicle is significant. The suggested retail price for Honda's 2012 Civic Sedan, for example, starts at $15,955, while the suggested retail price for its Civic natural gas model begins at $26,305 (Honda 2012). The only LPG vehicles available recently have been light- and medium-duty Ford and GMC trucks retrofitted with a conversion kit (EERE 2010). The cost of LPG conversion ranges from $4,000 to $12,000, depending on the make and model of vehicle (EERE 2012d). The conversion cost for a CNG vehicle is also significant; NGVA (2011) estimates the cost of converting a new light-duty vehicle to natural gas at between $12,000 and $18,000 with installation.

Vehicle manufacturers do expect that the incremental cost for CNG vehicles should decline as sales volume increases, enabling greater economies of scale, though they could remain moderately more expensive than conventional vehicles. An important factor in the additional cost of a CNG vehicle is the compressed storage tank. The cost of an onboard steel CNG storage tank capable of storing 8 gge of CNG is about $1,250, and a carbon fiber tank can be more than $3,100 (NPC 2012). Some buyers of CNG vehicles may also choose to install a home refueling station, which can add another $4,000 to $5,000 to the cost of owning and operating a CNG vehicle.

To partially offset such costs, the federal government and many states have offered tax credits or other incentives for natural gas and LPG vehicles. Consumers who purchased a CNG vehicle before the end of 2010, for example, could qualify for a federal tax credit of up to $4,000 (fueleconomy.gov 2012), and consumers who installed a home CNG refueling appliance by the end of 2013 qualified for a tax credit of up to $1,000 under the Alternative Fuel Infrastructure Tax Credit (EERE 2013a). Absent federal tax credits, it is more challenging to recoup the price premium associated with natural gas vehicles through fuel-cost savings over time.

B.3.2 Energy Cost of Travel

While natural gas and LPG vehicles entail significant price premiums, they also provide operational savings over time. When compared on an energy-equivalent basis, CNG vehicles achieve roughly the same fuel economy as gasoline-powered vehicles. The base-model 2012 Honda Civic Sedan, for example, has an EPA rating of 39 mpg on the highway, while the 2012 Honda Civic natural gas model is rated at 38 mpg (Honda 2012). Yet natural gas is much cheaper than gasoline. As of July 2013, the average U.S. retail price for gasoline was $3.65 per gallon, while the average retail price for CNG was $2.14 per gge (EERE 2013b). Even with this differential, however, the high premium cost associated with CNG vehicles leads to long payback times for the average driver (MIT 2011).

LPG is also less expensive than gasoline, costing an average of $2.73 per gallon as of July 2013 (EERE 2013b). Yet LPG has a lower Btu (British thermal unit) rating than gasoline, potentially leading to lower fuel economy. Rather than significant fuel-cost savings, lower maintenance costs are perhaps the most important reason for LPG's success in the market for high-mileage vehicles. LPG offers a combination of high octane, low carbon, and low oil-contamination characteristics that result in longer engine life in comparison to conventional gasoline engines. Because the fuel's mixture of propane and air is completely gaseous, the cold-start problems associated with liquid fuels are also reduced (EERE 2012b).

Looking forward, changes in the relative prices for gasoline, natural gas, and LPG are likely to have a significant influence on the degree to which the latter two emerge as competitive alternatives within the light-duty vehicle fleet. The expectation of natural gas remaining reasonably inexpensive, for instance, could induce auto manufacturers to develop more CNG models in the coming years. As a point of reference, the EIA, in its reference-case scenario in the most recent *Annual Energy Outlook*, projects that the price of gasoline will increase at an annual rate of 0.8% through 2040, that the price of CNG will increase at an annual rate of 0.9%, and that the price of LPG will increase at an annual rate of 0.4% (EIA 2013). Such long-term forecasts, however, are subject to great uncertainty.

B.3.3 Operational Performance

Comparing same-size engines, CNG engines generate slightly less power than gasoline engines, leading to slower acceleration and less power climbing hills (Yacobucci 2008, NRC 2013). LPG engines, on the other hand, have shown improved power performance. The recent introduction of sequential port-injection provides a great improvement over the older air-valve LPG fuel system. This product allows the engine control system designed for gasoline to distribute LPG into an engine more precisely and uniformly. The result is an LPG engine with better power and fuel economy (WGA 2008).

Although natural gas's octane is higher than that of gasoline (130 compared to 87 for unleaded gasoline), its storage density, even compressed, is much less than that of gasoline. As a result, a CNG fuel tank needs to be much larger than a gasoline tank to accommodate the same range (EERE 2013c). In practice, natural gas vehicles may be configured with somewhat larger tanks and in turn offer modest reductions in range. The tank in the 2012 Honda Civic NG, as already mentioned, displaces half of the trunk space and provides for a range of 192 miles (EPA city rating) to 304 miles (EPA highway rating; NRC 2013). Note that EPA ratings are generally overoptimistic with respect to mileage in real-world driving conditions, so the actual range may be even less. Due to the limited range, CNG vehicles have often been used for applications in which vehicles are operated in localized areas and can easily return to a central base to refuel. The range of LPG vehicles is greater, at 300 to 400 miles (Yacobucci 2005).

The performance of natural gas engines is sensitive to the specific composition of the natural gas. The fuel quality standard for natural gas vehicles is to include a minimum of 95% methane. At the time of extraction, natural gas contains between 70% and 90% methane. The processed natural gas in pipelines typically consists of 85% to 99% methane, varying seasonally. Natural gas suppliers could upgrade the composition of the gas for transportation sector needs, but the extra purification could increase fuel price. Variations in fuel composition can upset the air-fuel ratio in the engine, leading to higher emissions and lower efficiency. Significant amounts of heavier petroleum gases, such as propane and butane, can increase the tendency for engine knocking, leading to loss of engine power and progressive engine damage. In addition to the composition of the hydrocarbons, the water content, sulfur content, and residual compressor oil content influence the degree to which CNG engines are able to produce low emissions, operate at maximum efficiency, and maintain durability (M. J. Bradley and Associates 2005).

B.3.4 Greenhouse Gas Emissions

Compared to gasoline vehicles of comparable fuel efficiency, CNG vehicles offer about a 14% reduction in well-to-wheel carbon dioxide emissions (ANL 2012). A major concern, however, is that natural gas vehicles or upstream distribution infrastructure could leak methane, itself a greenhouse gas. Methane has a 34-times greater climate-warming impact than carbon dioxide, so even modest levels of leakage in the natural gas supply chain could undermine the GHG benefits of CNG in comparison to petroleum (Alvarez et al. 2012).

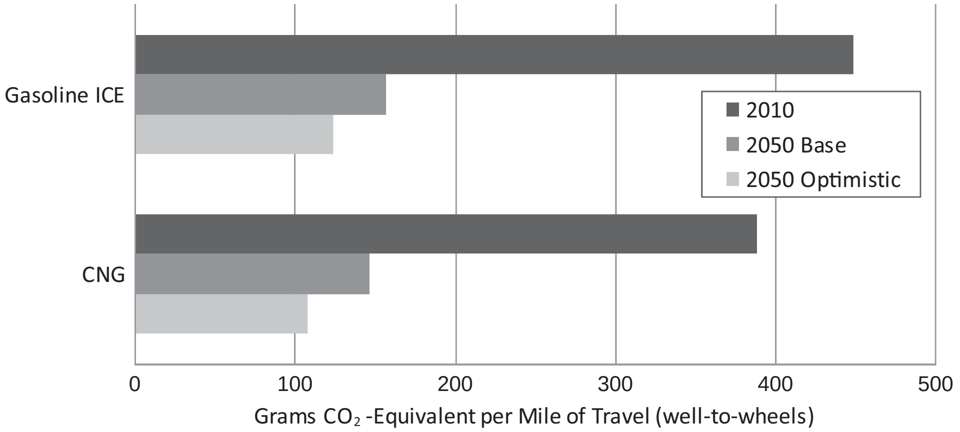
To examine the potential climate implications of natural gas and other alternative-fuel vehicles in relation to conventional vehicles, the research team conducted an exercise relying on emissions factors from ANL's GREET model to compare the performance of alternate fuel types and vehicle technologies. For each of the fuel types included, the team included GREET's specifications for a generic mid-size passenger vehicle in 2010 along with two hypothetical configurations for the same size vehicle in the 2050 time frame. Both of the hypothetical future models are broadly consistent with expectations or forecasts reported in the literature, but one embeds modest base-case assumptions, while the other is more optimistic. Many of the same technologies that will improve ICE vehicles will also improve the fuel economy of CNG vehicles. To provide a bounding estimate for future improvements, the researchers used the maximum mpg considered by the National Petroleum Council (NPC 2012) as an assumption for the 2050 base case. For the 2050 optimistic case, the researchers assumed a percentage-based improvement similar to that for the ICE optimistic case described in Appendix A. Table B.2 lists the assumed on-road (as opposed to EPA-rated) fuel economy for the current and future conventional and CNG vehicle specifications used in the analysis.

Based on these assumed specifications and GREET's emissions factors, Figure B.1 graphs the GHG emissions performance for current and future conventional and CNG vehicles in grams of CO_2-equivalent per mile. Note that the estimates are for well-to-wheels emissions, including extraction, processing, distribution, and combustion of the fuel within the vehicle.

Table B.2. Assumptions in emissions comparisons for CNG vehicles.

Vehicle Technology	Current MPG	2050 MPG (Base)	2050 MPG (Optimistic)
Gasoline ICE	24.8	72	91
CNG (gge)	25.6	69	93

Source: Computations by authors based on data from ANL (2012), NPC (2012), and NRC (2013).



Source: Computations by authors based on data from ANL (2012), NPC (2012), and NRC (2013).

Figure B.1. GHG reduction prospects for CNG in 2050.

B.3.5 Local Air Pollutant Emissions

All internal combustion engines, including those operating on CNG and LPG, emit ozone-forming compounds such as NO_x and non-methane VOCs—termed "criteria pollutants" and regulated by the EPA. LPG and natural gas vehicles, however, generally produce less air pollutants than gasoline vehicles when compared on a well-to-wheels basis. CNG vehicles, for example, emit 45% less VOCs, 12% less PM2.5, and 27% less NO_x emissions than otherwise comparable gasoline-fueled ICE vehicles (ANL 2012).

B.4 Market Prospects

The potential advantages of LPG in comparison to gasoline- or diesel-fueled vehicles are rather modest, with little evidence to suggest that the market share for LPG is likely to expand significantly in the coming decades. In contrast, CNG appears to hold greater promise due to its lower cost and moderate emissions improvements. For CNG to succeed, however, it will need to overcome a number of challenges, such as the lack of adequate refueling infrastructure, the current high price premiums for CNG vehicles, and competing uses for natural gas in other sectors.

B.4.1 Future Market Projections

In the reference case for its *Annual Energy Outlook*, EIA (2013) projects that CNG and LPG vehicle sales will expand modestly in the coming decades, rising to 32,000 and 56,000 vehicles per year, respectively, by 2040. This would represent less than a half of a percent of all light-duty annual vehicle sales. In contrast to EIA's rather tepid forecast, OEMs—encouraged by dramatic declines in the cost of natural gas—have in recent years begun to introduce new CNG models. If this trend holds, CNG adoption might easily exceed EIA's current projections.

B.4.2 Factors Affecting Market Prospects

The remainder of this section discusses some of the main obstacles that CNG and LPG will need to overcome in order to achieve significantly greater market share in the light-duty fleet.

Availability of refueling stations. The current lack of refueling stations stands as a major barrier to wide adoption of LPG and CNG vehicles. As noted earlier, there were fewer than 2,700 LPG stations in the country as of 2012, just over 1,100 CNG stations, and fewer than 60 LNG stations (EERE 2012e). While the number of LPG stations exceeds the number of refueling stations for any other type of alternative fuel, it still represents less than 2% of the more than 150,000 stations for conventional gasoline and diesel (API 2013). Further, many of the existing natural gas and LPG refueling stations are for dedicated fleets and are not accessible to the general public.

The provision of CNG refueling infrastructure is particularly challenging financially given that CNG stations can cost three to four times as much as conventional gasoline stations (WGA 2008). The National Petroleum Council estimates that a dedicated CNG station costs about $1.5 million, while a modular CNG station connected to an existing gasoline station would cost around $400,000 (NPC 2012). Absent additional investment, however, the low availability of refueling stations dampens demand for vehicle adoption, and low vehicle market share in turn discourages investment in additional refueling stations. In light of this problem, natural gas and LPG are perhaps most feasible, at least in the near term, for vehicles that are centrally garaged, are operated in a well-defined geographical area, and can be fueled at a single location or at a limited network of stations. The most cost-effective markets for CNG and LPG vehicles are in high fuel-use fleets such as transit, airport, taxi, shuttle, municipal, refuse, ports, and delivery and distribution. Long-haul trucks, which can refuel at stations located strategically along the Interstate highway system, are another promising market for natural gas (WGA 2008).

One option for expanding refueling infrastructure is to build partnerships between large anchor fleets and fuel providers that construct new fueling stations to service the anchor fleets. Many natural gas providers will build a station at no cost to the customer in return for a minimum fuel volume contract. A commitment of 250,000 gallons per year is generally adequate for fuel providers to construct a new refueling station. The station can be opened to the public, thereby increasing the available refueling infrastructure to local, smaller fleets and private vehicle owners. The development of public infrastructure may encourage greater adoption of natural gas vehicles and LPG vehicles, especially by smaller fleets that cannot afford their own refueling station (WGA 2008).

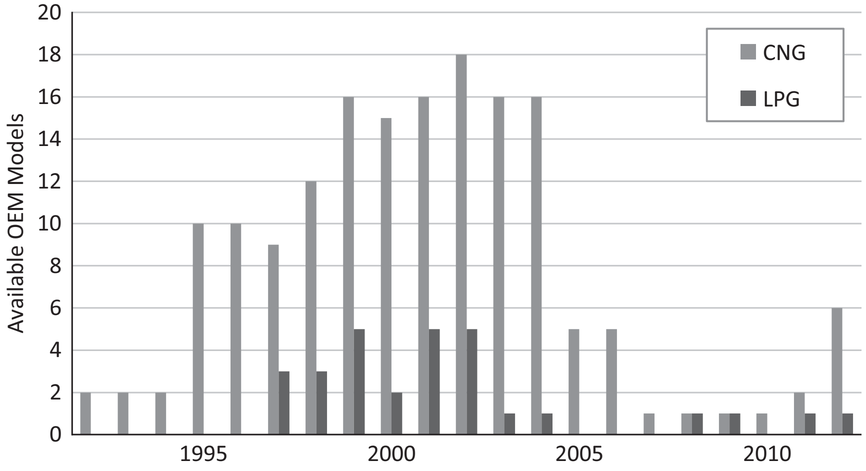
Cost and availability of CNG and LPG vehicle models. The currently limited number of OEM CNG and LPG models, the relatively limited number of conventional vehicle models that can be converted to CNG or LPG, and the high price premium associated with both new vehicles and conversion kits have the effect of limiting adoption of CNG and LPG.

From the 1970s to 1990s, universal conversion kits allowed the conversion of a greater selection of vehicles at a lower cost than today. In 1997, an addendum to the Clean Air Act raised the testing requirements for CNG and LPG conversions and rendered universal kits impermissible. The tighter regulations, while protecting the environment, also made conversions more difficult and costly. Under the more-stringent regulations, conversion kits for different engine families must be tested and certified separately. For instance, a conversion company must design and manufacture a unique conversion kit to certify the 2008 model year 4.6L V8 Ford engine family.

Due to the high investment cost, small-volume manufacturers that develop conversions focus their efforts on the most frequently requested, high-sales fleet vehicles. This in turn limits the variety of vehicle models available to the public (WGA 2008). The year before the new EPA regulation addendum took effect, about 14,000 alternative-fuel conversions were accomplished. In the year the new policy was enacted, the number of conversions of all alternative-fuel vehicles dropped to 8,500 and then steadily declined in subsequent years to around 1,000 conversions per year (Mokhtarian and Cao 2004). Consequently, LPG vehicles lost more than half of their market share between 1995 and the middle of the first decade of the 21st century. The decline in LPG vehicle ownership may be due to the lack of vehicle choice, but it is also possible that the limited availability of options reflects market rejection of LPG vehicles.

In the state of California, CARB certification in addition to EPA certification is required for all conversions, increasing the financial cost for conversion manufacturers and for buyers. Most fuel system providers are relatively small and cannot finance both the EPA and CARB certifications. Most companies, therefore, choose to obtain only the EPA certification to gain market access in 49 states, foregoing CARB certification and the California market. Hence, adoption of LPG and CNG vehicles through conversions in the state of California is a difficult strategy (WGA 2008).

It is still possible that more OEMs could begin to offer CNG and LPG models. As described earlier, OEMs began to offer natural gas models in the early 1990s and LPG models in the late 1990s. Market offerings increased through the early 2000s but then entered a period of decline. In just the past few years, however, stimulated by rising oil prices as well as the increased supply and decreased price of natural gas resulting from horizontal drilling techniques, the number of OEM CNG models, at least, appears to be on the rise once again, as shown in Figure B.2. This could reflect an expectation on



Source: EERE (2012a).

Figure B.2. Available OEM CNG and LPG light-duty models, 1992–2012.

the part of auto manufacturers that the current low cost of natural gas will persist, leading to increased adoption prospects and in turn setting the stage for even more OEM models being offered in the future.

Performance limitations. CNG vehicles face a range limitations in comparison to conventional vehicles, and this could deter some consumers from choosing natural gas. With CNG having lower energy density than gasoline, the vehicles must carry larger fuel tanks, in turn reducing cargo space. These problems could be addressed in the future by producing hybrid-electric versions of the vehicles, which would allow for greater range as well as a smaller fuel tank (WGA 2008).

To remedy the short range of CNG vehicles and the safety concerns associated with highly pressurized CNG fuel tanks, the U.S. Department of Energy set a goal to develop a technology that could store as much natural gas at the lower pressure of 500 psi as can be stored in a conventional CNG tank at 3,600 psi. This goal was achieved in 2007 by a team of researchers that developed carbon briquettes with nanopores capable of storing natural gas (NSF 2007). Once integrated with vehicle manufacturing, such technology could provide safer, lighter, and smaller fuel tanks. Other novel materials capable of holding an even greater density of natural gas and extending the range of CNG vehicles are also possible in the future (NRC 2013).

Another performance issue for CNG vehicles is power. The acceleration power of the Honda Civic GX, for example, is less than that of its gasoline counterpart due to lower horsepower (113 hp versus 140 hp) and greater weight (2,910 lbs versus 2,652 lbs). The heavier weight of the GX results from the larger and heavier CNG fuel tank (Alapati 2010). Here again it is possible that this issue could be at least partially addressed through the addition of hybrid-electric vehicle technology.

Perceived safety concerns. LPG and CNG are safer to use than gasoline in some respects. The ignition temperature of LPG is higher than that of gasoline, and the concentrations for both LPG and natural gas have to be greater than for gasoline before the fuels ignite. The dissipation rate of natural gas is also faster than that of gasoline. Still, public perceptions of the hazards of natural gas and LPG tanks and refueling stations could hinder broader adoption of these technologies. The most significant safety difference between these alternative fuels and gasoline is that the latter is stored at refueling stations and on vehicles as a liquid at atmospheric temperature and pressure. In contrast, LPG and CNG are stored under pressure. CNG, stored under high pressure at 2,000 psi or more on light-duty vehicles, presents the greatest concerns. Valve or tank failure at this pressure could result in an explosion, while a gas leak in a confined space, such as a garage, could lead to an accumulation of gas at a dangerous level of concentration (WGA 2008).

Unresolved environmental concerns about fracking. Technological and economical improvements in horizontal drilling with hydraulic fracturing to further expand the economically recoverable supply of natural gas could reinforce the cost advantages of natural gas over petroleum. It is unclear, however, whether the environmental impacts of this extraction technique could constrain its future application. As previously discussed, there are remaining concerns about the effects on surrounding groundwater supplies (e.g., Osborn et al., 2011). While some experts are cautious in their views about the long-term production potential from unconventional sources, others believe that as much as 64% of U.S. natural gas production could come from unconventional sources by 2020 (Vidas and Hugman 2008).

Competing uses for natural gas. As noted earlier, natural gas is already used in many other applications, such as power generation, industrial processes, and residential heating and cooking. Depending on available supply, its use in transportation could hinge on its relative value across these different possible uses (NRC 2013).

Potential for biomethane. Gathering natural gas from landfills, animal waste, sewage, and other renewable resources could provide an additional supply of natural gas and remove a greenhouse gas (methane) that otherwise would have been released into the atmosphere. The crude natural gas collected from such sources, typically referred to as biogas, can be purified and refined into biomethane to produce fuel for vehicles. The production technology to collect, process, and distribute biomethane is currently more established in Europe and elsewhere than in the United States. Iceland operates 100% of its natural gas vehicle fleet using biomethane, and Switzerland and Sweden power more than 50% of their natural gas vehicles with biomethane (WGA 2008). In Austria, the number of biomethane production plants has grown from approximately 50 in 1999 to 350 in 2008 (Baumgartner, Kupusovic, and Blattner 2010). As part of an economic recovery package, the European Commission invested five billion euros in the European Green Cars initiative, and biomethane for transportation was one of the main research topics (EC, undated). Only a few projects to process biogas from landfills for transportation currently exist in the United States, mostly in California (Lear 2008). As the European examples show, lack of technical capabilities is not a barrier to the increased production of renewable natural gas. The Department of Energy estimates that the United States could produce enough biomethane to replace 10 billion gallons of gasoline annually, given supportive economic and regulatory conditions, from such sources as landfills, animal waste processing, and sewage (WGA 2008).

Potential for methanol. Another technical option receiving some attention is to convert natural gas into methanol, which can then be used to power existing flex-fuel vehicles with a modest investment in an air/fuel mixture control and an alcohol sensor. The additional vehicle expense is estimated at between $100 to $200. The equivalent of a gallon of gasoline in methanol can be produced for about $2.00 when natural gas costs $8 per million Btus (MIT 2011). Natural gas is currently priced well below that figure, suggesting that methanol could be a cost-effective alternative to gasoline. Methanol can also be blended with gasoline for use in vehicles, similarly to the way ethanol is blended with gasoline. Despite the favorable economics, methanol demand has remained low in recent years, in part due to the phaseout of methyl-tertiary butylether (MTBE), a fuel additive aimed at increasing fuel octane levels that was linked to groundwater contamination issues. MTBE is derived from methanol and butane. Methanol also has about half the energy content of traditional gasoline, so the range of a tank of 100% methanol fuel is only about half that obtained from a similarly sized tank of gasoline. Nevertheless, it has been suggested that methanol represents a promising alternative fuel with the potential to fuel a large portion of the U.S. transportation fleet (MIT 2011).

References

Alapati, J. 2010 (January 18). "Car Review: Honda Civic GX." Reporter mag.com.

Alvarez, R. A., S. W. Pacala, J. J. Winebrake, W. L. Chameides, and S. P. Hamburg. 2012. "Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure." *Proceedings of the National Academy of Sciences*, 109 (17): 6435–6440.

ANL. 2012. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)*, Fuel Cycle Model version 1 2012. U.S. Department of Energy.

API. 2013. Oil & Natural Gas Overview: Service Station FAQs. http://www.api.org/oil-and-natural-gas-overview/consumer-information/service-station-faqs (accessed July 20, 2013).

Baumgartner, B., M. Kupusovic, and H. T. Blattner. 2010. *National Report on Current Status of Biogas/Biomethane Production – Austria.* Intelligent Energy - Europe Programme.

BP. 2012. *BP Statistical Review of World Energy 2012.*

BTS. 2013. Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances. *National Transportation Statistics.* http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html (accessed September 6, 2013).

EC. Undated. Green Cars. http://ec.europa.eu/research/industrial_technologies/green-cars_en.html (accessed September 25, 2012).

EERE. 2010. *Clean Cities 2010 Vehicle Buyer's Guide.*

EERE. 2012a. Light-Duty Vehicle Search. Alternative Fuels Data Center. http://www.afdc.energy.gov/vehicles/search/light/ (accessed September 21, 2012).

EERE. 2012b. Propane Benefits and Considerations. http://www.afdc.energy.gov/fuels/propane_benefits.html (accessed September 21, 2012).

EERE. 2012c. Propane Fuel Basics. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/propane_basics.html (accessed September 21, 2012).

EERE. 2012d. Propane Vehicle Conversions. Alternative Fuels Data Center. http://www.afdc.energy.gov/vehicles/propane_conversions.html (accessed September 21, 2012).

EERE. 2012e. Alternative Fueling Station Total Counts by State. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/stations_counts.html (accessed September 20, 2012).

EERE. 2012f. Natural Gas. Alternative Fuels Data Center. http://www.afdc.energy.gov/vehicles/natural_gas.html (accessed September 21, 2012).

EERE. 2013a. Federal Laws and Incentives. Alternative Fuels Data Center. http://www.afdc.energy.gov/laws/ (accessed September 11, 2013).

EERE. 2013b. Fuel Prices. http://www.afdc.energy.gov/fuels/prices.html (accessed September 12, 2013).

EERE. 2013c. Natural Gas Benefits and Consideration. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/natural_gas_benefits.html (accessed September 12, 2013).

EIA. 2012a. Renewable and Alternative Fuels: Alternative Fuel Vehicle Data. http://www.eia.gov/renewable/afv/users.cfm (accessed September 12, 2013).

EIA. 2012b. Natural Gas Explained: Use of Natural Gas. http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_use (accessed September 20, 2012).

EIA. 2012c. *U.S. Crude Oil, Natural Gas, and NG Liquids Proved Reserves: With Data for 2010.*

EIA. 2012d. Natural Gas: U.S. Dry Natural Gas Proved Reserves. http://www.eia.gov/dnav/ng/hist/rngr11nus_1a.htm (accessed September 20, 2012).

EIA. 2013. *Annual Energy Outlook 2013.*

ETSAP. 2009. *Liquid Petroleum Gas and Natural Gas Internal Combustion Engines.*

Fueleconomy.gov. 2012. Federal Tax Credits for Alternative Fuel Vehicles. http://www.fueleconomy.gov/feg/tax_afv.shtml (accessed September 21, 2012).

Honda. 2012. To Each Their Own Civic. http://automobiles.honda.com/civic/ (accessed September 21, 2012).

Hyundai. 2009. "Hyundai Elantra LPi Hybrid Official Press Release"

IEA. 2012. *World Energy Outlook 2012.*

Lear, J. 2008 (November 20). "NGV Technology Efforts: Biogas for Transportation." Presented at the Natural Gas Vehicle Technology Forum, Downey, California.

Litovitz, A., A. Curtright, S. Abramzon, N. Burger, and C. Samaras. 2013. "Estimation of Regional Air-Quality Damages from Marcellus Shale Natural Gas Extraction in Pennsylvania." *Environmental Research Letters*, 8 (1): 014017.

MIT. 2011. *The Future of Natural Gas.* MIT Energy Initiative.

M. J. Bradley and Associates. 2005. *Natural Gas as a Transportation Fuel: Best Practices for Achieving Optimal Emissions Reduction.* Northeast States Center for a Clean Air Future and International Council on Clean Transportation.

Mokhtarian, P. L. and X. Cao. 2004. *The Future Demand for Alternative Fuel Passenger Vehicles: A Diffusion of Innovation Approach.* California Department of Transportation.

NGVA. 2010. *Guide to Available Natural Gas Vehicles and Engines.*

NGVA. 2011. Fact Sheet: Converting Light-Duty Vehicles to Natural Gas.

NPC. 2007. *Meeting the Challenges of the Nation's Growing Natural Gas Demand.*

NPC. 2012. *NPC Future Transportation Fuels Study: Advancing Technology for America's Transportation Future.*

NRC. 2013. *Transitions to Alternative Vehicles and Fuels.* The National Academies Press, Washington, D.C.

NSF. 2007. "From Farm Waste to Fuel Tanks." Press release.

O'Dell, J. 2011. "BRC Fuel Maker Again Selling Phill Home CNG Fuel Station." http://www.edmunds.com/autoobserver-archive/2011/03/brc-fuelmaker-again-selling-phill-home-cng-fuel-station.html.

Osborn, S. G., A. Vengosh, N. R. Warner, and R. B. Jackson. 2011. "Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing." *Proceedings of the National Academy of Sciences*, 108 (20): 8172–8176.

PGC. 2009. *Potential Supply of Natural Gas in the United States.*

TCPA. 2008. Chapter 5: Natural Gas. In *The Energy Report 2008.*

Vidas, H. and B. Hugman. 2008. *Availability, Economics, and Production Potential of North American Unconventional Natural Gas Supplies.* The INGGA Foundation.

WGA. 2008. *Transportation Fuels for the Future: Natural Gas and Propane.*

Yacobucci, B. D. 2005. *Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues.* Congressional Research Service.

Yacobucci, B. D. 2008. *Natural Gas Passenger Vehicles: Availability, Cost, and Performance.* Congressional Research Service.

APPENDIX C

Liquid Biofuels

The displacement of petroleum with liquid fuels produced from biomass, commonly referred to as "biofuels," promises several potential advantages. Estimates suggest that domestically produced biofuels could further the objective of energy security by meeting roughly a third of U.S. transportation fuel needs (Parker et al. 2011). Also, depending on their feedstocks and production methods, biofuels could help reduce greenhouse gas emissions from the transportation sector.

Biofuels can be classified by their technological and economic maturity. First-generation biofuels include ethanol from the fermentation of corn, sugar cane, and other sugary or starchy food crops along with biodiesel derived from oil seeds such as soy and canola through a chemical process known as transesterification. (Waste fats and cooking oil can also be used to produce biodiesel, but these feedstocks are more limited in quantity.) These first-generation fuels are widely in use today, and most people use the term "biofuels" to mean ethanol and biodiesel.

There are a wide variety of potential feedstocks and production pathways for more advanced, second-generation biofuels. Most prominent among these is the production of cellulosic ethanol or butanol through biochemical processes using wood, grasses, or crop wastes (e.g., corn stover) as feedstocks. Thermochemical processes can also be used with biomass feedstocks to create drop-in gasoline and diesel replacements (often described as green gasoline and green diesel or renewable diesel) that work well with existing vehicles and distribution infrastructure without the need for blending. These thermochemical processes include biomass gasification followed by Fischer-Tropsch catalytic processing, gasification to produce methanol followed by the conversion of methanol to gasoline, pyrolysis followed by hydroprocessing, and other hybrid approaches (NRC 2009, 2013). Algae, which offers the advantage of requiring less land and water to produce, is also being explored as a potential feedstock for biofuels (NPC 2012, NRC 2013).

There are a number of challenges and uncertainties related to the broader use of biofuels. These include issues associated with distribution logistics, biomass feedstock availability, and the environmental effects of large-scale domestic production and consumption of biofuels. It remains unclear which approaches for producing biofuels will be most effective in the long run at scales and costs needed to offset a significant portion of U.S. petroleum consumption. This appendix discusses recent experience with biofuels in the United States along with issues and factors that will influence the future penetration of biofuels in the surface transportation sector.

Unlike other alternative fuels such as natural gas or hydrogen, first-generation biofuels are generally not used alone in vehicles but rather are blended with gasoline or diesel fuel. Ethanol is routinely blended with gasoline in mixtures of 10% or less (E10) but can be blended all the way up to 85% (E85) in the United States. One advantage of the E10 blend is that conventional engines can burn this mix of ethanol efficiently without any modifications. Biodiesel can likewise be blended with conventional diesel fuel in a mix known as BD20. As with E10 for gasoline engines, conventional diesel engines can use BD20 efficiently without any modifications.

Ethanol is the dominant biofuel for light-duty vehicles in the United States today (the majority of which use gasoline engines), with biodiesel used in some light-, medium-, and heavy-duty vehicles with diesel engines. Much of the material in this appendix focuses on ethanol, but the discussion encompasses biodiesel and other biofuels as well.

C.1 Production, Distribution, and Refueling

Biofuel production can be broken up into several steps. First, biomass must be grown and harvested. After being harvested, the biomass must be stored and transported to a biorefinery, where it is converted to biofuel. After the biofuel is produced, it must be transported to blending stations before it is distributed to retail stations for sale and consumption. The following discusses these steps in more detail.

C.1.1 Production

For ethanol currently refined in the United States, the dominant production supply chain begins with corn production, mostly in the Midwest. The corn is typically delivered by truck or rail to an ethanol plant or biorefinery, where it is then processed into cornstarch and fermented. In 2011, ethanol supplied about 10% by volume of total U.S. demand for gasoline (NRC 2013).

An alternative to corn-based ethanol is cellulosic ethanol. Cellulosic ethanol can be made from breaking down the woody fibers in trees, grasses, and crop wastes. The process used to make cellulosic ethanol requires less energy per unit of fuel and generally produces lower emissions than the corn ethanol process. During 2011, three cellulosic biorefineries were in operation worldwide, collectively producing an estimated 3 million gallons of ethanol (Parker et al. 2011). However, the commercial viability of cellulosic ethanol conversion technologies at much larger scales has yet to be demonstrated.

Biodiesel is produced by processing vegetable oils or animal fats and can be made from a wide variety of feedstocks. The biodiesel fuels produced by different feedstocks vary in certain characteristics, which can limit their suitability for commercial use. One of the most important properties is known as the cloud point, the temperature at which the fuel begins to gel and solidify. Higher cloud points are problematic for operations in cold-weather climates during winter months. The domestic production of biodiesel is considerably less than ethanol. Total U.S. biodiesel production was 343 million gallons in 2010, 967 million gallons in 2011, and 969 million gallons in 2012 (EIA 2013c). In 2011, biodiesel supplied less than 1% of total U.S. transportation fuel demand (NRC 2013).

Renewable diesel, a second-generation biofuel, is the product of fats or vegetable oils that are refined in a process that involves hydrogenating triglycerides to remove metals and compounds with oxygen and nitrogen. A key benefit of renewable biodiesel in comparison to biodiesel is that it meets quality standards that allow it to be blended in any combination with petroleum-based diesel fuel without modifying vehicle engines or fueling infrastructure (EERE 2012b).

Another pathway is algae-based biofuels. Algae cultivation suitable for biofuel production requires sunlight and a source of carbon dioxide. To enhance productivity, most algae cultivation schemes for biofuels involve using carbon dioxide concentrations well above the atmospheric level—for example, a stream of captured CO_2 emissions from a fossil-fueled power production plant. Due to the early stage of development of algal oil processes, the net greenhouse gas emissions performance of algal biofuels remains uncertain, as does the ability of algae to provide sufficient feedstock for large-scale production at reasonable cost (Bartis and Van Bibber 2011, NPC 2012, NRC 2013). Algae does, however, have the advantage of requiring much less land and water for production than herbaceous energy crops, nearly eliminating concerns about emissions from indirect land-use change (Williams et al. 2009).

C.1.2 Distribution

The most economical method of transporting liquid fuels is via pipelines. Gasoline, for example, is transported in large quantities from refineries to distribution centers via pipeline. In the United States to date, however, about 60% of ethanol is delivered to fuel blending facilities by rail, with another 30% by truck and 10% by barge (NPC 2012). Pipelines are not generally used to transport ethanol for a variety of reasons. First, water and other impurities that normally reside in fuel pipelines can be absorbed by ethanol. The water and impurities can then damage engines or degrade performance. Second, much of the existing pipeline infrastructure flows from the Gulf of Mexico north and east, while biofuels produced in the Midwest need to travel in the opposite direction and to the coasts (NPC 2012). While ethanol is produced in more than 20 states, 90% of the production capacity is clustered in just eight Midwest states—Iowa, Nebraska, Illinois, Minnesota, South Dakota, Indiana, Kansas, and Wisconsin. Since roughly 80% of the U.S. population lives near the coasts, the distribution of biofuels at much greater volumes would pose significant challenges (Denicoff 2007). Transporting biodiesel via pipeline is also problematic; due to certain properties, it can sometimes cling to pipeline walls and get picked up by other fuels that flow through the pipeline subsequently (NPC 2012).

C.1.3 Consumption and Refueling

Once ethanol is transported to blending facilities, it is mixed with gasoline into the final fuel blend and then trucked to retail outlets. Consumption of ethanol in the United States has grown from 1.7 billion gallons in 2000 to 12.9 billion gallons in 2012 (EIA 2013c). Nearly all of the ethanol currently consumed in the United States is blended with gasoline in volumes containing up to 10% ethanol (E10) for use in conventional vehicles.

The EPA issued waivers allowing the sale of 15% ethanol blends (E15) for use in any light-duty vehicles with a model year of 2001 or later. According to Koenig (2012), E15 was first offered for sale by a station in Kansas in 2012. While the retail price of E15 is less than that of lower ethanol blends, Koenig notes that the price differential is somewhat misleading given that the higher ethanol concentration reduces the energy content of the fuel, resulting in a reduction in miles per gallon and vehicle range. Auto manufacturers have also been resistant to endorse the use of E15, even in new vehicles, claiming that the vehicles are not optimized to use blends of ethanol higher than E10 (Koenig 2012).

Many automakers have produced specially configured flex-fuel vehicles to accommodate ethanol in blends of up to 85% (E85). The usage of E85 is currently concentrated in the Midwest, where the majority of American corn is produced. The availability of E85 fueling stations in the United States remains limited to date, with about 2,300 stations that are predominately concentrated in the Midwest (EERE 2013). The weather in many states dictates that the ethanol content of E85 be reduced to a 70% blend during colder months to prevent cold starting problems.

As with ethanol, biodiesels can be blended with conventional diesel at manufacturing facilities before being distributed by tanker truck, avoiding the need for separate storage infrastructure at gas stations. U.S. consumption of biodiesel, most of which is currently produced from soybean oil, has grown from 10 million gallons in 2001 to 870 million gallons in 2012, but continued growth may be hindered by competing land uses (EIA 2013c).

C.1.4 Government Policies to Support Biofuels

While biofuels offer energy security benefits, they face important limitations in terms of cost and performance. Reductions in greenhouse gas emissions are modest with current feedstocks and production processes, and there are additional environmental concerns related to land use, water consumption, and local air pollution emissions. Even with these limitations, however, use of biofuels has grown rapidly over the past two decades. Strong federal and state regulations and incentives have played a major role in spurring this growth.

The federal and state governments have supported biofuels through a broad array of policy interventions. Without this support, biofuels would not be cost-competitive with conventional gasoline and diesel fuel, even at the higher petroleum prices experienced over the past few years. In response to the 1970s oil embargo, the Energy Tax Act of 1978 removed a $0.04 per-gallon excise tax on gasoline for "gasohol" blends containing at least 10% ethanol (Koplow 2006). This was followed by a series of federal tax credits to further support biofuels, as summarized in Table C.1. The United States had also imposed a tariff of $0.54 per gallon on ethanol from Brazil for many years to help protect U.S. ethanol producers, though this expired in 2011 (Schnepf 2013).

Beyond tax policy, the federal government and some states have further supported growth in biofuels through renewable fuel standards that require fuel vendors to provide an escalating supply of ethanol, biodiesel, and more advanced biofuels. At the federal level, the Energy Independence and Security Act of 2007 set a renewable fuel standard (RFS2) that began with 13 billion gallons in 2010 and increases each year to reach a total of 36 billion gallons by 2022. RFS2 was finalized in February 2010 and defines four categories of fuels: cellulosic biofuel, biomass-based diesel, advanced biofuels, and other renewable fuels. Fuels from each category must meet different standards for greenhouse gas reductions to qualify—for instance, cellulosic biofuels must meet a 60% reduction over the petroleum baseline—and each category has separate volumetric targets for each year (EPA 2010).

Schnepf (2013) estimated that U.S. government outlays for biofuels peaked at $7.7 billion in 2011 and then declined to $1.3 billion in 2012 with the expiration of the ethanol blender's tax credit. Since current biofuel production processes, if stripped of tax incentives, are not yet cost-competitive with petroleum-based fuels for the most part, future increases in biofuel use in the United States will likely require continued subsidies along with the implementation of progressively more-stringent renewable fuel standards under RFS2.

C.2 Vehicle Technologies

Biomass-derived ethanol can be combusted efficiently in conventional vehicles using E10, but low-alcohol blends such as E10 do not qualify as alternative fuels under the Energy Policy Act of 1992. FFVs sold in the United States are able to use blends that range from 100% gasoline to 85% ethanol;

Table C.1. Federal tax credits available for qualifying biofuels.

Legislation	Tax Credit ($/gallon)	Expiration Date
Volumetric Ethanol Excise Tax	0.45	12/31/2011
Small Ethanol Producer Credit	0.10	12/31/2011
Biodiesel Tax Credit	1.00	12/31/2013
Small Agri-Biodiesel Producer Credit	0.10	12/31/2013
Renewable Diesel Tax Credit	1.00	12/31/2013
Credit for Production of Cellusoic and Algae-Based Biofuel	1.01	12/31/2013

Source: Schnepf (2013).

blends above E85 are not used because higher ethanol concentrations can make it difficult for vehicles to start in cold weather.

FFVs include a sensor that automatically detects the amount of ethanol in the fuel, and the vehicle computer then modifies the fuel injection and spark timing accordingly. This involves a modest incremental cost, although automakers generally offer FFVs at the same price as comparable conventional vehicles.

The impressive sales of FFVs in the United States to date may reflect the concerted marketing efforts of auto manufacturers motivated by the opportunity to gain credits under the CAFE mandate rather than a response to strong consumer demand for the ability to fuel with E85. Between 1998 and 2009, the number of FFVs in the United States increased from a very small number to nearly 10 million (EIA 2013b). Yet available estimates indicate that only about 860,000 of these are fueled primarily with E85 (EIA 2013a).

C.3 Cost and Performance

Configuring conventional vehicles to run on biofuels involves minimal additional cost. Absent subsidies, however, ethanol and biodiesel remain more expensive than gasoline and diesel on an energy-equivalent basis. Additionally, biofuels face certain power and range limitations. Finally, though advanced biofuels promise potentially impressive reductions in GHG emissions, they may exacerbate some air quality challenges, especially for PM and NO_x.

C.3.1 Vehicle Cost

In comparison to other alternative-fuel vehicle technologies, such as electric vehicles or hydrogen fuel-cell vehicles, FFVs are relatively easy to produce, requiring only modest changes to conventional vehicle design. Corts (2010) estimates that the additional cost for producing an FFV in comparison to an otherwise identical conventional vehicle is only around $100 in most cases. Assuming that the other challenges associated with biofuels—such as higher energy-equivalent fuel cost and relative paucity of refueling infrastructure—could be addressed, vehicle cost would not be an impediment to much broader adoption.

C.3.2 Energy Cost of Travel

While gasoline and ethanol prices are both prone to volatility, ethanol tends to be more expensive than gasoline on a gge basis. In October of 2010, for example, the national average price of gasoline was $2.78 per gallon, while E85 sold for $3.45 per gge (EERE 2010). In January of 2012, the average cost of gasoline had risen to $3.76 per gallon, while E85 was selling for $4.96 per gge (EERE 2012a). Biodiesel also tends to be more expensive than diesel fuel on an energy-equivalent basis, though the margin is much smaller than that observed for E85 and gasoline. In January of 2012, the national average price of diesel was $3.86, while BD20 sold for $4.02 per gallon of diesel equivalent (EERE 2012a).

C.3.3 Operational Performance

Ethanol contains less energy than gasoline on a volumetric basis, which is why the respective costs of gasoline and E85 are typically compared on an energy-equivalent basis. A gallon of ethanol contains the energy content of 0.67 gallons of gasoline. This means that an FFV running on E85 will have only 72% of the range provided by pure gasoline, or about 74% of the range provided by E10. Correspondingly, the fuel economy for FFVs using E85 is about 25% to 30% lower, measured on a per-gallon basis rather than on an energy-equivalent basis, than when using conventional fuel (West et al. 2007). Beyond cost considerations, then, the use of E85 is also less convenient since it requires more frequent refueling stops.

Note that vehicles optimized specifically for ethanol blends of E85 through E100 (100% ethanol) can in theory operate at equal or greater efficiency than when running on pure gasoline. This is due to ethanol's higher octane rating, allowing its use in higher-compression engines. Sensors monitoring the alcohol content can work in tandem with a turbocharger to push extra air into the engine cylinders when running on high-ethanol blends, producing extra power without losing fuel economy. This type of technology, however, is currently only in use in a few high-end supercars and concept cars (West et al. 2007).

C.3.4 Greenhouse Gas Emissions

Given the energy- and fertilizer-intensive nature of U.S. corn production and the potential for associated land-use changes to affect emissions, several studies (e.g., Mullins, Griffin, and Mathews 2010) of the well-to-wheels greenhouse gas effects of corn ethanol showed negligible reductions or even net increases in GHGs. ("Well-to-wheels" refers to the full fuel cycle, including producing, distributing, and combusting the fuel.) Hence, the well-to-wheels GHG emissions associated with biofuels are subject to uncertainty and are a continued focus of research.

In an earlier study, Delucchi (2006) compared well-to-wheels GHGs for gasoline, corn-based E90, and cellulosic E90 based on hypothetical specifications for an FFV in both the 2010 and 2040 time frames. The results are shown in Table C.2. Conducted before the recent advent of more-stringent federal fuel economy standards, the analysis assumes only a modest improvement in the fuel economy for a conventionally fueled

Table C.2. Well-to-wheels GHG reductions for E90 vehicles in 2010 and 2040.

Fuel	2010		2040		
	GHG Emissions (grams/mile CO_2 equiv.)	Percent Reduction vs. 2010 Gasoline	GHG Emissions (grams/mile CO_2 equiv.)	Percent Reduction vs. 2010 Gasoline	Percent Reduction vs. 2040 Gasoline
Gasoline	550.7	—	504.1	8%	—
E90 corn	539.7	2%	458.7	17%	9%
E90 cellulosic	308.4	44%	146.2	73%	71%

Source: Delucchi (2006).

vehicle, and in turn for FFVs, between 2010 and 2040. Even so, the potential GHG emissions reductions for cellulosic ethanol in the 2040 time frame, and even in the 2010 time frame, are significant. The reductions for corn-based ethanol, in contrast, are modest.

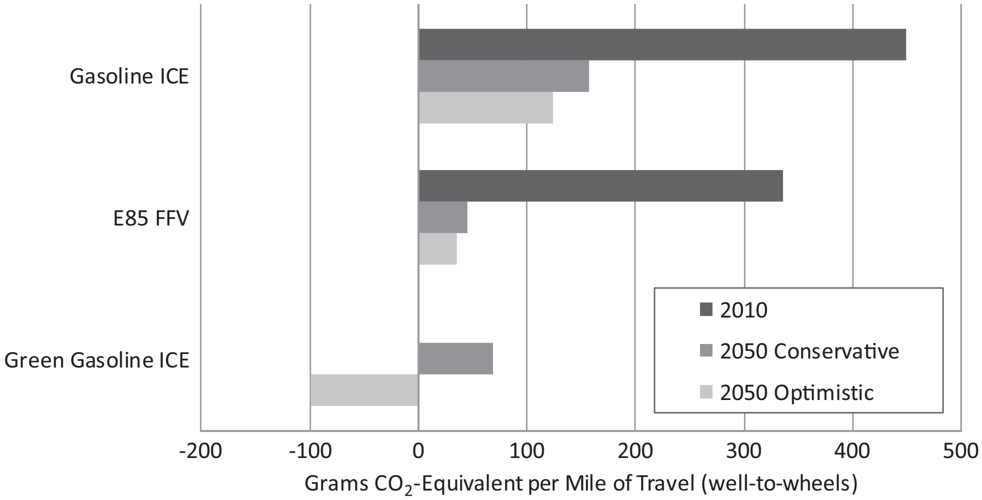
Cellulosic ethanol, examined on a well-to-wheels basis, is not generally expected to eliminate all GHG emissions because there are still emissions from the production of feedstocks and fertilizers and from distribution and land use changes. Indeed, estimates of the full fuel-cycle GHG emissions for ethanol vary substantially depending on the method of analysis, with assumptions about the proper allocation of emissions to coproducts and about the estimation and inclusion of indirect emissions stemming from land use changes responsible for much of the uncertainty (e.g., Farrell et al. 2006, Searchinger et al. 2008, Williams et al. 2009). Additionally, cellulosic ethanol has yet to be produced at commercial scale, adding further uncertainty to the estimates.

To facilitate a consistently framed examination of the GHG emissions reduction potential for the different fuels and vehicle technologies considered in this study, the research team conducted an exercise relying on emissions factors from ANL's GREET model (ANL 2012). The team used the GREET specifications for a mid-size passenger vehicle in 2010 along with two hypothetical configurations for similar vehicles in the 2050 time frame. The two future cases are broadly consistent, with expectations in the literature regarding possible advances in fuels and vehicle technologies, but one embeds moderate baseline assumptions while the other is more optimistic.

In the following, the GHG emissions modeling results are presented for conventional vehicles and biofuel vehicles for 2010 and 2050. The intent of including both current and future conventional vehicles is to help clarify not only how biofuels might perform in relation to the current light-duty fleet but also how they might perform against conventional fuels and vehicles with much-improved fuel economy in the future. On-road (as opposed to EPA-rated) fuel economy is used for all vehicles, and corn-based E85, switchgrass-based cellulosic E85, and gasoline derived thermochemically from biomass are compared on a well-to-wheels basis. For current biofuels, corn-based E85 estimates from GREET are used. For the 2050 ethanol baseline scenario, baseline 2050 fuel economy estimates from NRC (2013) and GREET estimates of carbon intensity for switchgrass-based cellulosic E85 are used. For the 2050 ethanol optimistic scenario, the fuel economy is increased to reflect NRC's (2013) optimistic estimates.

ANL's GREET model (ANL 2012) estimates that a current FFV running on corn-based E85 would produce about 25% less GHGs on a well-to-wheels basis than an otherwise similar conventional vehicle; with cellulosic E85, the well-to-wheels reduction could be greater than 65%. It is important to note that GREET does not include emissions from indirect land-use changes associated with growing biomass, which are uncertain but potentially substantial (NPC 2012, NRC 2013). As noted, under some assumptions of emissions from land use change, current corn ethanol can have higher GHGs than conventional gasoline. Because the GREET model is used to compare GHGs across fuels, in Figure C.1 a case is not shown where corn ethanol has higher GHGs than gasoline, but it is important to continue to monitor the research in this area. Sources of uncertainty regarding future emissions for biofuels include the effects of land use changes, potential process improvements, changes in emissions estimates associated with coproducts, and whether carbon capture and storage is used during production. To bound future estimates, the researchers also looked at future cases of thermochemical drop-in gasoline with and without CCS, both of which include the indirect effects of land use changes as estimated by NRC (2013). Table C.3 provides a summary of the assumptions used in the GHG comparison test cases, including fuel economy for the vehicles in miles per gallon of gasoline equivalent (mpgge) and carbon intensity of the fuels in kilograms of carbon dioxide equivalent (CO_2e) per gallon of gasoline equivalent (kg CO_2e/gge).

Based on these assumed specifications and GREET's emissions factors, Figure C.1 graphs the greenhouse gas emissions performance for current and future conventional and biofuel



Source: Computations by authors based on data from ANL (2012) and NRC (2013).

Figure C.1. GHG reduction prospects for liquid biofuels in 2050.

vehicles in grams CO_2-equivalent per mile of travel. All of the estimates are for well-to-wheels emissions. Note that no value is listed for drop-in green gasoline in 2010 because this product is still in the research and development phase. Additionally, given that the optimistic case for green gasoline includes carbon capture and sequestration in the production process, net GHG emissions are actually negative, consistent with plausible future outcomes from NRC (2013).

C.3.5 Local Air Pollutant Emissions

Although advanced liquid biofuels promise significant GHG reduction benefits in future decades, their expected effects with respect to air quality are less certain. The GREET model (ANL 2012) estimates, for example, that the use of corn-based E85 could lead to increased emissions for volatile organic compounds, nitrogen oxides, and fine particulate matter in comparison to standard gasoline. Future reductions in air pollutants from biofuels could be achieved, however, as biofuel feedstocks and production processes are improved and rely on electricity with fewer emissions.

C.4 Market Prospects

Assisted by government subsidies and RFS2 requirements, the production of biofuels has scaled up rapidly in recent years, and the number of FFVs has increased as well. Most projections indicate increased production over the next several decades, though there is greater uncertainty regarding their ultimate market potential.

Table C.3. Assumptions for biofuels emissions comparisons.

Assumptions	2010	2050 Base	2050 Optimistic
Assumed fuel economy for gasoline ICE and FFV			
mpgge	24.8	72	91
Life-Cycle Fuel Carbon Intensity Assumptions for FFV running on E85			
Pathway	Corn ethanol	Cellulosic ethanol from switchgrass	Cellulosic ethanol from switchgrass
kg CO_2e/gge	8.3	3.2	3.2
Life-Cycle Fuel Carbon Intensity Assumptions for gasoline ICE running on drop-in green gasoline			
Pathway	N/A	Thermochemical with indirect land-use change	Thermochemical with indirect land-use change and carbon capture and sequestration
kg CO_2e/gge	N/A	5.0	-9.0

Source: Computations by authors based on data from ANL (2012) and NRC (2013).

C.4.1 Future Market Projections

In its most recent *Annual Energy Outlook*, the EIA (2013b) projects that the share of new light-duty cars and trucks sold with flex-fuel capability will hold steady at approximately 9% between 2012 and 2040. However, usage of E85 in the light-duty fleet over this same time period is expected to accelerate, growing from about 117 million gallons in 2012 to about 2 billion gallons in 2040. EIA's forecast for E85 is highly sensitive to assumptions about the price of oil. Under EIA's high oil price scenario, for example, use of E85 in 2040 increases to 7.4 billion gallons.

The U.S. Department of Agriculture (USDA) issues 10-year projections for corn production, including the share that will be devoted to corn ethanol, with the most recent release offering estimates through 2023 (USDA 2013). About 5 billion bushels of U.S. corn were diverted to make ethanol and by-products in 2011-2012, representing about 40% of the total U.S. corn crop. In 2022–2023, the USDA expects that the amount of corn used for ethanol will be about the same, at 5.3 billion bushels. Because total production is expected to rise, though, corn for ethanol will only account for about 34% of total corn production. The farm price per bushel is forecasted to drop from $6.22 in 2011–2012 to $4.85 in 2022–2023, which could translate into lower costs for corn ethanol (USDA 2013).

Several additional studies have examined long-range prospects for biofuel production in the United States (e.g., Perlack et al. 2005, DOE 2011, NRC 2011). Perlack et al. (2005) examined the question of whether biofuel production could displace 30% of current U.S. petroleum consumption by 2030, which would translate to 90 billion gallons of biofuels per year. The authors concluded that biofuels could achieve that goal under aggressive assumptions about improved grain yields, expansion of production to idle cropland and pastures, and greater utilization of residues and manures.

Several reviews of the Perlack study, however, have cautioned that the assumptions employed might be overly aggressive. West et al. (2009) used a sensitivity analysis to understand the likelihood of meeting the goal of 90 billion gallons under various conditions. They concluded that oil and feedstock prices, large-scale development of energy crops, and improvements in cellulosic conversion yields would all be important factors in whether the goal could be met. For example, if short-rotation woody crops were not available, the expected yield would be about 78% of the 90 billion gallon per year target. If no additional energy crops became available, the yield might be only 50% of the target value.

The DOE updated the Perlack study in 2011. The updated study forecasted that 767 to 1,305 million tons of additional biomass could be available in 2030, depending on energy crop productivity assumptions, at a farm gate price of less than $60 per ton. They found that the potential resource is more than adequate to produce 20 billion gallons of cellulosic ethanol (DOE 2011).

C.4.2 Factors Affecting Market Prospects

While the projections and studies just discussed suggest the possibility for continued growth in biofuels, there are several remaining issues and challenges that could, if not successfully addressed, act to limit their ultimate market potential.

Economics. The primary barrier for biofuels to displace large amounts of petroleum is economic; unless the cost to produce cellulosic biofuels declines, such fuel will require subsidies or mandates to be competitive with oil at any price less than $190 per barrel (NRC 2013). While drop-in fuels such as green gasoline and green diesel appear to hold promise over the longer term, they are still at a relatively early stage in the research and development cycle, and their economic viability remains uncertain. Another concern is the potential for higher food prices if food crops are diverted for fuel production or if the production of energy crops drives up the price per acre of arable land that could otherwise have been used to produce food.

Uncertain technical prospects for cellulosic ethanol. Presently in the United States almost all ethanol is produced from corn. While cellulosic ethanol promises higher yields and greater greenhouse gas emissions reductions, it is produced in only limited quantity—mainly in demonstration projects—given its high cost. Many technologies for biological and thermochemical conversion of cellulosic feedstocks to ethanol are being explored, but to date, a low-cost, efficient, and commercially scalable solution has yet to emerge (Yang and Wyman 2008, Laser et al. 2009). Farmers will need to have some certainty that the demand for cellulosic feedstocks will rise significantly before they are willing to invest in the production of cellulosic feedstocks.

Air quality effects. Emissions for certain criteria pollutants can be worse for corn-based ethanol than for gasoline-fueled vehicles. If criteria pollutant emissions continue to play an important role in government regulations, corn-based biofuels may not qualify for subsidies or other benefits. Biofuels perform better with respect to greenhouse gases, but the benefits from corn-based biofuels are modest at best. This could lead to more pressure to move from corn to cellulosic feedstocks for greater emissions reductions.

Blending and storage capacity. The present number of blending facilities is relatively small and would need to be greatly increased to accommodate a significant role for ethanol and biodiesel within the transportation sector. These facilities have relatively high capital costs, and producers may be unwilling to make the necessary investments until there is greater certainty regarding future market share for biofuels. Ethanol is commonly blended into conventional gasoline in concentrations of up to E10, and this may rise over time to E15. As the total volumetric requirements of the RFS rise annually, however, and as a progressively more efficient vehicle fleet uses less gasoline, higher blending percentages will be required to meet biofuel targets. In contrast, this blend-wall challenge is not an issue for drop-in biofuels, which will likely hasten their development.

Transport capacity. The biomass ethanol supply chain uses trucks, rail, and, in some cases, barges to distribute feedstocks, ethanol, and the final blended product. As discussed earlier, nearly 60% of ethanol currently travels by rail and another 30% by truck. Significant increase in the production and transportation of feedstocks and biofuels, without the wider use of pipelines, would add further stress to the national freight system.

Vehicle stock and refueling infrastructure. Tyner, Dooley, and Viteri (2011) provide further analysis of the blend wall that caps the amount of ethanol usable by the transportation sector as a result of overall fuel demand and limits on blending ratios. Expanding consumption to meet a mandate of 22 billion gallons per year of renewable fuel by 2022 using only ethanol would, in the authors' estimation, require over $30 billion in infrastructure and manufacturing investments to expand usage of E85 from 30 million gallons in 2010 to 23.5 billion gallons in 2022. This is compatible with projections of growth in flex-fuel vehicles but would require massive expansion in the number of gas stations offering E85 dispensers for those FFVs to actually use E85.

Fuel price volatility. If the cost of feedstocks and the price of gasoline fluctuate significantly, farmers and biofuel producers may not have confidence in their ability to produce biofuels profitably over the longer time frames required to justify significant capital investments. As an example, the high price of sugar combined with the low price of petroleum contributed to the short-term crash of biofuels in Brazil during the early 1990s (Moreira and Goldemberg 1999).

References

ANL. 2012. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)*, Fuel Cycle Model version 1 2012. U.S. Department of Energy.

Bartis, J. T. and L. Van Bibber. 2011. *Alternative Fuels for Military Applications.* RAND Corporation, Santa Monica.

Corts, K. 2010. "Building Out Alternative Fuel Retail Infrastructure: Government Fleet Spillovers in E85." *Journal of Environmental Economics and Management.* 59: 219–234.

Delucchi, M. 2006. *Lifecycle Analysis of Biofuels.* Institute of Transportation Studies, University of California, Davis.

Denicoff, M. R. 2007. *Ethanol Transportation Backgrounder: Expansion of U.S. Corn-Based Ethanol from the Agricultural Transportation Perspective.* U.S. Department of Agriculture.

DOE. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.*

EERE. 2010. *Clean Cities Alternative Fuel Price Report.*

EERE. 2012a. *Clean Cities Alternative Fuel Price Report.*

EERE. 2012b. Hydrogenation-Derived Renewable Diesel. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/emerging_green.html (accessed October 17, 2013).

EERE. 2013. Alternative Fueling Station Locator. Alternative Fuels Data Center. http://www.afdc.energy.gov/locator/stations/ (accessed October 17, 2013).

EIA. 2013a. Renewable and Alternative Fuels: Alternative Fuel Vehicle Data. http://www.eia.gov/renewable/afv/index.cfm (accessed October 17, 2013).

EIA. 2013b. *Annual Energy Outlook 2013.*

EIA. 2013c. *Monthly Energy Review, September 2013.*

EPA. 2010. *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis.*

Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammen. 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science*, 311 (5760): 506–508.

Koenig, B. 2012 (July 12). "Kansas Gas Station First to Offer E15 Ethanol-Blend Fuel." *The New American.*

Koplow, D. 2006. *Biofuels – At What Cost? Government Support for Ethanol and Biodiesel in the United States.* The Global Subsidies Initiative, International Institute for Sustainable Development, Geneva.

Laser, M., H. Jin, K. Jayawardhana, B. Dale, and L. Lynd. 2009. "Projected Mature Technology Scenarios for Conversion of Cellulosic Biomass to Ethanol with Coproduction Thermochemical Fuels, Power, and/or Animal Feed Protein." *Biofuels, Bioproducts and Biorefining*, 3 (2): 231–246.

Moreira, J. R. and J. Goldemberg. 1999 (April). "The Alcohol Program." *Energy Policy*, 27 (4): 229–245.

Mullins, K. A., W. M. Griffin, and H. S. Matthews. 2010. "Policy Implications of Uncertainty in Modeled Life-Cycle Greenhouse Gas Emissions of Biofuels." *Environmental Science & Technology*, 45 (1): 132–138.

NPC. 2012. *Future Transportation Fuels Study: Advancing Technology for America's Transportation Future.*

NRC. 2009. *Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts.* The National Academies Press, Washington, D.C.

NRC. 2011. *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy.* The National Academies Press, Washington, D.C.

NRC. 2013. *Transitions to Alternative Vehicles and Fuels.* The National Academies Press, Washington, D.C.

Parker, N., B. Jenkins, P. Dempster, B. Higgins, and J. Ogden. 2011. Chapter 1: The Biofuels Pathway. In J. Ogden and L. Anderson (eds.), *Sustainable Transportation Energy Pathways: A Research Summary for Decision Makers.* Institute of Transportation Studies, University of California, Davis.

Perlack, R., L. Wright, A. Turhollow, R. Graham, B. Stokes, and D. Erbach. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.* U.S. Department of Agriculture and U.S. Department of Energy.

Searchinger, T., R. Heimlich, R. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change." *Science*, 319 (5867): 1238–1240.

Schnepf, R. 2013. *Agriculture-Based Biofuels: Overview and Emerging Issues.* Congressional Research Service.

Tyner, W., F. Dooley, and D. Viteri. 2011. "Alternative Pathways for Fulfilling the RFS Mandate." *American Journal of Agricultural Economics*, 93 (2): 465–472.

USDA. 2013. Agricultural Projections to 2023. http://www.usda.gov/wps/portal/usda/usdahome?contentid=2013/02/0021.xml&contentidonly=true (accessed October 17, 2013).

West, B., A. López, T. Theiss, R. Graves, J. Storey, and S. Lewis. 2007. "Fuel Economy and Emissions of the Ethanol-Optimized Saab 9-5 Biopower." *SAE Technical Paper*, SAE 2007-01-3994.

West, T., K. Dunphy-Guzman, A. Sun, L. Malczunski, D. Reichmuth, R. Larson, J. Ellison, R. Taylor, V. Tidwell, L. Klebanoff, P. Hough, A. Lutz, C. Shaddix, N. Brinkman, C. Wheeler, and D. O'Toole. 2009. *Feasibility, Economics, and Environmental Impact of Producing 90 Billion Gallons of Ethanol per Year by 2030.* Sandia National Laboratory.

Williams, P., D. Inman, A. Aden, and G. A. Heath. 2009. "Environmental and Sustainability Factors Associated with Next-Generation Biofuels in the U.S.: What Do We Really Know?" *Environmental Science & Technology*, 43 (13): 4763–4775.

Yang, B. and C. Wyman. 2008. "Pretreatment: The Key to Unlocking Low-Cost Cellulosic Ethanol." *Biofuels, Bioproducts and Biorefining.* 2 (1): 26–40.

APPENDIX D

Electric and Plug-In Hybrid Vehicles

This appendix focuses on EVs that can be partially or fully powered by batteries charged from an off-board source of electricity (e.g., grid power). Two possible configurations are considered: BEVs and PHEVs.

BEVs only operate on electricity. Once the batteries of a BEV are drained, the vehicle can no longer be driven until its batteries have been recharged. The Nissan Leaf, Chevy Spark, Tesla Model S, Honda Fit EV, and others fall in the BEV category. PHEVs include both batteries and (as currently configured) a gasoline-powered ICE. The batteries provide sufficient storage to allow for a limited range of travel in all-electric mode. As the battery charge becomes depleted, the vehicle can rely on power generated through the combustion of gasoline for additional range. With the ability to rely on fuel combustion as needed, the battery pack provided with a PHEV does not need to be as large as that for a BEV. The Chevy Volt, Toyota Plug-In Prius, Ford C-Max Energi, and Honda Accord Plug-In are examples of the PHEV category.

HEVs not capable of being plugged in, such as the Honda Insight and the original Toyota Prius, are not included in this appendix but rather are discussed with other advanced technologies for conventional vehicle technologies in Appendix A. The logic for this division is that with HEVs, all of the vehicle's power ultimately originates with the combustion of petroleum. The capabilities enabled by hybrid technology, such as regenerative braking and automatic engine shutoff, can thus be viewed as strategies for recycling and making more efficient use of the petroleum power. In contrast, BEVs and PHEVs receive some or all of their power from off-board sources of electricity, creating a distinct set of challenges and opportunities.

There are several potentially compelling motivations for seeking a transition from conventional vehicles to BEVs or EVs:

- **Energy security.** Most of the nation's electric power is generated from domestic sources of energy. Displacing a significant volume of gasoline and diesel with electricity would thus foster greater energy independence and security.
- **Greenhouse gas reductions.** Electric energy can be generated from renewable, low-carbon sources such as solar and wind power. A shift to EVs and PHEVs, combined with an effort to increase the share of low-carbon electricity on the grid, could therefore help reduce the nation's emissions of greenhouse gases.
- **Improved air quality.** Because BEVs and PHEVs running in battery-only mode do not emit air pollutants, a shift to EVs could be helpful in meeting EPA's urban air quality requirements. While the combustion of coal and natural gas to produce electricity does create air pollutants, power plants are often located away from population centers and can be equipped or retrofitted with pollution control devices as needed, making the resulting emissions less problematic for human health. Here again, a major shift to renewable energy would reduce air pollution at these point sources as well.
- **Reduced cost of driving.** Due to the efficiency through which electricity can be stored in a battery and then discharged to propel a vehicle, the per-mile cost of driving on electric power is a small fraction of the cost of driving on gasoline or diesel. Provided that battery improvements reduce the considerable premium currently required for the purchase of BEVs and PHEVs, a shift to EVs could also allow for more affordable total costs of ownership.

Based on such potential benefits, the major auto manufacturers have been exploring EV technology for some time. In the early 1990s, in an effort aimed at improving air quality, CARB adopted new vehicle emission regulations that included a ZEV mandate. The ZEV regulations required large auto manufacturers to offer ZEVs for sale by 1998, with the share of sales growing from 2% in 1998 to 10% by 2002. In response to this mandate, all of the major auto companies began to design and test EVs. Ultimately, though, only GM with its EV-1 and Honda with its EV Plus produced dedicated BEV models; other companies developed BEV conversions of conventional vehicle models, such as the Ford Ranger EV and Toyota RAV4 EV. Additionally, most of the auto manufacturers only offered their EV models through leasing programs; only Toyota made its product, the RAV4 EV, available for sale.

As documented in the movie *Who Killed the Electric Car*, California's first attempt to promote the commercialization of electric vehicles through its ZEV program was not successful. Only 4,000 BEVs were sold or leased in California between 1996 and 2002, representing about 0.01% of statewide light-duty vehicle sales during that period. This failure can be attributed to several factors, including high technology costs, concerns about the reliability and safety of batteries, and sustained low gasoline prices in the 1990s. In response to a subsequent lawsuit filed against California by the three major U.S. auto manufacturers, the ZEV mandate was suspended by CARB in 2002. Shortly thereafter, most manufacturers began to terminate lease agreements and then repossessed and destroyed the vehicles. Only Toyota RAV4 EVs—which had been available for sale rather than for lease—avoided this fate.

This was followed by a relatively brief interlude during which the world's major automobile manufacturers showed less interest in electric vehicles. For most of the past decade, the only BEVs available for sale or lease were neighborhood electric vehicles (NEVs) with a maximum speed of 25 mph and high-end, luxury automobiles developed by start-up companies such as Tesla.

In the last few years, however, there has been renewed interest in the development and marketing of EVs. This is due, in part, to CARB's decision in 2008 to reinstitute the ZEV mandate, which will take effect beginning in model year 2015. Additionally, technology advances over the past decade have enabled manufacturers to make further progress on some of the earlier EV challenges. In 2010, GM released a commercial PHEV, the Volt, with an advertised all-electric range of 35 miles. Next, in 2011 Nissan delivered its BEV hatchback, the Leaf, with an advertised range of about 75 miles between recharges, and Toyota has now released a PHEV version of its popular Prius model. Other firms that have released BEV or PHEV models, or are planning to do so in the near future, are BMW, Chevrolet, Fiat, Ford, Honda, Mitsubishi, and Smart.

Because of the potential benefits of transitioning to electric vehicles, a number of state and federal initiatives to promote the development and adoption of electric vehicles have been recently enacted as well. For example, as part of the American Recovery and Reinvestment Act of 2009, a tax credit of up to $7,500 has been established for the purchase of electric vehicles. The DOE has already invested more than $5 billion in research, development, and manufacturing of batteries and other components of electric vehicles and charging infrastructure (DOE 2010).

D.1 Production, Distribution, and Refueling

Electricity to charge BEVs and PHEVs can be obtained via the existing power grid. Assuming relatively limited penetration of electric vehicles, it should be possible to accommodate the additional load with existing infrastructure. To support widespread adoption, however, grid transmission and distribution infrastructure upgrades could be required. Additionally, the current mix of electric generation capacity in the United States still relies to a large extent on coal and natural gas plants. To fully reap the potential air quality and greenhouse gas emission reduction benefits, a transition to EVs would need to be accompanied by a major shift to lower-carbon sources of electricity. Finally, while most EV owners would be expected to rely on at-home charging stations for their main source of electricity, the relatively limited driving range of most BEVs, as currently configured, suggests the need for a broader network of publicly accessible charging stations, and considerably faster recharge times, to accommodate a significant level of market penetration of BEVs as the primary household vehicle.

D.1.1 Current Electric Generation

In assessing the potential for transitioning to EVs, it is useful to consider the ability of the U.S. power grid to handle the additional load created by charging (Kintner-Meyer, Schneider, and Platt 2007; Shao, Pipattanasomporn, and Rahman 2009; NPC 2012; NRC 2013). From the perspective of aggregate power generation, an assessment by Kintner-Meyer, Schneider, and Platt (2007) suggests that existing U.S. capacity provides sufficient slack (i.e., excess capacity during the nighttime hours) to power roughly 70% of the nation's light-duty fleet through the use BEVs or PHEVs. NPC's more recent estimate is that existing capacity could accommodate electrifying half of the current vehicle fleet if vehicles were charged at night (NPC 2012). Both of these estimates demonstrate the deep availability of excess nighttime capacity and the importance of charging during off-peak hours to accommodate large-scale adoption of electrified transportation. NRC (2013) projects that electricity demand from the grid to power electric vehicles will rise to about 286 terawatt hours (TWhs) by 2050, or 7% of the projected total electricity usage, well within the historic growth of the grid. As discussed in later sections, however, other challenges related to distribution and recharging exist.

The U.S. electrical power system is complex, consisting of generating plants, high-voltage transmission lines, local distribution facilities, and communications networks that must interact to provide stable and reliable electricity to customers under varying load conditions. The flow of electricity within the system is controlled by dispatch centers that buy and sell electricity based on agreements with interconnected utilities and other power providers. The system is divided into three major networks—the Eastern, Western, and Texas Interconnected Systems—within which the dispatchers and utilities operate (EIA, undated).

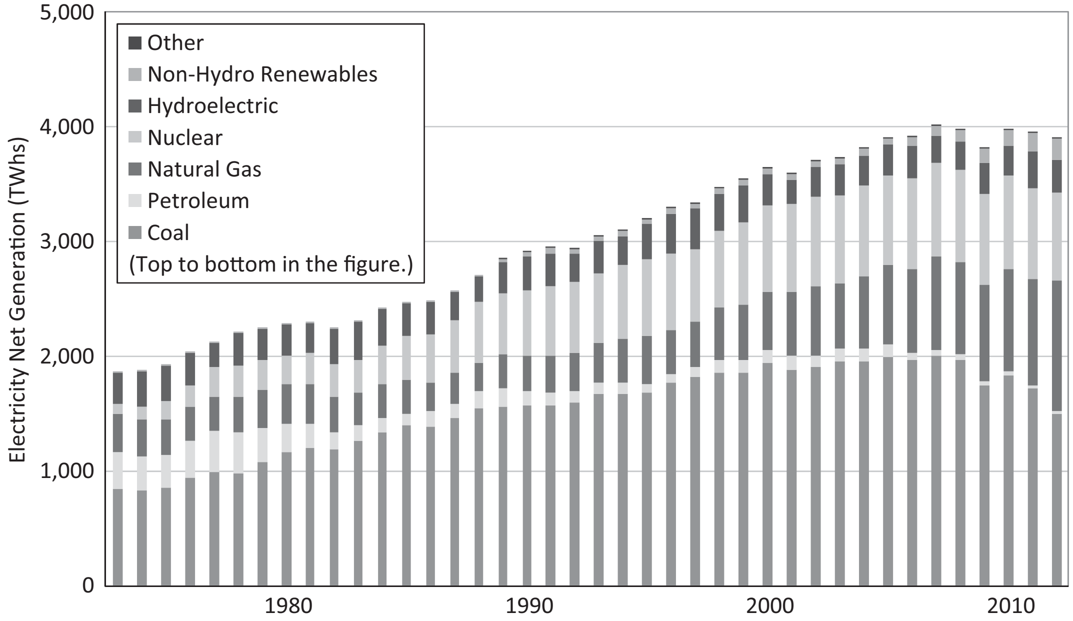
As of 2012, according to EIA (2013b), net U.S. electric power-sector generation totaled around 3,900 TWhs. This included 38.5% from coal, 29.2% from natural gas, 19.7% from nuclear, 7.0% from conventional hydroelectric power, 4.8% from other renewable sources (biomass, geothermal, wind, and solar), and 1.0% from oil. Note that the mix of electricity sources varies greatly across states and regions. California, for example, has a less carbon-intensive electric grid than the U.S. average, with almost 29% of total net generation coming from renewable sources inclusive of conventional hydropower (EIA 2012a). Figure D.1 illustrates the growth in electric production for the United States as a whole, by source, over the past 40 years.

One of the challenges of managing the electric grid is that the demand for energy exhibits considerable variation by time of day, day of week, and season. In theory, this could be addressed by storing excess electricity generated during off-peak hours for subsequent use during peak periods. In practice, however, electricity storage options such as batteries and flywheels have remained costly, while opportunities for pumped storage (pumping water uphill during off-peak periods and then releasing it over turbines to generate hydropower during peak periods) are geographically limited. Accordingly, the approach for matching supply to demand has been to run certain power plants on a continuous basis to meet base demand and then to bring on additional capacity as demand rises (EERE 2002).

In planning for base demand, utilities are interested in plants that provide the lowest generating costs when operated at nearly full capacity year round. This usually involves coal-fired plants, nuclear plants, and conventional hydropower plants. Coal and nuclear plants in particular are expensive to shut down and start up again and as such are best adapted to relatively continuous use. As demand rises above base loads, utilities next bring intermediate or mid-merit plants on line. These are often combined-cycle natural gas plants that are relatively easy to cycle up and down and also provide reasonably low-cost generation. Finally, as demand reaches its highest levels, utilities must bring on still more plants. Often referred to as "peakers," these may be operated just a few hundred hours each year. This operational profile favors lower construction costs (since there will be fewer hours of revenue-generating operation to recoup the capital investment) and also requires the ability to easily cycle. Based on these factors, utilities often select less costly (but also less efficient) combustion turbines fired by natural gas or oil for peak power (EERE 2002).

D.1.2 Cleaner Sources of Electricity

The extent to which some of the potential benefits of EVs can be realized will depend on the sources of energy used to power the grid. One of the main objectives behind the effort to develop EVs in the 1990s, as embodied in CARB's ZEV mandate, was to improve air quality, especially in urban areas. While the generation of electricity at power plants typically releases air pollutants, such plants are often located far from



Source: EIA (2013b, Table 8.2b).

Figure D.1. Growth in U.S. electric generation by source.

urban areas. The act of driving an EV, on the other hand, produces no additional emissions, and a significant amount of all driving (particularly the shorter trips that could be accommodated by electric vehicles with limited range) occurs in urban areas. Therefore, even if much of the power on the grid is generated from coal, a significant shift from conventional vehicles to EVs could result in air quality improvements in many urban areas. Still, air pollution in rural settings is not harmless, and there are some coal-fired power plants located close to cities. Adopting a cleaner mix of power generation could therefore lead to even greater air quality benefits.

More recently, the potential of EV technology to help mitigate climate change has received increasing attention. Unlike with local air pollutants, greenhouse gases create the same effects on climate regardless of where they are emitted. For this reason, the potential climate benefits of transitioning to EVs depend entirely on the mix of sources used to generate grid electricity. In short, the prospect of shifting from conventional vehicles to EVs creates additional incentive to increase reliance on electricity sources that produce little or no emissions, including wind, solar, hydrokinetic, geothermal, biomass, and nuclear. In the remainder of this section, current and future prospects for such alternatives are briefly considered.

Solar power. Solar energy represents a vast potential source of clean, renewable power; harvesting solar energy on just a quarter of a percent of the nation's land area would provide enough electricity to meet current U.S. consumption (NRC 2010). There are two main methods for converting solar radiation to electricity: photovoltaic (PV) panels and concentrating solar power (CSP) that uses focused solar energy to drive a steam-turbine generator. While the cost of these technologies has declined in recent years, solar power is still more expensive than other sources of electricity. Additionally, solar generation is inconsistent—varying by latitude, time of year, and meteorological conditions—and unavailable at night. Any effort to significantly increase the share of solar energy on the grid would thus likely require large-scale deployment of storage capacity (batteries, flywheels, etc.) to help balance temporal variations in the supply and demand for electricity. In short, the cost of solar power technologies, including both generating modules and balance of system costs, will need to decline substantially over the next several decades to overcome current economic and technical barriers (NRC 2010).

Wind power. Wind is another potentially significant source of clean and renewable energy, with estimates suggesting that wind resources in the United States could produce several times the amount of electricity consumed by the nation (NRC 2010, Crane et al. 2011). As with solar power, however, wind power is intermittent and thus creates load-balancing challenges. Onshore wind power is viewed as relatively mature, though there may be opportunities for further cost reductions with more deployment experience and improvements in wind turbine components (NRC 2010). Offshore wind power is comparatively less developed, with some deployment in Europe but relatively little in the United States, but promises potential access to substantial wind resources. As an added benefit, offshore wind power can be located close to major population and load centers along the coast (Kempton et al. 2007). Continued development of offshore turbines is expected to help reduce capital as well as operations and maintenance costs (NRC 2010).

Hydro and wave power. There are two categories of hydroelectric power: conventional and emerging hydrokinetic. Conventional hydroelectric power (e.g., hydroelectric dams) is inexpensive and offers comparatively low greenhouse gas emissions on a life-cycle basis (mainly from the production and transportation of concrete and steel as well as construction activities when first building the dam). While opportunities for large new hydroelectric dams in the United States are limited (NRC 2010), there may be options for smaller-scale conventional hydroelectric projects if local environmental concerns can be managed (INL 2006). Unconventional hydroelectric technologies to harness energy from waves, tides, currents, and rivers are still emerging but could be deployed, assuming considerable technological advances, on a large scale by the 2035 time frame (NRC 2010).

Geothermal power. Geothermal or hydrothermal power-generation technologies rely on naturally occurring reservoirs of steam, hot water, or hot rocks in the earth's crust to generate electricity. Utility-scale technologies convert heat into steam to run a turbine in much the same way that fossil fuels are used to generate electricity (NRC 2010, Crane et al. 2011). Conventional hydrothermal plants make use of hot water and steam trapped in permeable rocks at depths of up to 3 kilometers. These resources produce stable and inexpensive electricity with low life-cycle GHG emissions, but they are geographically concentrated in the western United States and limited in quantity. An emerging technology not yet deployed is enhanced (or engineered) geothermal systems (EGS), which use hot rocks at depths between 3 and 10 kilometers. The aggregate energy potential for EGS is much greater than that for traditional hydrothermal, and the resource is more geographically dispersed. Before this potential can be realized, though, further research and innovation will be needed in the areas of deep thermal drilling, managing the resource, and avoiding the triggering of seismic activity (NRC 2010, Crane et al. 2011).

Biomass power. Biomass can be produced and harvested with the aim of generating electricity, but biomass has competing uses as well, such as for liquid fuels and food and animal feed. Some biomass waste and residues, however, are best suited for power generation; recent estimates suggest that using such biomass resources for electricity could supply 10% to 20% of the nation's power demand. If the country were to increase the amount of biomass devoted to electric production to around a billion dry tons annually, the amount of the nation's electricity generated from biomass would rise to about 40% (NRC 2010). Achieving this level, though, would require some dedicated crop production in addition to waste and residues. This would almost certainly compete with the production of biomass for liquid fuels, and potentially with the production of food and animal feed crops. Near-term opportunities for biomass power include co-firing biomass in existing coal power plants (Ortiz et al. 2011), dedicated biomass power plants, and generating electricity as a coproduct in manufacturing biofuels. Longer-term opportunities include breakthroughs in the digestion and gasification of biomass to produce an economic biogas for combustion and the engineering of new biomass strains to enhance photosynthesis efficiencies (NRC 2010).

Nuclear power. Nuclear power plants provide around 20% of the nation's electricity, but this source has not expanded significantly in recent years (EIA 2012c). Lack of growth in the nuclear industry stems from several important challenges and risks. These include the high capital costs of constructing a nuclear plant, difficulties associated with environmental permitting and liability, unresolved issues regarding how and where to store spent nuclear fuel on a long-term basis, concerns that nuclear proliferation increases the chances that terrorists could gain access to nuclear material, and the risk of natural disasters triggering nuclear catastrophes (LaTourrette et al. 2010). The latter can lead to strong local opposition to the siting of new nuclear power plants, and the recent meltdowns in Fukushima following the earthquake and tsunami are likely to intensify such opposition. On the other hand, nuclear power also offers advantages. Once constructed, nuclear power plants provide an inexpensive source of base load power that generates no harmful air pollutants or greenhouse gases. With increasing concerns over the threat of climate change, the lack of emissions in particular has stimulated renewed interest in nuclear power. A recent forecast from the EIA assumes that the nuclear industry will add about 19.1 gigawatts of new generating capacity by 2040. In February of 2012, the U.S. NRC voted to approve Southern Company's application to build two new nuclear reactors, Units 3 and 4, at its Vogtle plant, the first reactors to receive construction approval in over 30 years. As of early 2012, the U.S. NRC had applications for a total of 28 new reactors. Given the challenges and concerns described previously, however, it is unclear how many of the proposed plants will actually be built (EIA 2012c).

Carbon capture and sequestration. It may also be possible to reduce the carbon intensity of electricity generated from coal and natural gas through carbon capture and sequestration (also known as carbon capture and storage). CCS is the process of removing CO_2 from the emissions stream prior to its release into the atmosphere and then storing it permanently, such as in underground geologic formations. By capturing and storing the CO_2, CCS can avoid upwards of 90% of CO_2 emissions. There are several promising pathways for CCS, but a significant amount of technological and policy development is required before these systems will be economical and deployable at scale. DOE is currently funding a program to demonstrate the technical viability of alternative approaches to CO_2 capture from existing and planned power plants (NETL 2013). To date, however, no full-scale commercial power plants with CCS have been deployed, and research, development, and demonstration efforts continue.

Cost of alternatives. Levelized costs—that is, the per-unit costs of electric power production taking into consideration plant operating capacity, capital costs, fixed operating and maintenance costs, variable operating and maintenance costs, and transmission investments—for lower-carbon power sources such as wind and solar have improved in recent years relative to traditional power sources (EIA 2013a). Yet the more cost-competitive nature of certain alternatives does not imply that it would be inexpensive to pursue a rapid transition from fossil-based electric power generation to renewable sources. To begin with, levelized cost estimates pertain to building and operating *new* capacity, whereas much of the nation's current electricity supply is provided by *existing* coal and natural gas plants; such plants are more economical to operate given that the capital costs are already invested. Additionally, as described in the preceding text, all of the renewable or low-emissions options face certain challenges, such as limited resources (e.g., for current geothermal technology or new conventional hydropower projects), competition for resources (e.g., biomass), intermittency (wind and solar), perceived safety and security concerns that translate to significant public acceptance challenges (nuclear), and the need for further technical advances (e.g., unconventional hydroelectric technologies, enhanced geothermal energy, and carbon capture and sequestration).

D.1.3 Distribution

In discussing electrical distribution issues, it is helpful to distinguish between the longer-range *transmission* of power from plants to major load centers (e.g., cities) and the shorter-range *distribution* of power within load centers to individual commercial, industrial, and residential customers. This is discussed in the following.

Long-range transmission. Existing transmission capacity is not viewed as imposing significant constraints on the adoption of EVs (Kintner-Meyer, Schneider, and Platt 2007; May and Johnson 2011). On the other hand, new transmission capacity investments will likely be needed to enable growth in the amount of renewable energy on the grid, which would in turn help maximize the environmental benefits of shifting to EVs.

This is because many of the best locations for siting renewable energy facilities are in sparsely populated regions far from high-capacity transmission lines—on the high plains for wind turbines, for example, or in the Southwest for solar arrays (Kaplan 2009).

Investment in new long-range transmission capacity faces several challenges. To begin with, the permitting process for new transmission lines can be difficult and time consuming. Projects that span multiple states, for example, must receive approval from the Federal Energy Regulatory Commission as well as individual permits in each state through which the line passes. Financing new transmission capacity for certain types of renewable energy can also prove problematic; because of the intermittent nature of solar and wind, lines built to accommodate peak power will be underutilized much of the time, making it more difficult to recover costs. Relatedly, there is little agreement on who should ultimately bear the costs of the new capacity—just those customers who will benefit directly from the new transmission (i.e., customers of utilities connected to the line) or all customers in the broader network who will ultimately benefit from greater system capacity and reliability (Kaplan 2009).

Local distribution. In contrast to long-range transmission, where increased capacity would mainly be helpful in supporting an expanded role for renewable electricity on the grid, many local distribution networks are likely to require upgrades simply to accommodate the demand patterns imposed by EV charging. The main constraint involves the capacity of local transformers in residential areas in relation to the amount of power drawn when charging an EV (NPC 2012). Secondary transformers in the United States are typically designed to accommodate three to six houses. The amount of electricity drawn when charging an EV, however, can be about the same as that used to power an entire house. A Nissan Leaf charging on a 240-volt, 15-amp circuit, for example, translates to a 3.6-kW load (watts are calculated as volts multiplied by amps), which is greater than the amount used by an average home in Berkeley, California. If several homes connected to the same transformer were to charge EVs at the same time, perhaps on a warm summer afternoon with air-conditioning also in use, the transformer could easily become overloaded, triggering a local brownout (May and Johnson 2011).

Achieving a significant transition to EVs is thus likely to require considerable investment on the part of utilities to upgrade secondary transformers. The need will be most acute in neighborhoods with a greater share of likely early adopters (e.g., affluent urban or suburban locations with strong environmental leanings where residents are able to afford EVs and are motivated to make such purchases), in older neighborhoods where transformers were originally sized for smaller houses (i.e., 100-amp service rather than the 200-amp service more commonly in use for new houses today), and in areas of the country where peak demand for air-conditioning was not viewed as a requirement in designing the local distribution system (May and Johnson 2011).

D.1.4 Recharging

Electric vehicles have onboard chargers that interface with grid outlets to allow proper charging of the battery packs. In theory, BEVs and PHEVs can charge from any available outlet. Indeed, this is one of the key advantages of EVs in comparison to conventional vehicles and other alternative-fuel options: that they can be charged at home, or perhaps at work, with little or no additional investment. On the other hand, most BEVs offer limited driving range (e.g., less than 100 miles) in comparison to conventionally fueled vehicles. For extended travel, many owners may find it necessary on occasion to recharge their vehicles when they are away from their home or work locations. This section considers both the availability and potential configurations of charging infrastructure to support such needs. The discussion is most applicable to BEVs, which must rely entirely on electric power; while PHEV owners might opt to replenish their charges in the midst of their travels, they can also choose to rely on readily available petroleum fuel should they run low on electric charge before returning home.

Publicly accessible charging infrastructure. Even with their limited range, BEVs can accommodate typical trip patterns for many drivers without the need to recharge during the day. A 50-mile range BEV, for example, can easily handle a round-trip commute of 10 to 15 miles each way. For BEVs to achieve significant market penetration as primary vehicles for households, though, it may nonetheless prove necessary to deploy a network of publicly accessible charging stations, for two reasons. First, owners whose daily travel is occasionally greater than the range enabled by a single battery charge might find it necessary, or at least convenient, to recharge their vehicles during the course of their travels, and the availability of publicly accessible charging stations would make this possible. Second, the limited range capacity of most current and projected BEV models may lead to range anxiety on the part of prospective buyers—that is, the concern that they could one day run out of charge and become stranded before they are able to return home. The knowledge that publicly accessible charging infrastructure is available, even if it never proves to be needed, may help overcome this concern, thus paving the way for more BEV purchase decisions. While most charging is expected to occur at home (NPC 2012), publicly available charging infrastructure would reduce range anxiety and enable extended daily travel.

Following such logic, the Obama administration, in support of its goal for widespread adoption of EVs, has devoted millions of stimulus dollars from the American Recovery and Reinvestment Act (ARRA) to fund the installation of publicly accessible charging infrastructure (DOE 2010). As of September 2013, there were a little more than 19,000 publicly accessible charging stations in the United States (EERE 2013a). About 1,500 of these are located in California, some of which are residual from earlier efforts to support the state's ZEV mandate in the 1990s and early 2000s.

Charging levels. Separate from the availability of public charging infrastructure, another potential concern for EVs is the amount of time required to fully recharge a depleted battery pack. When a vehicle is being charged at home overnight, a lengthy recharge time may be viewed as acceptable. If an EV owner needs to recharge in the middle of the day between trips, in contrast, a much faster recharge time would be desired. Higher levels of charging provide more power to the battery per given unit of time, and can recharge batteries faster (EERE 2011).

Level 1 charging, the slowest and least expensive, refers to the use of a standard three-prong household electric outlet running at 120 volts and 15 amps. To illustrate the speed of Level 1 charging, consider a Nissan Leaf with its 24-kWh battery pack. A circuit with 120 volts and 15 amps supplies a 1.8-kW load; at this rate it could take up 13 hours (24 kWh divided by 1.8 kW) to fully charge the Leaf—acceptable performance for charging a vehicle overnight but certainly not for a quick midday recharge. The main advantage of level 1 charging is that it relies on existing household outlets; no further electrical installation work is required.

Level 2 charging uses a 240-volt circuit at 15, 20, 30, or even 60 amps, translating to a load of between 3.6 and 14.4 kW. At the upper end of this spectrum, it would take a little less than 2 hours to fully charge the Leaf's 24-kWh battery. Level 2 is viewed as the desired standard for home EV charging and is usually installed as a permanent wall-mounted electric vehicle supply equipment (EVSE) unit to regulate vehicle charging safety. NPC estimated the cost of purchasing and installing such units in a typical residential garage at about $1,500 to $4,000 (NPC 2012). It found that commercial installation of Level 2 charging infrastructure ranged from $2,700 to more than $30,000, depending on the amount of construction and infrastructure required.

Level 3 charging, defined as loads exceeding 14.4 kW, can charge EVs even more quickly. Such loads exceed the capacity of most residential electrical panels, making Level 3 charging more applicable for areas with access to industrial or commercial electrical service. Level 3 charging also requires an EVSE unit. NPC estimated that direct-current Level 3 charging infrastructure and installation can cost more than $50,000 (NPC 2012).

Fast charging. Another term often used in discussions of EV charging infrastructure is "fast charging," which has been defined as the ability to charge an EV in 30 minutes or less (EERE 2011). The basic goal of fast charging is to enable EV owners to recharge their vehicles in the midst of their travel without too much delay; the need to spend a much longer time to recharge a vehicle would almost certainly be viewed as a major inconvenience that could deter many prospective owners from purchasing an EV. Even 30 minutes may be viewed as too inconvenient for a significant share of customers, given that refueling a gasoline tank typically takes about 5 minutes or so.

Two conceptual approaches to fast charging have been considered. The first involves the installation and operation of publicly accessible fast-charging kiosks that offer some form of Level 3 charging, although further research may be needed to verify that fast charging does not cause battery packs to deteriorate more rapidly. Some of the ARRA funding for public EV charging mentioned previously has been invested in the fast-charging kiosk concept (DOE 2010). An alternate approach to fast charging is battery swapping, in which depleted batteries are mechanically removed from EVs and replaced with fully charged batteries in less than 2 minutes. This concept was first introduced by the firm Better Place (Better Place 2011), which subsequently filed for bankruptcy; more recently, Tesla Motors has announced its intent to develop a network of battery swapping stations for its customers (Tesla 2013a).

Vehicle-to-grid power. One longer-term possibility for EV charging infrastructure is often described as vehicle-to-grid power. The basic idea would be to use the collective battery storage capacity of the EV fleet to help balance variations in supply and demand on the grid. Even small amounts of power provided back to the grid could regulate grid frequency and provide other ancillary services to the grid. When not in use, EVs plugged into the grid could draw power during off-peak hours when there is slack capacity and then feed energy back into the grid during periods of higher demand. From a systemwide perspective, vehicle-to-grid power would reduce the need to invest in more generation capacity for peak loads. It could also make it possible to increase the share of power on the grid that comes from intermittent renewable sources such as solar and wind, for which periods of production do not always align with peak demand. Finally, it could create an opportunity for EV owners to earn a small profit by buying electricity from the grid at lower cost during off-peak hours and then selling back at higher prices in peak hours.

On the other hand, vehicle-to-grid power would also accelerate the degradation of an EV's battery pack, and large-scale implementation of this idea would require a range of advanced smart-grid technologies still under development. Thus, though promising in concept, the vehicle-to-grid idea requires further study and demonstration (Sovacool and Hirsh 2009). The U.S. Air Force is testing the vehicle-to-grid concept for non-tactical vehicles located at several military installations (Simeone 2013).

D.1.5 Current and Future Electricity Costs

Retail electricity prices in the United States vary by region depending on the type of power plants, fuels, and pricing regulations and structures. Prices are usually highest in Hawaii—over 25 cents per kWh in 2010—due to the state's heavy reliance on fuel oil. At the other end of the spectrum, Wyoming had the lowest rates in the nation in 2010, at a little over 6 cents per kWh, based in part on low-cost hydropower from federal dams. The average retail price in 2011 for the United States as a whole was 10.0 cents per kWh; industrial customers enjoyed the lowest rates, with an average price of 6.9 cents, while residential customers faced the highest rates of around 11.8 cents (EIA 2012b).

Looking forward, whereas the price of oil is generally expected to increase, prices for electricity may remain relatively flat. In the reference-case projections in the most recent *Annual Energy Outlook* from the EIA, the world price for imported crude oil, in 2011 dollars, rises from $102 per barrel in 2011 to $155 per barrel in 2040, an increase of about 52% (EIA 2013a). The average U.S. retail price of electricity rises, again in 2011 dollars, from 9.9 cents per kWh to 10.8 cents per kWh over this same period, an increase of just 9%. Based on these assumptions about future energy prices, and setting aside any future fuel economy improvements for conventionally fueled vehicles and for EVs, the comparative per-mile fuel-cost advantage of electricity may continue to widen.

One factor that could increase the future cost of electricity would be a shift to greater use of renewable sources, although the effect on prices could still be modest. In a recent analysis, the EIA evaluated the cost implications of imposing a hypothetical clean energy standard that would require 80% of electricity generation to come from hydroelectric, wind, solar, geothermal, biomass power, municipal solid waste, landfill gas, nuclear, coal-fired plants with carbon capture and sequestration, and natural gas-fired plants with either carbon capture and sequestration or combined-cycle technology by 2035. The results indicated that such a standard would increase the average retail price of electricity to 11.7 cents per kWh, a 29% increase over the reference-case scenario used in the study (EIA 2011). (The analysis did not include a provision for banking or borrowing clean energy credits, which could reduce the cost of compliance.)

Greater incorporation of time-of-day electricity pricing, on the other hand, could further reduce the cost of electricity for charging EVs. With time-of-day pricing, the cost of electricity is higher during peak hours when demand is highest and lower during off-peak hours when there is slack generation capacity. Such rate structures are relatively common but are typically aimed at large-scale industrial and commercial customers. Increasingly, though, utilities are beginning to make time-of-day rates available as an option for their residential customers. The Northern California utility Pacific Gas and Electric (PG&E) offers residential customers a flat rate structure as well as a time-of-day rate structure aimed at EV owners. (In both cases the rate structures are also *tiered*, meaning that the per-kWh rate increases with total volume of use.) For flat-rate customers, the price of electricity begins at 11.87 cents per kWh and escalates up to 40.03 cents per kWh. For time-of-day customers, in contrast, the off-peak price of electricity begins at 4.14 cents per kWh and escalates up to 32.35 cents per kWh, while the peak price begins at 27.49 cents per kWh and escalates up to 55.96 cents per kWh (PG&E, undated). By choosing a time-of-day rate structure and recharging their vehicles mainly at night, EV owners may have the opportunity to save considerably on the retail cost of electricity, further enhancing the fuel-cost advantages of EVs.

D.2 Vehicle Technology

Following the unsuccessful efforts to develop and market EVs in the 1990s, the underlying technology has progressed significantly. Several BEV and PHEV models have been released in the past few years, and many more are anticipated in the near future.

Current models still face limitations—most notably significant price premiums on the order of $10,000 or more stemming from the current cost of battery technology, as well as reduced range compared to gasoline ICE vehicles. Most of the BEV models that have been released or are planned for the near future, for example, are limited to around 100 miles or less between charges, while an ICE averaging 30 miles per gallon might be able to drive for more than 300 miles between refueling stops.

Battery technology. Commercial success for EVs will likely hinge on the extent to which future advances in battery technology can help reduce the cost and improve the performance of such vehicles. Relatively recent battery cost estimates range from $500 to $800 per kWh (NPC 2012, NRC 2013), though costs continue to decline. For a PHEV with a 16-kWh battery pack, this would translate into a premium of $8,000 to $13,000. To compete effectively with conventional vehicle technologies in the future, significant further reductions in cost will likely be needed. Other important areas for improvement are battery weight, which influences an EV's efficiency and in turn range (Shao, Pipattanasomporn, and Rahman 2009), calendar and cycle life, specific energy (Wh/kg), specific power (W/kg), and energy density (W/liter).

These different aspects of battery performance are influenced by the chemistry involved. Options developed to date include lead-acid, nickel metal hydride, lithium-ion, and sodium nickel metal chloride. All of these battery types present advantages and disadvantages in the context of BEV and PHEV applications, so there is no clear choice for the best battery for all applications. Additionally, there are inherent trade-offs between energy density, power density, cycle life, and cost so that even for a particular type of battery, it is necessary to design them for specific applications.

For each of these chemistries, cells and modules of different amp-hour ratings and voltages have been developed and manufactured by battery producers around the world. Most of the electric vehicles and hybrids produced in the early years used either lead-acid or nickel metal hydride batteries, whereas the most recent BEV and PHEV models are using lithium-ion batteries. Lithium-ion batteries provide several advantages over other types of batteries such as, most notably, longer vehicle range. Lead-acid batteries, in contrast, are used primarily in low-speed NEVs with a relatively short range of 25 to 50 miles and a top speed of 25 mph, while nickel metal hydride batteries were employed in the early (non-plug-in) hybrids.

The key requirements for the energy storage unit for a particular vehicle design are safety and abuse tolerance, usable energy stored, peak power, and cycle and calendar life. These requirements must be met with a unit with a weight and volume that are less than specified values based on the driveline packaging. Energy storage and peak power affect vehicle performance attributes such as range and acceleration, while cost and cycle life are important from a marketability perspective. Whether a particular type of battery is suitable for electric vehicles depends on the desired characteristics of the vehicle in which it is to be used. For example, peak power is important for HEV batteries, while usable energy is much more important for PHEVs and BEVs.

Plug-in hybrid technology. Beyond the issues associated with battery technology just outlined, the integration of electric power with the internal combustion engine for PHEVs involves additional technical considerations such as power blending strategies and battery charging and discharging modes. One key design choice is how to employ the power generated by the internal combustion engine. In the Chevy Volt, power from the ICE is used mainly to charge the battery pack, which in turn powers the drivetrain. The other alternative, essentially an extension of the approach employed in most conventional hybrids, is to blend output from the battery and ICE in powering the drivetrain.

A related question is how to manage discharge from the battery. Two modes are possible—charge-depleting and charge-sustaining. In charge-depleting mode, the vehicle relies mainly on power from the battery, which is therefore discharged more quickly. In charge-sustaining mode, the battery energy is kept at roughly the same energy level by using power from the engine or from regenerative braking to recharge the batteries during driving. HEVs, which do not rely on an off-board source of power, must by definition rely on charge-sustaining mode, whereas PHEVs use both. PHEVs typically operate in charge-depleting mode until the battery energy falls to a specified level, after which the operation shifts to charge-sustaining mode. Some PHEV designs use only battery power during charge-depleting mode, while other designs use engine power as well to boost the combined efficiency of engine and battery power. The split between electricity and gasoline usage for either vehicle type would depend on its use pattern—in particular, how frequently it is driven on trips that exceed the possible range in charge-depleting mode, after which the ICE will be relied upon more heavily.

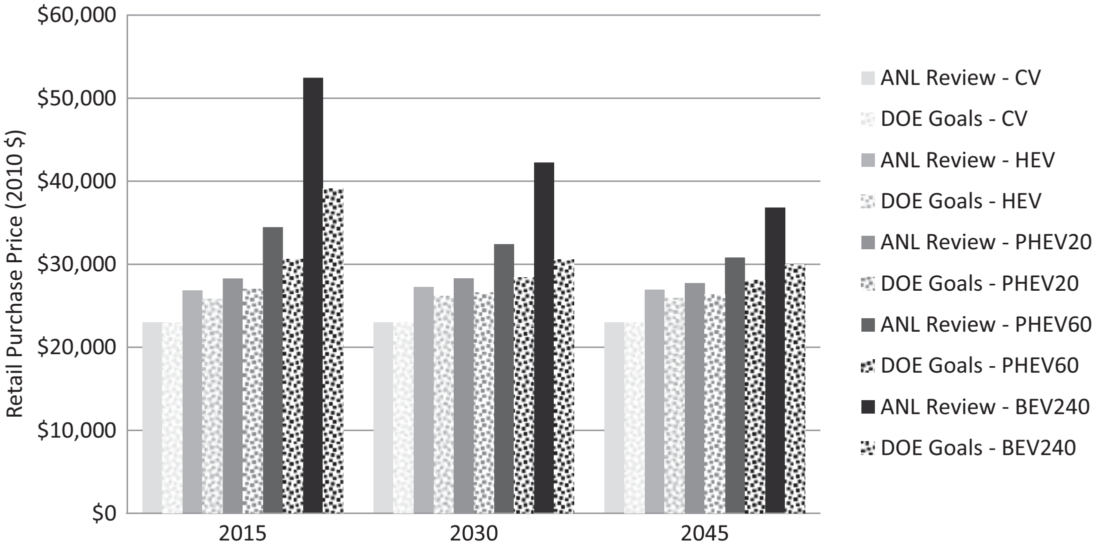
D.3 Cost and Performance

Current and anticipated BEV and PHEV models perform quite well in some regards; they offer impressive power and torque, lower per-mile fuel costs than conventional vehicles, and zero tailpipe emissions. On the negative side of the ledger, as noted previously, most EVs offer only a limited driving range and can require a long amount of time to recharge, and they also require a significant price premium to cover the costs of the battery pack. The potential for greater adoption of EVs in the future will likely hinge on advances in battery technology that help reduce vehicle cost and, for BEVs in particular, increase range.

D.3.1 Vehicle Cost

As already mentioned, the current premium for BEVs and PHEVs due to the high cost of batteries represents a significant barrier to broader adoption of electric vehicles. To illustrate the price difference between EVs and their more conventional counterparts, the Prius plug-in has a premium of almost $8,000 over the standard third-generation Prius HEV (Toyota 2013a, b), the Chevy Volt has a premium of almost $17,000 over the Chevy Cruze (GM, undated a, b), and the Nissan Leaf has a premium of almost $15,000 over the Nissan Versa (Nissan, undated b, c).

To help offset the cost of an EV, the federal government has offered tax credits of up to $7,500, depending on the battery capacity of the model purchased. Some states, such as California, offer additional subsidies. Given mounting pressure to trim federal and state budgets, however, it is unclear whether the public sector will be able to keep offering such financial support over the longer term. Absent public subsidies, the cost premium associated with EVs, largely reflecting the cost of the battery pack, will need to decline considerably to allow for mass market adoption. According to the findings of Michalek et al. (2011), the savings in per-mile fuel costs that result from powering a car with electricity rather than gasoline will not be sufficient for most drivers to recover the premium price for an EV unless gasoline becomes much more expensive than it is today or the price of batteries falls considerably.



Source: Plotkin and Singh (2009), Michalek et al. (2011).

Figure D.2. Potential decline in EV cost premiums through 2045.

As with any technology, it is reasonable to assume that, over time, battery capabilities will improve and prices will fall. There is considerable uncertainty, however, regarding the magnitude and pace at which costs will come down. As one point of reference, researchers at ANL, drawing on a review of the technical literature along with expert interviews, summarized expectations for future reductions in the price premium associated with EVs (Plotkin and Singh 2009). These were then compared with program goals established by the U.S. Department of Energy, as reported by Michalek et al. (2011).

Figure D.2 compares the results from the ANL review with the DOE goals for five types of vehicles in 2015, 2030, and 2045. The five vehicle types are a conventional vehicle (CV), an HEV, a plug-in hybrid with a 20-km (12-mile) all-electric range (PHEV20), a plug-in hybrid with a 60-km (37-mile) all-electric range (PHEV60), and a battery electric vehicle with a 240-km (150-mile) range (BEV240). The figure lists expected retail prices (2010 $), which are assumed to be about 50% higher than production costs. Solid bars correspond to the ANL results, while dotted bars represent DOE targets.

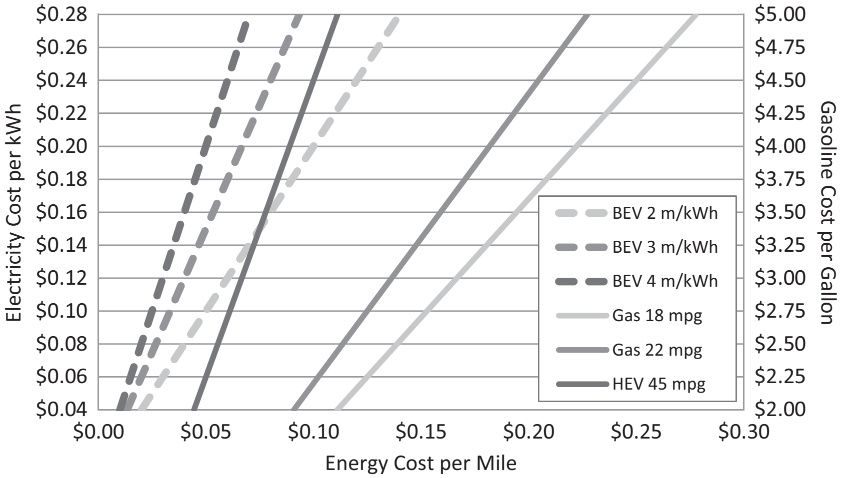
Several observations emerge from the data in this figure. First, EV costs are indeed expected to decline in real terms. Second, the expected reductions in premiums based on the ANL review are less than those based on the DOE targets; that is, DOE targets, at least relative to ANL results, appear optimistic. Third, even with the more optimistic DOE targets, a premium of several thousand dollars is still expected for both PHEVs and BEVs in 2045. In other words, according to these results, the premium for EVs will be smaller but still appreciable.

D.3.2 Energy Cost of Travel

While EVs may demand a significant premium for vehicle purchase, they perform quite well in terms of the energy cost of travel. Additionally, because BEVs are mechanically simpler than conventional vehicles, routine maintenance costs may be lower as well.

As noted earlier, the average residential cost of electricity in the United States was 11.8 cents per kWh in 2011. Assuming that the fuel efficiency for an EV is 3 miles per kWh, roughly in line with EPA's estimate for the Nissan Leaf (fueleconomy.gov, undated), the average cost per mile would be about 4 cents. By comparison, consider a conventional vehicle with impressive fuel economy, say 40 miles per gallon, and assume that the retail price of gasoline is $3.50 per gallon. This would translate to 8.75 cents per gallon, more than double the per-mile cost of electricity for the EV example.

The relative energy cost per mile for an EV in comparison to a conventional vehicle will ultimately depend on the cost of electricity, the efficiency of the EV in miles per kWh, the cost of gasoline or diesel, and the fuel economy of the conventional vehicle in miles per gallon. For PHEVs, the comparison also depends on the percentage of driving that occurs in all-electric mode versus driving powered by the internal combustion engine. Figure D.3, adapted from a chart developed by INL, compares the energy cost per mile for BEV models (the dashed lines) and conventional vehicles (the solid lines) with varying levels of fuel economy at different price levels for electricity and gasoline (INL undated). As shown, one can construct scenarios with very high electric costs and very low gasoline costs in which the energy cost of travel for a conventional vehicle would be as low as that for an EV. But at



Source: Adapted from INL (undated).

Figure D.3. Energy cost of travel for electric vehicles and conventional vehicles.

current prices—less than 12 cents per kWh and near $4 per gallon of gas—the energy costs for EVs are much lower than for conventional vehicles.

Looking solely at energy cost per mile, however, fails to account for significant differences in the initial cost of the vehicles. Because vehicles require a substantial up-front investment, it may be more instructive to examine the total cost of ownership on a per-mile basis. Such a measure ideally accounts for the present-value costs of capital expenses (including the vehicle and potentially any charging infrastructure installed at home), fuel, maintenance, battery replacement (if applicable), depreciation, insurance and amortization, and salvage value, allocated over total miles of travel during the period of ownership. A core challenge in estimating total ownership costs is the degree to which cost-per-mile computations are sensitive to each of the assumptions listed. Some analyses omit some of these parameters, making comparisons between different studies difficult.

Two of the most important and uncertain parameters in comparing total cost of ownership between EVs and conventional vehicles are the cost of batteries (and in turn the cost of an EV) and the cost of petroleum. As an example, Lemoine and Kammen (2009) found that EV battery prices would have to fall to less than $200 per kWh in order to break even with ICEs and HEVs at fuel costs of $4 per gallon and electricity prices of $0.10 per kWh. Michalek et al. (2011) looked at current EV cost estimates and then computed and compared total ownership costs on a per-mile basis with those for conventional vehicles at different price points. Their analysis found that the cost of gasoline would need to be well above $4 per gallon in order for PHEVs and BEVs, assuming currently envisioned battery and electricity costs, to compare favorably with conventional vehicles for total ownership costs. In short, as suggested by these two studies, it is likely that either battery costs will need to fall considerably or petroleum costs will need to rise and remain high on a sustained basis in order for EVs to represent an attractive cost proposition for many potential buyers absent continued subsidies. Such outcomes are certainly possible but cannot be taken as a given.

D.3.3 Operational Performance

The main performance issues for EVs—limited range and significant time to recharge—are mainly relevant for BEVs. PHEVs, in contrast, can run on the ICE as the battery becomes depleted, and any needed mid-trip refueling can occur at a gas station rather than at a charging station.

A number of manufacturers, including Chevrolet, Ford, Honda, Mitsubishi, Nissan, Tesla, and Toyota, have already released BEV models or are planning to do so within the next few model years. Among these, Tesla's Roadster and Model S sedan stand out as exceptions in terms of range. The Roadster has an advertised range of 245 miles (Tesla 2013c), while the Model S can be configured for a range of up to 265 miles (Tesla 2013b), but these are both high-end luxury vehicles with a corresponding price premium. Most models aimed at a broader consumer market have advertised ranges of around 100 miles or less, supported by battery packs of between 16 and 24 kWhs. As noted earlier, for example, the Nissan Leaf's 24-kWh battery pack provides an advertised range of about 75 miles (Nissan, undated a). While 100 miles is enough to accommodate most routine driving patterns, longer road trips would need to be supported by publicly accessible charging infrastructure. Even with Level 3 fast charging, the recharge time may be as much as 30 minutes, and this could deter many potential customers.

In addition to these BEV models, Ford, GM, Honda, and Toyota have recently released or begun to market PHEVs. GM's Chevy Volt, the first to market, now boasts an all-electric range of 38 miles (GM, undated b), while Toyota's plug-in Prius offers an all-electric range of 11 miles (Toyota 2013c). Ford is selling two plug-in models, the C-MAX Energi and the Fusion Energi, both offering all-electric ranges of 21 miles (Ford 2013a, b), and Honda's new plug-in Accord is configured for 13 miles of all-electric range (Honda 2013). The ability of these vehicles to operate based on power from the ICE reduces the need to provide for a longer range in electric mode.

D.3.4 Greenhouse Gas Emissions

The performance of EVs with respect to greenhouse gas emissions depends in part on the source used to generate the electricity. If the power is solar or produced by wind, for example, the reduction in GHGs can be substantial. If the power is generated by the combustion of coal, in contrast, then driving an EV can actually produce more life-cycle GHGs per mile than a conventional hybrid-electric vehicle (Michalek et al. 2011, Mashayekh et al. 2012). The general expectation, however, is that the average carbon intensity of grid power will continue to decline over time.

As part of this study, with the aim of facilitating a consistently framed examination of the GHG emissions reduction potential for the different fuels and vehicle technologies considered, the research team conducted an exercise relying on emissions factors from ANL's GREET model (ANL 2012). The analysis provides for a well-to-wheels analysis—that is, it includes emissions from the production, transport, and use of the fuel in the vehicle. For each of the fuels and vehicle technologies—gasoline, diesel, hybrid electric, natural gas, biofuels, plug-in and battery electric, and hydrogen—the team used GREET's specifications for a mid-size passenger vehicle in 2010 along with two hypothetical configurations estimated by NRC (2013) for similar vehicles in the 2050 time frame. The two future cases are generally consistent with expectations in the literature regarding possible advances in fuels and vehicle technologies, but one embeds baseline assumptions while the other is more optimistic.

In the following are presented the GHG emissions modeling results for conventional vehicles and EVs. For the latter, the analysis includes a PHEV with a 10-mile all-electric range, a PHEV with a 40-mile all-electric range, and a BEV. The intent of including both current and future conventional vehicles is to help clarify not only how PHEVs and BEVs might perform in relation to the current light-duty fleet but also how they might perform against conventional vehicles with much-improved fuel economy in the future.

Table D.1 lists the assumptions for the analysis, including on-road (as opposed to EPA-rated) fuel economy for both gasoline and electric mode, share of miles powered by gasoline and by electricity, and the emissions intensity of electric power generation. The 2010 case assumptions and results for all vehicles are derived from the GREET model. For 2050 baseline and optimistic cases, data from the NRC's *Transitions to Alternative Vehicles and Fuels* (NRC 2013) are used for future fuel economy for ICEs, HEVs, and BEVs. For the PHEV models, the electric-mode fuel economy ratings for the 2050 baseline and optimistic cases mirror the corresponding cases for the 2050 BEV models. For gasoline mode, the fuel economy

Table D.1. Assumptions in emissions comparisons for BEVs and PHEVs.

Fuel/Vehicle Scenario	*MPG (per gallon of gasoline equivalent)*		*Percent of Miles Powered By:*		Emissions Intensity of Electric Power Production
	Gasoline	Electric	Gasoline	Electric	
Gasoline ICE 2010	24.8	—	100%	0%	—
2050 baseline	72	—	100%	0%	—
2050 optimistic	91	—	100%	0%	—
PHEV10 2010	34.7	84.4	80%	20%	2010 U.S. Grid
2050 baseline	93	202	80%	20%	30% cleaner
2050 optimistic	121	296	80%	20%	50% cleaner
PHEV40 2010	34.7	84.4	40%	60%	2010 U.S. grid
2050 baseline	93	202	40%	60%	30% cleaner
2050 optimistic	121	296	40%	60%	50% cleaner
BEV 2010	—	84.4	0%	100%	2010 U.S. grid
2050 baseline	—	202	0%	100%	30% cleaner
2050 optimistic	—	296	0%	100%	50% cleaner

Source: Computations by authors based on data from ANL (2012) and NRC (2013).

assumptions for the 2050 baseline and optimistic PHEVs use the same ratings as for the 2050 baseline and optimistic HEVs (discussed in Appendix A). Finally, the assumed 20% of miles in electric mode for the PHEV10 and 60% of miles in electric mode for the PHEV40 align roughly with findings in the literature on typical driving profiles. These assumptions reflect a range of possible values for these vehicles in the middle of the century and are not intended as precise projections of the future.

Based on these assumed specifications and GREET's emissions factors, Figure D.4 graphs the greenhouse gas emissions performance for current and future conventional models, PHEVs, and BEVs. Again, values represent well-to-wheels emissions but do not include emissions associated with the production of the vehicle and battery pack.

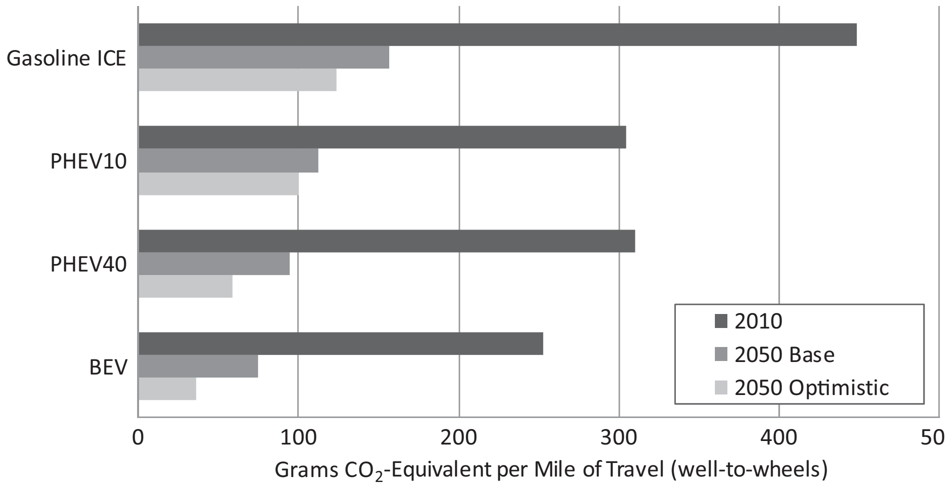
From these results, it appears that the BEV option uniformly outperforms the PHEVs as well as the ICE and HEV options. The picture is further complicated, however, if one considers full vehicle-life-cycle GHGs, including from the production of the vehicle and battery pack. The basic issue is that battery production, in comparison to other vehicle components, is currently an energy-intensive process. As shown by Mashayekh et al. (2012), the carbon emissions from the production of a large battery pack for a BEV, if apportioned over the expected lifetime miles of a vehicle, can account for as much as 20% of a BEV's GHG emissions. Factoring in emissions from battery production, therefore, brings the overall GHG performance of BEVs and PHEVs closer in line since PHEVs have smaller battery packs than BEVs.

D.3.5 Local Air Pollutant Emissions

While EVs can be expected to help reduce greenhouse gas emissions, their performance with respect to local air pollutants on a well-to-wheels basis is more mixed, particularly with respect to fine particulate matter (PM2.5) and SO_x. According to the GREET model (ANL 2012), for example, a current PHEV10 can be expected to generate 60% more PM2.5 and 40% more SO_x per mile than a comparable ICE on a well-to-wheels basis, while a current PHEV40 can be expected to generate 200% more PM2.5 and SO_x per mile. This is largely due to existing coal-fired power plants in the U.S. electricity mix. In the future, the retirement of older coal plants and pollution controls installed on newer power plants are expected to greatly reduce the amount of conventional air pollutants associated with charging electrified vehicles. One additional point to note is that EVs emit no pollutants while driving; rather, any air pollutants are created in the processes of producing or extracting feedstocks and generating power. As such, EVs, even if relying on power from fossil fuels, may still contribute to significant improvements in urban air quality.

D.4 Market Prospects

If one were to assume that future advances in battery technology led to significant cost reductions and greatly extended the range that an EV could be driven between charges, and further that publicly accessible fast recharging stations had been deployed across the road network, the potential market share for EVs within the light-duty fleet would be significant. Given the inherently lower per-mile costs of driving on electric power, the economic advantages of EV ownership would be compelling to most households. In fact, however, there is significant uncertainty surrounding the expected pace of battery technology advances, and the network of fast recharging infrastructure is still quite sparse. Given these challenges, unbiased estimates of future EV adoption rates tend to be rather conservative. The remainder of this section first reviews some of the market penetration projections that have been



Source: Computations by authors based on data from ANL (2012) and NRC (2013).

Figure D.4. GHG reduction prospects for PHEVs and EVs in 2050.

offered in the literature and then summarizes key issues and uncertainties that will have an influence on whether EVs will be successful.

D.4.1 Future Market Projections

In order to market BEVs and PHEVs, overall ownership costs must be comparable to those of conventional ICE vehicles of the same size and type. A higher premium for an EV may be tolerable if it can be shown that the life-cycle cost is equal to or lower than that of a corresponding ICE vehicle. In addition, of course, the functional utility of the BEV or the PHEV must meet the needs of the consumer. There have been a number of studies of marketing and ownership considerations relative to BEVs (e.g., Deloitte 2011, Axsen and Kurani 2013). Such studies generally indicate that there is a relatively small (10% to 20%), but nonetheless significant, potential market for BEVs assuming that the price differential is not too large. However, the predictions of sales and market penetration in the available studies vary widely. As would be expected, the potential market increases as the assumed range of BEVs is greater and the price differential is smaller.

Based on the discussion in previous sections, the prospects for a significant penetration of electric vehicles into light-duty automotive markets do not appear to be promising as long as the customer focuses primarily on the initial vehicle purchase price, at least until battery prices fall by 50% or more. Vehicle range and recharging time currently limit the utility of electric vehicles, and most consumers want a vehicle that can serve their most demanding requirements (e.g., the longest trips that they might take in a year) even if those requirements are infrequent. Alternative business models, such as BMW's program to loan gasoline ICE cars several times a year to customers who buy their EVs (Gareffa 2013), might reduce the anxiety of owning an EV that meets most, but not all, of a driver's needs. The higher initial price of the BEV and its reduced utility have made it difficult to sell electric vehicles except to consumers that place a high priority on environmental objectives and have the means to afford the additional premium. On the other hand, when purchase incentives have been available, as occurred in the late 1990s as part of the ZEV mandate, sales and leases of BEVs have shown a marked increase. Large incentives for the purchase of BEVs are again being offered—for example the $7,500 federal tax credit—and sales of BEVs have picked up over the past few years.

The characteristics of PHEVs should help alleviate consumers' concerns about BEVs. PHEVs have ranges similar to or greater than conventional vehicles, and their smaller battery could allow for a smaller incremental cost than BEVs. Nevertheless, the capital cost of PHEVs is still much higher than for conventional vehicles, and this incremental cost can reasonably be expected to dampen consumer demand.

There have been a number of sales projections of BEVs and PHEVs for over the next 20 to 30 years. In its most recent *Annual Energy Outlook*, for example, EIA (2013a) projects that combined annual sales for light-duty BEVs and PHEVs will increase from about 1,800 in 2010 to a little over 560,000 in 2040. This would correspond to about 3% of the projected market for new light-duty vehicles in 2040, estimated by EIA to be a little over 18 million. Actual U.S. plug-in vehicle sales have already surpassed EIA's early projections, however, with more than 53,000 sales in 2012 and more than 41,000 in the first 6 months of 2013 (EERE 2013b). Yet these still represent less than 1% of total U.S. vehicle sales. Since 2010, the Chevy Volt has been the market leader across plug-in vehicles, with more than 41,000 vehicles sold. The Nissan Leaf has sold about 29,000 vehicles, with the Toyota Plug-in Prius and Tesla Model S each selling around 12,000 (EERE 2013b). It seems likely that within the next 5 to 10 years, California and other states with similar incentives or regulations will experience the greatest sales of BEVs and PHEVs (Anderman 2010).

Baines and Nelson (2009) suggest that the penetration of BEVs after 2020 will start to increase, but that the overall market share will remain modest, not exceeding 15% by 2050. On the other hand, they project that the market share for PHEVs could increase to 60% by 2050 under a scenario in which virtually all new vehicles will be either HEVs, PHEVs, or BEVs.

CARB, in contrast, envisions a potential future in which BEVs and FCVs eventually emerge to dominate the light-duty vehicle market (CARB 2009). Under the CARB scenario—which should be viewed as more of a conceptual imagining of a plausible future than a formal forecast—conventional vehicle sales begin to decline after 2010, eventually being phased out entirely just after 2030. HEV sales begin to rise in the 2000s, peak at around 40% market share in 2020, and then decline to zero by 2040. PHEV sales, following a similar if slightly delayed trajectory, begin to ramp up in the later 2010s, peak at around 25% in 2030, and then decline to zero by 2040. Finally, BEVs and FCVs enter the market in significant numbers following 2020 and then account for nearly all sales by 2040.

One of the uncertainties of the CARB scenario is the fate of hydrogen fuel-cell vehicles. If fuel-cell vehicles decline in cost and hydrogen fueling infrastructure is developed, then BEVs will face strong competition from fuel-cell vehicles and perhaps fail to attain a significant market share. If FCV cost and lack of refueling infrastructure remain as significant barriers, then the market share of BEVs could rise significantly to dominate the market. Thus, the relative share of BEVs and FCVs in the CARB scenario, which collectively account for most new vehicles sales by 2040, is left unspecified.

D.4.2 Factors Affecting Market Prospects

As described in this appendix, the commercial success and societal benefits of EVs will depend on many uncertain factors. These can be summarized as follows.

Vehicle and battery costs. Given the current state of technology, a primary obstacle to EV market penetration will be the differential in the initial vehicle price compared to competing conventional ICE vehicles. Even as the technology matures, many expect that the premium could still be thousands of dollars without government subsidies. PHEVs with smaller batteries (lower all-electric range) are expected to have the lowest cost differential. Most but not all of this difference is due to battery cost. Battery costs have improved significantly in the past few years, but further improvement is still needed. Alternate chemistries with higher performance and lower costs than lithium-ion batteries may ultimately be required for widespread adoption.

Battery life cycle and replacement. In addition to the initial cost, battery life is critical to the successful market penetration of electric vehicles. Initial test data suggest that the cycle life appears to be adequate for light-duty applications, but there is greater uncertainty regarding calendar life.

Battery performance and range limitations. Current battery technology does not support driving distances comparable to conventional vehicle technology. Furthermore, Level 1 and even Level 2 recharging can take hours to complete, which may only be viewed as acceptable when recharging at home or at work. In order for wide-scale BEV adoption to occur, advances in battery technology that address these issues may prove necessary, although it is also possible that households could choose to purchase a BEV for short commutes and local trips and a conventional vehicle for longer trips. PHEVs are less affected by range limitations and recharge times given their ability to run on gasoline when needed.

Availability of publicly accessible fast recharging stations. Relatedly, major investments in publicly accessible stations capable of fast recharging may be needed to support wide-scale adoption of BEVs. However, if 30 minutes, the current standard for fast recharging, remains the fastest available option, then the time required to recharge a vehicle during the middle of a trip may still be viewed as sufficiently inconvenient to deter broad adoption of BEVs. Additionally, it remains unclear how investments in fast recharging will be coordinated and financed.

Impacts on the power grid. Significant penetration of electric vehicles could have an impact on the power grid, potentially necessitating investments in generation, transmission, and, especially, local distribution infrastructure. On the other hand, there is also a possibility that EVs might one day play a role in storing grid electricity for use during periods of peak power demand.

Changing electricity generation mix. In the future, new regulations that cause a shift away from coal to renewable and other less-polluting forms of power could affect both the price of electricity and the environmental benefits of promoting EVs.

Price of conventional fuel. The relative cost of petroleum-based fuel is also likely to influence the relative attractiveness of EVs. While many expect that electric vehicles could someday compete when gasoline is priced in the $2 to $4 per gallon range, the break-even price for gasoline given the current premiums associated with EVs is well over $4 per gallon for most driver profiles.

Improvements in other fuel vehicle technologies. Improvements in other fuels and vehicle technologies—for example, cheaper production costs for biofuels or fuel-cell vehicle components—would make it more difficult for EVs to compete for market share.

References

Anderman, M. 2010. *The Plug-in Hybrid and Electric Vehicle Opportunity Report.* Advanced Automotive Batteries.

ANL. 2012. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)*, Fuel Cycle Model version 1 2012. U.S. Department of Energy.

Axsen, J. and K. S. Kurani. 2013. "Hybrid, Plug-in Hybrid, or Electric-What Do Car Buyers Want?" *Transportation Research Board 92nd Annual Meeting Compendium of Papers*, paper no. 13-3028. Transportation Research Board of the National Academies, Washington, D.C.

Baines, L. and P. Nelson. 2009 (March). "Lithium Batteries: Possible Materials Issues." Presented at the 13th International Battery Materials Recycling Seminar, Fort Lauderdale, Florida.

Better Place. 2011. The Solution: Battery Switch Stations. http://www.betterplace.com/the-solution-switch-stations (accessed December 7, 2011).

CARB. 2009. Summary of Staff's Preliminary Assessment of the Need for Revisions to the Zero Emission Vehicle Regulation.

Crane, K., A. E. Curtright, D. S. Ortiz, C. Samaras, and N. E. Burger. 2011. "The Economic Costs of Reducing Greenhouse Gas Emissions under a United States National Renewable Electricity Mandate." *Energy Policy*, 39 (5): 2730–2739.

Deloitte. 2011. Unplugged: Electric Vehicle Realities Versus Consumer Expectations.

DOE. 2010. The Recovery Act: Transforming America's Transportation Sector, Batteries and Electric Vehicles.

EERE. 2002. *A Primer on Electric Utilities, Deregulation, and Restructuring of U.S. Electricity Markets.*

EERE. 2011. Battery Chargers for Electric Vehicles. http://www1.eere.energy.gov/vehiclesandfuels/avta/light_duty/fsev/fsev_battery_chargers.html (accessed December 7, 2011).

EERE. 2013a. Alternative Fueling Station Counts by State. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/stations_counts.html (accessed October 7, 2013).

EERE. 2013b. U.S. PEV Sales by Model. Alternative Fuels Data Center. http://www.afdc.energy.gov/data/10567 (accessed October 7, 2013).

EIA. 2011. Analysis of Impacts of a Clean Energy Standard as Requested by Chairman Hall.

EIA. 2012a. California Renewable Electricity Profile 2010. http://www.eia.gov/renewable/state/california/ (accessed October 3, 2012).

EIA. 2012b. Electricity Explained: Factors Affecting Electricity Prices. http://www.eia.gov/energyexplained/index.cfm?page=electricity_factors_affecting_prices (accessed October 3, 2012).

EIA. 2012c. What Is the Status of the U.S. Nuclear Industry? Energy in Brief. http://www.eia.gov/energy_in_brief/nuclear_industry.cfm (accessed October 3, 2012).

EIA. 2013a. *Annual Energy Outlook 2013.*

EIA. 2013b. *Monthly Energy Review, September 2013.*

EIA. Undated. Electric Power Industry Overview 2007. http://www.eia.gov/cneaf/electricity/page/prim2/toc2.html (accessed October 28, 2011).

Ford. 2013a. 2013 C-MAX Specifications: Engine. http://www.ford.com/cars/cmax/specifications/engine/ (accessed October 11, 2013).

Ford. 2013b. 2014 FUSION Specifications: Engine. http://www.ford.com/cars/fusion/specifications/engine/ (accessed October 11, 2013).

Fueleconomy.gov. Undated. 2012 Nissan Leaf. http://www.fueleconomy.gov/feg/noframes/32154.shtml (accessed December 8, 2011)

Gareffa, P. 2013. 2014 BMW i3 Gas-Loaner Program To Ease Range Concerns. http://www.edmunds.com/car-news/2014-bmw-i3-gas-loaner-program-to-ease-range-concerns.html (accessed October 9, 2013).

GM. Undated a. Chevrolet 2014 Cruze/2013 Cruze. http://www.chevrolet.com/cruze-compact-car.html (accessed October 14, 2013).

GM. Undated b. Chevrolet 2014 Volt/2013 Volt: Model Overview. http://www.chevrolet.com/volt-electric-car/ (accessed October 14, 2013).

Honda. 2013. Honda Accord Plug-in: Complete Specifications. http://automobiles.honda.com/accord-plug-in/specifications.aspx (accessed October 11, 2013).

INL. 2006. *Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants*, DOE-ID-11263.

INL. Undated. *Comparing Energy Costs per Mile for Electric and Gasoline-Fueled Vehicles.*

Kaplan, S. M. 2009. *Electric Power Transmission: Background and Policy Issues.* Congressional Research Service.

Kempton, W., C. L. Archer, A. Dhanju, R. W. Garvine, and M. Z. Jacobson. 2007. "Large CO_2 Reductions Via Offshore Wind Power Matched to Inherent Storage in Energy End-Uses." *Geophysical Research Letters*, 34 (2): LO2817.

Kintner-Meyer, M., K. Schneider, and R. Platt. 2007. *Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 1: Technical Analysis.* Pacific Northwest National Laboratory.

LaTourrette, T., T. Light, D. Knopman, and J. T. Bartis. 2010. *Managing Spent Nuclear Fuel: Strategy Alternatives and Policy Implications.* RAND Corporation, Santa Monica.

Lemoine, D. M. and D. M. Kammen. 2009. "Addendum to an Innovation and Policy Agenda for Commercially Competitive Plug-in Hybrid Electric Vehicles." *Environmental Research Letters*, 4: 039701.

Mashayekh, Y., P. Jaramillo, C. Samaras, C. T. Hendrickson, M. Blackhurst, H. L. McLean, and H. S. Matthews. 2012. "Potentials for Sustainable Transportation in Cities to Alleviate Climate Change Impacts." *Environmental Science & Technology*, 46: 2529–2537.

May, E. and S. Johnson. 2011. "Top 10 EV Challenges: Utilities Prepare for a Bumpy Road." *Public Utilities Fortnightly*, pp. 56–60.

Michalek, J. J., M. Chester, P. Jaramillo, C. Samaras, C.-S. Shiau, and L. B. Lave. 2011. "Valuation of Plug-in Vehicle Life-Cycle Air Emissions and Oil Displacement Benefits." *Proceedings of the National Academy of Sciences*, 108 (40): 16554–16558.

NETL. 2013. Coal and Power Systems: Major Demonstrations. http://www. netl.doe.gov/technologies/coalpower/cctc/index.html (accessed September 26, 2013).

Nissan. Undated a. 2013 Leaf: Charging and Range. http://www.nissanusa.com/electric-cars/leaf/charging-range/ (accessed October 14, 2013).

Nissan. Undated b. 2013 Nissan Leaf. http://www.nissanusa.com/electric-cars/leaf/ (accessed October 14, 2013).

Nissan. Undated c. 2013 Nissan Versa Note. http://www.nissanusa.com/cars/versa-note (accessed October 14, 2013).

NPC. 2012. *NPC Future Transportation Fuels Study: Advancing Technology for America's Transportation Future.*

NRC. 2010. *Electricity from Renewable Resources: Status, Prospects, and Impediments.* The National Academies Press, Washington, D.C.

NRC. 2013. *Transitions to Alternative Vehicles and Fuels.* The National Academies Press, Washington, D.C.

Ortiz, D. S., A. E. Curtright, C. Samaras, A. Litovitz, and N. Burger. 2011. *Near-Term Opportunities for Integrating Biomass into the U.S. Electricity Supply: Technical Considerations.* RAND Corporation, Santa Monica.

PG&E. Undated. PEV Pricing Options: Choosing a Charging Plan That's Right for You. http://www.pge.com/includes/docs/pdfs/shared/environment/pge/cleanair/electricdrivevehicles/PEV_rate_options.pdf (accessed December 8, 2011).

Plotkin, S. and M. Singh. 2009. *Multi-Path Transportation Futures Study: Vehicle Characterization and Scenario Analysis.* Argonne National Laboratory.

Shao, S., M. Pipattanasomporn, and S. Rahman. 2009. "Challenges of PHEV Penetration to the Residential Distribution Network." *Power & Energy Society General Meeting, PES '09, IEEE*, pp. 1–8, 26–30.

Simeone, N. 2013. DOD Electric Vehicles Will Supply Power to Local Grids. News: American Forces Press Service. http://www.defense.gov/News/NewsArticle.aspx?ID=118971 (accessed October 11, 2013).

Sovacool, B. and R. Hirsh. 2009. "Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-Grid (V2G) transition." *Energy Policy*, 37 (3): 1095–1103.

Tesla. 2013a. Battery Swap. http://www.teslamotors.com/batteryswap (accessed October 11, 2013)

Tesla. 2013b. Model S. http://www.teslamotors.com/models (accessed October 11, 2013).

Tesla. 2013c. The Roadster. http://www.teslamotors.com/roadster (accessed October 11, 2013).

Toyota. 2013a. Prius 2013. http://www.toyota.com/prius/ (accessed October 14, 2013).

Toyota. 2013b. Prius Plug-in Hybrid 2013. http://www.toyota.com/prius-plug-in/ (accessed October 14, 2013).

Toyota. 2013c. Prius Plug-in Hybrid 2013: Features & Specs. http://www.toyota.com/prius-plug-in/features.html#!/mpg/1235/1239 (accessed October 11, 2013).

APPENDIX E

Hydrogen Fuel-Cell Vehicles

Hydrogen has been used for various commercial applications for over a century, but serious interest in hydrogen as a transportation fuel began with the first hydrogen fuel-cell bus demonstration by Ballard Power Systems in 1993 (OFE 2000). Soon thereafter, many automakers began to launch their own hydrogen-fueled vehicle research and development programs. While hydrogen can be used in internal combustion engines, either as pure hydrogen (Cho 2004) or combined with natural gas (Burke et al. 2005), most auto automakers have focused on hydrogen fuel-cell vehicle technology, which will likewise be emphasized in this appendix. Over the longer term, the use of hydrogen as a transportation fuel could offer several compelling advantages:

- **Reduced petroleum use in transportation.** Hydrogen can be generated through several processes using a variety of feedstocks, many of which can be produced domestically. A large-scale shift to hydrogen could drastically reduce the use of petroleum in passenger transportation.
- **Greenhouse gas mitigation.** Some of the potential feedstocks for hydrogen, such as biomass or low-carbon electricity and water, would allow for very low well-to-wheel carbon emissions. And when hydrogen is processed within a fuel cell to produce electricity to power a vehicle, the only tailpipe by-product is water. Depending on how it is produced, then, hydrogen could support a dramatic reduction in GHG emissions from the transportation sector.
- **Improved air quality.** Vehicles powered by hydrogen fuel cells emit no harmful air pollutants from tailpipes and could thus improve air quality within urban areas by reducing mobile-source emissions. Depending on the processes and feedstocks used to generate hydrogen, there could also be reductions in harmful air pollutants at the point of fuel production.
- **High energy efficiency.** In comparison to the use of gasoline or diesel within an internal combustion engine, fuel cells are able to use the embodied energy within hydrogen much more efficiently. If the cost of producing and delivering hydrogen can be reduced such that it is roughly the same as the cost of gasoline or diesel, and if the cost of fuel-cell vehicles can likewise be reduced, then FCVs could offer significantly lower total per-mile energy costs of travel.

Some transit agencies have begun to explore the use of hydrogen fuel-cell buses, with a total of 25 fuel-cell buses being demonstrated in eight locations as of 2012 (Eudy, Chandler, and Gikakis 2012). However, light-duty vehicles are expected to offer a much larger market for hydrogen fuel. This appendix will focus on light-duty FCVs. Potential hydrogen applications in the medium- and heavy-duty fleets are considered in Appendix F.

E.1 Production, Distribution, and Refueling

While a significant quantity of hydrogen is already produced in the United States each year, most of this is used for applications other than transportation. To support a major shift to hydrogen as a transportation fuel, the total volume of hydrogen production would need to be expanded dramatically. It would also be necessary to develop the infrastructure for distributing hydrogen and refueling vehicles, requiring significant investment.

E.1.1 Current Hydrogen Generation

Hydrogen, like electricity, is an energy carrier. It does not occur naturally on earth but rather must be produced from other sources such as natural gas, coal, wood, water, or biomass. As of 2011, hydrogen production capacity within the United States exceeded 9 million metric tons per year. Roughly two-thirds of this amount is captive hydrogen—that is, hydrogen that is used where it is produced—for oil refineries and for making ammonia and methanol. The remaining third is merchant hydrogen, used mostly in off-site refineries and distributed by pipeline or liquid tankers (Joseck 2012).

To put current U.S. hydrogen production in perspective, a kilogram of hydrogen is roughly equivalent, in terms of embodied energy, to a gallon of gasoline, though fuel-cell vehicles achieve much higher fuel economy on an energy-equivalent basis. The total production of 9 million metric tons of hydrogen per year translates to about 25 million kilograms of hydrogen per day, capable of powering about 36 to 41 million FCVs (Joseck 2012). The total number of light-duty vehicles in the U.S. fleet, however, is approaching 250 million (ORNL 2012). Even assuming that all of the hydrogen currently produced in the United States could be redirected to transportation, the total volume would still need to be increased by almost an order of magnitude in order to replace current gasoline consumption.

E.1.2 Hydrogen Production Pathways

There are several feedstocks and processes that could be used to produce additional hydrogen for use as a transportation fuel. The most mature production process is thermochemical hydrocarbon conversion, encompassing such methods as steam methane reformation and gasification. Potential feedstocks include coal, oil, natural gas, and biomass. Steam reforming of natural gas, for example, is the most common method of hydrogen production today, used mainly for industrial and refining applications. Fossil fuels currently provide the cheapest option for producing hydrogen, but they also result in the emission of greenhouse gases as a by-product. Over the longer term, the resulting carbon emissions could be captured at the source and subsequently sequestered deep in the earth to mitigate climate effects, although the technical and financial feasibility of this concept at scale remains to be demonstrated. If CCS does not prove successful, the use of biomass as a feedstock, which draws carbon dioxide from the atmosphere as it grows, could serve as a low-carbon source of hydrogen (Ogden et al. 2011).

Electrolysis, in which electricity is used to split water into oxygen and hydrogen gas, is another option for producing hydrogen fuel. In terms of greenhouse gas emissions, the benefits of electrolysis depend on the feedstocks used to produce the electricity. With electricity generated from coal (or from natural gas, to a lesser extent) without carbon capture and sequestration, the production of hydrogen would still result in significant GHG emissions. If, on the other hand, the electricity is generated from low-carbon sources such as nuclear, solar, wind, hydropower, or thermal power plants with carbon capture and sequestration, then the production and use of hydrogen as a fuel would have very low well-to-wheel GHGs. Unfortunately, the production of hydrogen fuel from water using clean or renewable electricity is expected to remain more costly than hydrogen derived from fossil fuels or biomass over the next decade or more. Looking out even further, clean hydrogen could be generated via thermochemical water splitting with high-temperature heat from nuclear or concentrated solar power, via biological or photoelectrical water splitting, or via biomass pyrolysis, although these technologies are more economically challenging (Ogden et al. 2011, NPC 2012).

In examining alternate hydrogen production pathways, another consideration is whether the fuel is generated at a large central plant and then transported (e.g., via truck or pipeline) to refueling stations or is instead produced locally, at much lower volume, near the point of sale. Because mature distribution networks for natural gas, water, and electric power are already in place, steam reformation and electrolysis are both amenable to distributed generation. The per-unit cost of smaller-scale production is generally higher than for large-scale production at central plants. Absent a national hydrogen distribution network, however, and depending on the location of a refueling station and the volume of hydrogen required, distributed hydrogen production could in some cases be less expensive than producing hydrogen centrally and then distributing via truck.

Table E.1, based on a recent NRC study, provides a sense of the potential trade-offs (NRC 2013b). The table shows the

Table E.1. Future commercial-scale hydrogen production costs and emissions.

Scale	Feedstock	Process	Low Carbon	Cost ($2009/gge)
Centralized	Natural gas	Steam methane reformation	No	1.40
	Coal	Gasification	No	1.80
	Coal	Gasification with CCS	Yes	2.50
	Biomass	Gasification	Yes	2.10
	Water/wind	Wind power electrolysis	Yes	3.82
	Water/nuclear	Thermochemical splitting	Yes	1.39
Distributed	Natural gas	Steam methane reformation	No	1.60
	Water/grid	Grid power electrolysis	No	3.80

Source: NRC (2013b); costs in 2020 assuming 10 million FCVs on the road.

estimated costs (in 2009 dollars per gge) and emissions characteristics of several centralized and distributed hydrogen production processes and feedstocks in the 2020 time frame. Note that the estimates assume a very rapid rate of FCV adoption, with 10 million FCVs on the road by 2020, allowing for greater economies of scale in production costs. In other words, the table can be viewed as demonstrating what is possible on the fuel production side, as opposed to what is likely; the cost estimates would certainly be higher at lower levels of FCV adoption. Additionally, the estimated prices in the table focus solely on production and do not include transport costs for the centralized production methods, or station costs.

As indicated in the table, options involving distributed generation, electrolysis, or lower-carbon emissions generally entail higher production costs. The study from which these estimates were drawn assumed that an additional cost of $2 per gge would be required for distribution and station costs for the centralized production methods, and that an additional cost of $1.88 per gge for station costs would be required for the distributed production methods. Note that the recent significant decline in natural gas prices has contributed to the lower cost estimates for steam methane reformation in the table.

E.1.3 Distribution

For hydrogen that is produced on site at fueling stations, distribution is obviously not needed. As indicated in Table E.1, however, the per-unit cost of producing hydrogen in larger volume can be lower than distributed generation. As a result, it may be cheaper to produce hydrogen centrally and then transport it to a refueling station. The most cost-effective means of distributing hydrogen to a fueling station depends on volume of use. Three scales are commonly considered (Washington State DOT 2009):

- **Gaseous hydrogen tube trailers.** At small scales (roughly 20 to 60 refills per day), gaseous hydrogen can be delivered by trucks carrying tube trailers that store compressed gas.
- **Liquid hydrogen tank trailers.** At larger scales (200 to 500 refills per day), liquid hydrogen can be delivered by trucks with cryogenic tanks (cooled to less than minus 253 degrees Celsius). The hydrogen must be liquefied at the production facility, transferred to the tanks, and finally transferred to storage tanks at the fueling station. There is a cost and energy penalty in liquefying hydrogen, but the higher-volume capacity makes this a better option than tube trailers with greater demand.
- **Gaseous hydrogen pipelines.** Finally, gaseous hydrogen can be delivered by pipelines in the same manner as natural gas. However, pipelines for hydrogen are quite expensive, requiring alloy steel to avoid hydrogen embrittlement of low-carbon steel and special seals due to the small molecule size. Estimated costs range from $1 million to $1.5 million per mile in urban settings. The delivery of hydrogen via pipeline might therefore become cost-effective only when FCVs have achieved significant market share, on the order of 25% or more of the on-road fleet (Washington State DOT 2009).

E.1.4 Hydrogen Fueling Stations

Should hydrogen emerge as a successful transportation fuel, it is expected that most vehicles will refuel at stations similar to current gasoline filling stations. Building out a network of hydrogen refueling stations will require significant investment. As of early 2012, there were fewer than 80 hydrogen stations in the United States, with a significant share in California, and more than 20 additional stations in the planning stages (Fuel Cells 2000, 2012b). Most of these are for demonstration programs, however, and are not intended for public use. Existing stations tend to be small, and a number have been decommissioned.

To provide a sense of the scale of the investment that could be required to develop a network of hydrogen fueling stations, the API reports that there are more than 150,000 locations across the country that sell gasoline, including service stations, truck stops, convenience stores, and marinas (API 2013). To support early-stage market penetration for FCVs, one study estimated that the total number of hydrogen fueling stations needed would be about 3% to 7% of the current number of gasoline stations (Nicholas and Ogden 2006). This roughly translates to between 4,500 and 11,000 stations, up to two orders of magnitude above the existing number of stations.

If hydrogen fuel-cell technology were to become so successful that FCVs eventually replaced fossil-fueled internal combustion engines within the light-duty fleet, then the number of hydrogen fuel stations would continue to expand, ultimately approaching the current number of gasoline stations. Yet stations have high capital requirements, with cost estimates falling in the range of $1 million to $7 million, depending on size and configuration (NPC 2012).

Hydrogen stations are costly, in large part because they are more complex than existing fueling stations. Gasoline is stored as a liquid at ambient temperature both at the station and in the vehicle. As a result, the two main components of a gasoline fueling station are a storage tank and a dispenser. In contrast, hydrogen is likely to be produced or stored in different forms or pressures at the station and on the vehicle. Stations might store hydrogen as a cryogenic liquid, store it as a gas at moderate pressure (less than 2,500 psi), produce it on-site at low to moderate pressures, or receive it from a pipeline at low pressures (hundreds of psi). In contrast, most current FCV prototypes are equipped with tanks that store hydrogen at 5,000 or 10,000 psi. (While other forms of onboard hydrogen storage, such as cryogenic tanks for liquid hydrogen, have been explored, it appears that FCVs will rely on high-pressure gaseous storage for at least the near future.) As such, hydrogen stations are likely to require a compressor in addition to a storage tank and dispenser, and may require a vaporizer as well if the hydrogen is stored cryogenically at the station.

The high cost of hydrogen fueling stations poses a chicken-and-egg type of problem for the successful rollout of hydrogen fueling stations. Specifically, absent a sufficient number of FCV owners, fuel providers will be reluctant to build hydrogen fueling stations given the considerable cost involved. At the same time, prospective FCV buyers will hesitate to make the transition to hydrogen unless they know that it will be convenient to access fueling stations. Ideally a small number of stations could be built before the initial rollout, with additional stations to be added as FCV ownership increases. In practice, though, this may prove difficult to coordinate.

One concept for overcoming the challenge of providing hydrogen fuel to early FCV adopters is the mobile refueler (CEC 2004). A mobile refueler consists of a trailer that contains all the components necessary to fuel vehicles—storage tank, compressor, and dispenser—and can be moved from one place to another. For example, a mobile refueler might serve one neighborhood on Mondays and Thursdays, another on Tuesdays and Fridays, and so forth. Although mobile refuelers would be less than ideal in terms of convenience, they might still play a valuable role in supporting initial adoption until a broader network of permanent hydrogen fueling stations emerges.

As with electric and natural gas vehicles, home refueling with hydrogen is a realistic possibility at some point. Options might include a tri-generation appliance that uses natural gas to produce some combination of heat, electric power, and hydrogen fuel, or a home electrolysis device. Over the foreseeable future, however, such technology is likely to be priced out of the reach of most households, necessitating the consideration of publicly accessible hydrogen refueling infrastructure to enable a large-scale shift to hydrogen as a transportation fuel (Ogden et al. 2011).

E.1.5 Current and Future Hydrogen Costs

The present cost of hydrogen as a transportation fuel for the end user would be high given the nascent state of the market. While a few hydrogen refueling stations exist, most of these are for demonstration projects and are oversized relative to demand. This has the effect of inflating the apparent cost by allocating capital investments over a smaller quantity of dispensed fuel. Drawing on data from existing stations, however, Wipke et al. (2010b) estimated that early hydrogen costs for a station operating at higher volume would fall in the range of $8 to $10 per kilogram for on-site natural gas reformation and $10 to $13 per kilogram for on-site electrolysis. Another study (NRC 2013b) projected the cost of hydrogen fuel at roughly $10 per kilogram in the near term. Along similar lines, the NPC (2012) estimated the near-term cost for centrally produced and delivered hydrogen to fall in the range of $9 to $12 per kilogram and the cost for distributed hydrogen to fall in the range of $15 to $25 per kilogram.

In a high market penetration scenario considered in the NRC study, infrastructure begins to scale up after 2015, and hydrogen costs decline to about $4 per kilogram by 2050 (NRC 2013b). Ultimately, though, the cost of hydrogen fuel will depend on such factors as aggregate demand, advances in technology, type of production and feedstock, production scale, and mode of transport for any centrally produced hydrogen.

E.2 Vehicle Technology

Auto manufacturers initiated fuel-cell vehicle development programs in the late 1990s. The effort to commercialize hydrogen FCVs has received considerable public and private support and interest in the intervening years, and California has played an important role in this history. The formation of the California Fuel Cell Partnership (CFCP) in 1999—a collaboration involving public agencies, auto manufacturers, fuel providers, and other interested parties—marked an important early milestone. The CFCP works to demonstrate and promote the potential for fuel-cell vehicles and has engaged in many activities aimed at bringing FCVs closer to market. Members conduct outreach to the public, fleet owners, and public officials, and they also train first responders on hydrogen-related issues. Above all, the CFCP seeks to stimulate collaboration among public and private groups working toward the development and adoption of fuel cells and hydrogen (CFCP, undated).

The California Air Resources Board's ZEV program has also been influential in the development of FCVs (CARB 2013). Launched in the 1990s and subject to several revisions in the years that followed, the main aim of the program has been to require auto manufacturers to produce specified quantities of ZEVs for sale in California. As part of the program, CARB has mandated the demonstration of limited numbers of FCVs. In the most recent ZEV revisions, auto manufacturers have the opportunity to meet credit requirements through some combination of FCVs along with battery electric vehicles. This allows automakers to choose which of the technologies best meet their strategic plans.

At the federal level, the U.S. Department of Energy funds fuel-cell research and development through the U.S. DRIVE Partnership (previously known as FreedomCAR and the Partnership for a New Generation of Vehicles), which has existed since 1993 (NRC 2013a). The U.S. Department of Energy's Alternative Fuel Data Center resource provides a comprehensive listing of additional federal and state programs related to hydrogen (EERE 2013). While many involve cash or tax incentives to promote adoption of hydrogen fuel and FCVs, regulatory mandates such as the ZEV program have also been employed. Without public subsidies and regulations, it is unclear that FCVs would have progressed as far as they have. Indeed, the costs for both vehicles and fueling infrastructure are prohibitive.

Over the past 10 years, though, most automakers have demonstrated fuel-cell vehicles. The organization Fuel Cells 2000 has compiled a list of such vehicles around the world (Fuel Cells 2000, 2012a). Some of the models referenced are prototype or concept vehicles, but many are based on commercial platforms. Honda, Toyota, Daimler, GM, and Hyundai have all announced plans to commercialize FCVs by around 2015 (NRC 2013b). To achieve successful market penetration, continued technological advances and cost reductions for fuel-cell vehicle technologies will be crucial. The two main vehicle development challenges involve the fuel cell and onboard hydrogen storage. Other key components of hydrogen fuel-cell vehicles are electric motors, power controllers, and batteries for hybrid operation and cold-start support. The following discussion draws upon an overview from Ogden et al. (2011) on the challenges and prospects for FCV technology.

Fuel-cell technology. Fuel cells can be thought of as highly efficient electrochemical engines that combine hydrogen and oxygen to produce electricity, which is then used to power an electric motor to propel the vehicle. There is no combustion, however, or emissions of greenhouse gases or local air pollutants from the vehicle tailpipe. Rather, water is the sole by-product of FCV operation (Ogden et al. 2011, NRC 2013b).

One of the most important fuel-cell technologies for transportation applications is the proton exchange membrane. Vehicle manufacturers have made significant progress with PEM fuel-cell systems—the size and weight, for instance, have been reduced such that a fuel cell now fits easily within a compact vehicle, and FCVs provide strong driving performance and tolerance for low-temperature operations. There are, though, some remaining challenges—most notably with respect to durability and cost. Current PEM fuel-cell systems have a lifetime of about 2,500 hours in on-road tests, well short of the 5,000-hour life viewed as a target for commercialization. PEM fuel-cell durability is continuing to increase, however, and laboratory tests have demonstrated lifetimes of more than 7,000 hours (NRC 2013a).

The cost of fuel-cell technology, often measured in dollars per kilowatt, is currently quite high, owing in part to low production volumes. The U.S. Department of Energy, however, has estimated that if current fuel-cell configurations were produced at greater scale—on the order of 500,000 units per year—the cost would fall to about $49 per kW (NRC 2013a). This would translate to about $4,000 for an 80-kW system, which is roughly twice the cost of a comparable internal combustion engine. The target cost set by DOE is $30 per kW, which developers hope to achieve via improved materials, reduced use of platinum, and increased power density (Ogden et al. 2011). At $30 per kW, fuel cells would still be more expensive than ICEs, but the differential would be more modest.

Onboard hydrogen storage technology. The other current challenge for hydrogen vehicles is determining the most cost-effective way to store enough hydrogen on board to accommodate a 300-mile range. The main options include high-pressure cylinder tanks, super-cooled liquid hydrogen, or the use of metal hydrides or other special materials able to absorb hydrogen under pressure. Absent breakthroughs in the latter two approaches, most manufacturers to date have opted for compressed hydrogen in their demonstration vehicles, and this is expected to be the technology of choice for at least the near term. Demonstration FCVs produced by Daimler Chrysler, GM, Honda, Hyundai, and Toyota have been able to achieve ranges of 270 to 400 miles using tanks with compressed hydrogen stored at 5,000 to 10,000 psi (Ogden et al. 2011).

Estimates for the cost of mass-produced compression tanks based on current technology fall in the range of $12 to $19 per kilowatt hour. This translates to about $2,800 for a tank able to hold enough hydrogen to provide a compact FCV with a range of 300 miles (NRC 2013a).

E.3 Cost and Performance

Demonstration FCVs offer generally strong performance, acceptable range, strong fuel economy, and—depending on how the hydrogen is produced—the potential for significant reductions in greenhouse gas and criteria pollutant emissions. The main limitation, other than lack of refueling stations, is high vehicle premiums.

E.3.1 Vehicle Cost

The cost of fuel-cell vehicles at present is hard to determine, given that fuel-cell vehicles are not widely available and so far only small numbers have been produced. Therefore, most studies have taken the approach of projecting future vehicle prices based on assumptions about the rate of market adoption and the reduction of costs with greater economies of scale and learning. On commercial introduction around 2015, one estimate is that FCVs are expected to have a price premium of about 1.4 times that of gasoline ICE vehicles (NPC 2012). Other studies provide more conservative estimates. Ogden et al. (2011) present a series of future cost estimates linked to year and cumulative FCV sales: 5,000 FCVs sold by 2014 with a cost of $140,000 per vehicle, over 50,000 sold by 2015 with a cost of $75,000, over 300,000 sold by 2017 with a cost of $50,000, and two million sold by 2020 with a cost of $30,000. In this same projection, the cost premium of FCVs ultimately levels out in the 2025 time frame to about $3,600 more than the cost of a conventional vehicle.

E.3.2 Energy Cost of Travel

The energy content in a gallon of gasoline is comparable to that in a kilogram of hydrogen. On an energy-equivalent basis, the fuel economy for today's FCVs is about twice that of comparable gasoline ICEs, and about 35% to 65% higher than that of a gasoline hybrid electric. In a review by the National Renewable Energy Laboratory of second-generation FCVs participating in the U.S. Department of Energy's hydrogen demonstration program, the adjusted city/highway fuel economy ranged from 42 to 56.5 miles per kilogram (mpkg) (Wipke et al. 2010a). A study by Sun, Ogden, and Delucchi (2010) estimated fuel economies of 57 mpkg in 2012 and 67.7 mpkg in 2025. The GREET model (ANL 2012) estimated current fuel economy for a mid-sized passenger FCV to be about 52 mpgge (mpgge is roughly the same as mpkg), while a NRC study estimated that the on-road fuel economy for a similar FCV in 2050 could range from around 140 to 170 mpgge (NRC 2013b).

As indicated by these estimates, the fuel economy of FCVs is generally expected to exceed that of conventional vehicles. Additionally, as described earlier, analysis in the NRC report suggests that the retail cost of hydrogen fuel could fall to about $4 per kilogram by 2050 assuming significant adoption (NRC 2013b), which would provide the ability to compete with gasoline in the range of $2 to $3 per gallon. Gasoline has been above that range in recent years, and many projections (e.g., EIA 2013) anticipate further increases in gasoline prices in the coming decades. Thus it appears likely that the energy cost of travel for an FCV could be either comparable to or less than, and possibly much less than, the energy cost of travel for a gasoline-fueled vehicle.

E.3.3 Operational Performance

Beyond the question of fuel-cell durability, current demonstration FCVs do not appear to suffer any particular performance challenges. Speed and power are acceptable, and vehicle range—at least with compressed hydrogen storage at 10,000 psi—appears to rival that of conventional vehicles. Refueling time is likewise not a problem. Rather, the main near-term challenges relate to vehicle cost and sufficient availability of refueling infrastructure.

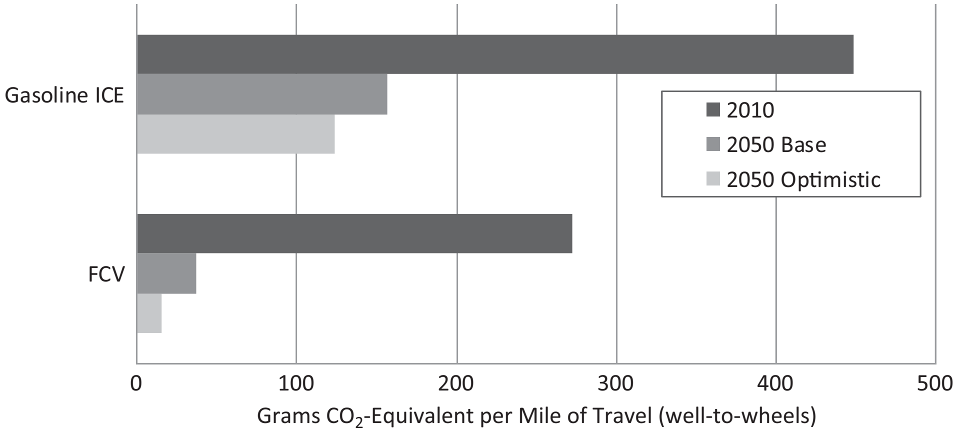
E.3.4 Greenhouse Gas Emissions

FCVs can be expected to offer at least moderate, and potentially significant, reductions in greenhouse gas emissions in comparison to conventionally fueled vehicles. Unlike the emissions of greenhouse gases from the combustion of gasoline or diesel in an ICE, the onboard conversion of hydrogen to electricity releases no GHG emissions. Rather, all of the emissions associated with hydrogen stem from its production and transport—that is, from the well-to-tank portion of the fuel cycle. Thus the magnitude of the GHG emissions benefits depends largely on the method of producing and transporting hydrogen.

Using data from the U.S. Department of Energy's demonstration program, researchers at the National Renewable Energy Laboratory compared the well-to-wheels greenhouse gas emissions from present fuel-cell vehicles based on different hydrogen production pathways. As a point of reference, the researchers considered a mid-size petroleum-fueled passenger vehicle that was estimated to produce 484 grams of CO_2e emissions per mile. In comparison, emissions for an FCV fueled via on-site reformation of natural gas would be reduced by 25% on average (at 362 grams of CO_2e per mile), while emissions from an FCV fueled via electrolysis using electricity from the grid would be reduced by 22% on average (at 378 grams of CO_2e per mile). The study also noted that fueling an FCV based on electrolysis with renewable electricity would produce no GHG emissions (Wipke et al. 2010c).

As part of this study, with the aim of facilitating a consistently framed examination of the GHG emissions reduction potential for the different fuels and vehicle technologies considered, the research team conducted an exercise relying on emissions factors from ANL's GREET model (ANL 2012). For each of the fuels and vehicle technologies—gasoline, diesel, hybrid electric, natural gas, biofuels, plug-in and battery electric, and hydrogen—the team used GREET's specifications for a mid-size passenger vehicle in 2010 along with two similarly configured vehicles in the 2050 time frame. The two hypothetical future cases are intended to be broadly consistent with expectations in the research literature regarding possible advances in fuels and vehicle technologies, but one embeds modest assumptions while the other is more optimistic.

Figure E.1 presents the GHG emissions modeling results for conventional vehicles and FCVs. The GREET model for 2010 FCV efficiency and well-to-wheels emissions is used, and for future fuel economy and well-to-wheels emissions, fuel economy assumptions from NRC (2013b) are used, reduced by 17% to adjust for on-road fuel economy. The intent of including current as well as future conventional vehicles is to help clarify not only how FCVs might perform in relation to the current light-duty fleet, but also how they might perform against conventional vehicles with much-improved fuel economy in the future. Table E.2 lists the salient assumptions for the analysis, including on-road (as opposed to EPA-rated)



Source: Computations by authors based on data from ANL (2012) and NRC (2013b).

Figure E.1. GHG reduction prospects for hydrogen FCVs in 2050.

fuel economy and the assumed carbon intensity, in kilograms of CO_2e per gallon of gasoline equivalent (kg CO_2e/gge), of hydrogen production and transport.

NRC provided several estimates of GHG emissions for different methods of hydrogen production and distribution (NRC 2013b). For the 2050 estimates, two GHG values are used from their scenarios. As shown in the table, the first is referred to as a partial use of CCS case, which involves a mix of central natural gas and coal with CCS, central biomass without CCS, and distributed natural gas reforming without CCS. The second, more optimistic, low-GHG case uses more central natural gas with CCS, some central biomass without CCS, electrolysis from a low-GHG grid, and a small amount of distributed natural gas reforming without CCS. Based on these assumed values and GREET's emissions factors, Figure E.1 graphs the well-to-wheels greenhouse gas emissions performance, in grams of CO_2e per mile of travel, for current and future conventional models and FCVs. Note that the GREET model estimates that current FCV emissions are 272 grams per mile, which is about 40% less than current ICE emissions. This is due to the GHGs associated with making hydrogen from natural gas without CCS. The emissions for the two future FCV cases are much lower, at 37 grams per mile and 15 grams per mile, owing to the higher vehicle efficiencies and lower GHGs associated with future hydrogen production assumed by NRC (2013b).

E.3.5 Local Air Pollutant Emissions

As with greenhouse gas emissions, the implications of a shift to FCVs for criteria pollutants—the local air pollutants subject to EPA regulations—depend to some degree on how the hydrogen is produced. Regardless of the production pathway, however, a shift to FCVs should result, on a well-to-wheels basis, in at least moderate and possibly significant reductions in VOCs, CO, NO_x, and SO_x. Emissions of particulate matter (PM10 and PM2.5), in contrast, appear to be more sensitive to the method of hydrogen production (Sun, Ogden, and Delucchi 2010; ANL 2012). Several production pathways would lead to increased well-to-wheels particulate matter emissions in comparison to gasoline-fueled vehicles. The increase would be most significant if the hydrogen were produced via electrolysis using the current U.S. grid mix (Ogden et al. 2011), given the degree to which it relies on coal combustion, although increased substitution of natural gas or other generation for coal would lessen this effect. Additionally, many power plants

Table E.2. Assumptions in emissions comparisons for hydrogen FCVs.

Time Frame Scenario	Gasoline ICE (mpg)	FCV (mpgge)	Hydrogen Production Assumptions	Carbon Intensity (kg CO_2e/gge)
2010	24.8	52	Central natural gas reforming	14.08
2050 base	72	138	Partial use of CCS	5.1
2050 optimistic	91	171	Low-GHG production mix	2.6

Source: Computations by authors based on data from ANL (2012) and NRC (2013b).

are located away from dense settlements, mitigating the human health impacts to some extent.

E.4 Market Prospects

While FCVs offer considerable promise, the barriers that would need to be overcome to support significant market adoption are also significant. Perhaps unsurprisingly, then, future projections for the uptake of FCVs vary widely.

E.4.1 Future Market Projections

The U.S. Energy Information Administration's projections from the most recent *Annual Energy Outlook* are rather pessimistic regarding the prospects for FCVs over the next several decades (EIA 2013). In the reference-case scenario, EIA projects that the total number of FCVs in the light-duty fleet will only reach 70,000 by 2040, with 4,700 FCVs projected to be sold that year. Even in the high economic growth scenario, total FCVs are projected at just 80,000 in 2040.

Other studies, however, present much more optimistic forecasts. Greene et al. (2008), for example, in a study for the U.S. Department of Energy, developed three scenarios for future FCV sales drawing upon historical growth in hybrid-electric sales as an analog. Within the three scenarios, the number of light-duty FCV sales in 2025 ranges from 500,000 at the low end to 2.5 million at the high end. CARB has laid out a vision in which both battery electric vehicles and FCVs begin to enter the market in significant numbers by 2020 and together account for virtually all light-duty vehicle sales by 2040 (CARB 2009).

E.4.2 Factors Affecting Market Prospects

Over the past decade there has been much technical progress in fuel cells and fuel-cell vehicles. Fuel-cell stacks operate for many more hours before they fail, and their power density is much higher. Vehicle range has increased almost four-fold. Vehicles can start and operate in cold temperatures. Nevertheless, there are several barriers and areas of uncertainty that must be addressed in order for fuel-cell vehicles to achieve significant market penetration.

Hydrogen cost and feedstocks. The present cost for delivered hydrogen is too high to compete with gasoline, and the cost for renewably generated hydrogen is higher still. Yet future projections suggest that hydrogen produced from natural gas or coal should ultimately provide for lower per-mile energy costs than gasoline-fueled ICE vehicles. Beyond offering several production pathways supportive of energy independence, however, one of the main attractions for hydrogen as a transportation fuel is the potential for very low well-to-wheels emissions of greenhouse gases and criteria pollutants. If the cost of renewable hydrogen can be reduced to the same level, the motivations for investing in a shift to FCVs will be more compelling.

Fuel-cell cost. The cost of fuel cells is much higher than the cost of an internal combustion engine. Most projections, however, assume that the cost differential between fuel cells and ICEs can be pared substantially. Indeed, in some ways fuel cells are simpler and easier to produce than engines. For example, they have no moving parts, and they operate at much lower temperatures. Until low-cost fuel cells can be manufactured, though, the increased vehicle cost will be a barrier to consumers.

Fuel-cell lifetime. From a marketability perspective, fuel cells must be able to operate roughly the lifetime of the vehicle; otherwise, owners would be required to replace a very expensive component. A decade ago, early versions of fuel cells were not expected to last even a couple of years in normal vehicle operation. While this challenge has yet to be entirely resolved, much progress has been made. The fifth-generation fuel-cell stack from General Motors, for example, is expected to last 120,000 miles (CFCP, undated).

Onboard hydrogen storage cost. High-pressure compressed-hydrogen storage tanks, which require expensive materials and processes to manufacture, are another factor in the significant premium associated with current hydrogen vehicles. Researchers are working on other technologies, such as metal hydrides, to reduce the cost of onboard hydrogen storage for FCVs. Reducing the cost of storing sufficient hydrogen to enable a reasonable driving range (e.g., 300 miles or greater) could play an important role in reducing the overall cost of FCVs and, in turn, enhancing their market prospects.

Refueling infrastructure. As described earlier, vehicle manufacturers and energy firms will need to coordinate with one another in rolling out FCVs and refueling stations since a successful transition to hydrogen as a transportation fuel will depend on both. A network of hydrogen fueling stations and supportive distribution infrastructure will require significant investment, so fuel providers are unlikely to develop such a network absent significant uptake of FCVs. At the same time, consumers will be reluctant to purchase FCVs unless refueling infrastructure exists. Therefore, some public-sector involvement in subsidizing or mandating early refueling infrastructure would prove extremely helpful and perhaps would even be necessary.

Competing fuels and vehicle technologies. To achieve significant market share, FCVs will need to compete well not only with conventional petroleum-fueled vehicles, but also with other alternative-fuel options such as biofuels, natural gas, battery electric vehicles, and plug-in hybrids. Automakers must choose where to focus their funding for research, development, and marketing. If they come to believe, for example, that battery electric vehicles or plug-in hybrids could lead to more profit, then efforts to develop and commercialize FCVs could receive less emphasis.

References

ANL. 2012. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)*, Fuel Cycle Model version 1 2012. U.S. Department of Energy.

API. 2013. Oil & Natural Gas Overview: Service Station FAQs. http://www.api.org/oil-and-natural-gas-overview/consumer-information/service-station-faqs (accessed July 20, 2013).

Burke, A., Z. McCaffrey, M. Miller, K. Collier, and N. Mulligan. 2005. *Hydrogen Bus Technology Validation Program.* UC Davis Institute of Transportation Studies.

CARB. 2009. Summary of Staff's Preliminary Assessment of the Need for Revisions to the Zero Emission Vehicle Regulation.

CARB. 2013. Zero Emission Vehicle (ZEV) Program. http://www.arb.ca.gov/msprog/zevprog/zevprog.htm (accessed October 2, 2013).

CEC. 2004. California Hydrogen Fueling Station Guidelines.

CFCP. Undated. Recent Announcements Show Progress. http://www.cafcp.org/recent-announcements-show-progress (accessed November 8, 2010).

Cho, A. 2004. "Fire and ICE: Revving up for H2." *Science*, 305 (5686): 964–965.

EERE. 2013. Hydrogen Laws and Incentives. Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/laws/3255 (accessed October 2, 2013).

EIA. 2013. *Annual Energy Outlook 2013.*

Eudy, L., K. Chandler, and C. Gikakis. 2012. Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012. National Renewable Energy Laboratory.

Fuel Cells 2000. 2012a. Fuel Cell Vehicles (from Auto Manufacturers).

Fuel Cells 2000. 2012b. U.S. Hydrogen Fueling Stations.

Greene, D., P. Leiby, B. James, J. Perez, M. Melendez, A. Milbrandt, S. Unnasch, and M. Hooks. 2008. *Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements.* Oak Ridge National Laboratory.

Joseck, F. 2012. "Current U.S. Hydrogen Production." *DOE Hydrogen and Fuel Cells Program Record.*

Nicholas, M. and J. Ogden. 2006. "Detailed Analysis of Urban Station Siting for the California Hydrogen Highway Network." *Transportation Research Record: Journal of the Transportation Research Board, No. 1983:* 129–139. Transportation Research Board of the National Academies, Washington, D.C.

NPC. 2012. *Future Transportation Fuels Study: Advancing Technology for America's Transportation Future.*

NRC. 2013a. *Review of the Research Program of the U.S. DRIVE Partnership: Fourth Report.* The National Academies Press, Washington, D.C.

NRC. 2013b. *Transitions to Alternative Vehicles and Fuels.* The National Academies Press, Washington, D.C.

OFE. 2000. *Fuel Cell Handbook*.

Ogden, J., C. Yang, J. Cunningham, N. Johnson, X. Li, M. Nicholas, N. Parker, and Y. Sun. 2011. Chapter 3: The Hydrogen Fuel Pathway. In J. Ogden and L. Anderson (eds.), *Sustainable Transportation Energy Pathways.* Institute of Transportation Studies, University of California, Davis.

ORNL. 2012. *Transportation Energy Data Book*, Edition 31.

Sun, Y., J. Ogden, and M. Delucchi. 2010. *Societal Lifetime Cost of Hydrogen Fuel Cell Vehicles.* Institute of Transportation Studies, University of California, Davis.

Wipke, K., S. Sprik, J. Kurtz, and T. Ramsden. 2010a. *Controlled Hydrogen Fleet and Infrastructure Demonstration Project.* National Renewable Energy Laboratory.

Wipke, K., S. Sprik, J. Kurtz, T. Ramsden, and J. Garbak. 2010b. *Entering a New Stage of Learning from the U.S. Fuel Cell Electric Vehicle Demonstration Project*. National Renewable Energy Laboratory.

Wipke, K., S. Sprik, J. Kurtz, T. Ramsden, and J. Garbak. 2010c. "DOE's National Fuel Cell Vehicle Learning Demonstration Project—NREL's Data Analysis Results." In G. Pistoia (ed.), *Electric and Hybrid Vehicles: Power Sources, Models, Sustainability, Infrastructure and the Market.* Elsevier Press.

Washington State DOT. 2009. *Alternative Fuels Corridor Economic Feasibility Study.*

APPENDIX F

Medium- and Heavy-Duty Vehicles

The preceding appendices have focused on alternative fuels and emerging vehicle technologies in the light-duty fleet, including passenger cars, pickup trucks, vans, and sport utility vehicles. This appendix shifts focus to MHDVs, beginning by introducing the types and applications of MHDVs and then discussing the alternative fuels and vehicle technology improvements currently being examined in the context of MHDVs. The appendix closes with a summary of the most-promising alternative fuels and vehicle technologies for different classes of MHDVs based on their size and use characteristics.

F.1 Classifying Medium- and Heavy-Duty Vehicles

Trucks provide services, and there are almost as many different types of trucks as there are services to be provided. For example, vans can be configured for package delivery, beverage delivery, and refrigerated food delivery, and there are likewise many possible configurations for trailers hauling varying types of freight over long distances. Different truck applications are also subject to very different usage patterns, ranging from the low speeds with frequent starts and stops of a waste-collection vehicle to the long periods at cruise speed for long-distance tractor-trailers. In the following are discussed several possible ways of classifying MHDVs, with the aim of providing greater insight into the potential utility of alternative fuels and vehicle technologies across the spectrum of MHDV applications.

F.1.1 Classifying MHDVs by Gross Vehicle Weight

Vehicles in the United States are commonly categorized into eight classes based on gross vehicle weight—a term describing the maximum operating mass of a vehicle as specified by the manufacturer, including the weight of the vehicle itself and fuel, cargo, passengers, and the like. Class 1 vehicles have a GVW of less than 8,500 pounds and are typically used for passenger travel. Class 2 vehicles, with a GVW of between 8,500 and 10,000 pounds, include large sport utility vehicles, pickup trucks, vans, and some multipurpose vehicles. While some Class 2 vehicles are used for passenger travel, others (often referred to as Class 2b) are employed as service vehicles. Classes 3 through 6 include various types of medium-duty vehicles with a GVW of from 10,000 to 26,000 pounds. Classes 7 and 8 are described as heavy-duty vehicles with a GVW of greater than 26,000 pounds. The maximum GVW of trucks in the United States is limited to 80,000 pounds in most instances.

The forms and functions of MHDVs vary significantly both within and across these classes. For example, Classes 2b, 3, and 4 include large pickup trucks, step vans, smaller delivery trucks, and mini-buses. Class 5 and 6 vehicles include large walk-in delivery trucks, school buses, and bucket trucks—trucks configured with telescoping booms and buckets used to perform utility maintenance and other functions. Class 7 and 8 vehicles include fire engines, urban and intercity buses, cement trucks, refuse trucks, tankers, and tractor-trailers.

Tables F.1 and F.2, drawing on an NRC study, list typical applications, gross vehicle weight, payload capacity, approximate share of the combined medium- and heavy-duty fleet, load-specific fuel economy, aggregate fuel consumption, and annual mileage for the different classes of MHDVs. As indicated by the data in the tables, there is significant crossover in the types of applications across classes, with the main differentiating factor being GVW.

As of 2010, there were about 18 million MHDVs in the United States. As shown in Table F.2, Class 2b accounted for just under half of this total. Most of the MHDVs in Classes 3 through 8 are diesel powered; of the Class 2b vehicles, however, only about a quarter rely on diesel (ORNL 2012). Because of their weight, number, and long-distance travel patterns, Class 8b vehicles are responsible for about 60% of the fuel

Table F.1. Applications, weight, and payload for MHDV classes.

Class	Applications	Gross Vehicle Weight (lbs.)	Typical Payload Capacity (lbs.)
2b	Large pick-up, utility van, multipurpose, mini-bus, step van	8501–10,000	3,700
3	Utility van, multipurpose, mini-bus, step van	10,001–14,000	5,250
4	City delivery, parcel delivery, large walk-in, bucket, landscaping	14,001–16,000	7,250
5	City delivery, parcel delivery, large walk-in, bucket	16,001–19,500	8,700
6	City delivery, school bus, large walk-in, bucket	19,501–26,000	11,500
7	City bus, furniture, refrigerated, refuse, fuel tanker, dump, tow, concrete, fire engine	26,001–33,000	18,500
8a	Straight trucks: dump, refuse, concrete, furniture, city bus, tow, fire engine	33,001–80,000	20,000–50,000
8b	Combination trucks: tractor-trailer, van, refrigerated, bulk tanker, flat bed	33,001–80,000	40,000–54,000

Source: NRC (2010).

consumption of all MHDVs, even though they only make up about 16% of the entire MHDV fleet. Class 6 and Class 2b vehicles are each responsible for another 12% to 13% of total MHDV fuel consumption. The fuel economy of MHDVs in miles per gallon, not surprising, generally declines with increased GVW. As shown in the table, however, fuel economy measured in ton-miles per gallon increases with greater weight; in other words, larger trucks are the most fuel-efficient transporters.

F.1.2 Classifying MHDVs by Sector

Another possibility for classifying MHDVs is by the sector in which they work. Until 2002, the U.S. Department of Commerce periodically carried out the Vehicle Inventory and Use Survey (VIUS), which recorded the number, uses, and other characteristics of vehicles in the United States (ESA 2004). Drawing on the last VIUS survey from 2002, Table F.3 shows the total number of MHDVs in Classes 3 through 6 (combined medium-duty) and Classes 7 and 8 (combined heavy-duty) as well as the share in each of these groupings employed in different sectors. Although the total number of MHDVs has likely increased in the past decade, it is possible that the allocation of this fleet across sectors may still be similar.

As shown in the table, the dominant sectors for medium-duty vehicles in Classes 3 through 6 are, in descending order, construction, agriculture, and for-hire transportation and warehousing. For heavy-duty vehicles in Classes 7 and 8, the

Table F.2. Fleet share, fuel use, and annual miles for MHDV classes.

Class	Share of MHDV Fleet	Typical Load-Specific Fuel Economy (ton-miles/gallon)	Annual Fuel Consumption Total for Class (billion gallons)	Average Annual Vehicle Miles (thousands)	Annual Miles Total for Class (billions)
2b	48%	26	5.5	15–40	93
3	12%	30	1.5	20–50	12
4	4%	42	0.53	20–60	4
5	4%	39	0.26	20–60	2
6	6%	49	6.0	25–75	41
7	7%	55	1.9	75–200	9
8a	4%	115	3.5	25–75	12
8b	16%	155	28	75–200	140

Source: NRC (2010).

Table F.3. Use of MHDVs by sector.

Sector	Class 3–6	Class 7–8
Number of vehicles (millions)	*2.9*	*2.3*
For-hire transportation or warehousing	9.6%	30.1%
Construction	18.4%	15.9%
Agriculture	16.2%	12.2%
Retail trade	7.1%	5.4%
Waste management, landscaping, or administrative support	5.4%	5.0%
Manufacturing	3.3%	4.9%
Wholesale trade	5.5%	4.8%
Utilities	5.0%	1.1%
Leasing	6.2%	4.6%
Personal	4.8%	2.5%
Mining	1.1%	2.4%
Other services	6.6%	2.8%
Not in use	6.4%	5.1%
Unknown	4.4%	3.2%

Source: ESA (2004), ORNL (2012).

dominant sectors are for-hire transportation and warehousing, construction, and agriculture. Note that MHDVs in the leased vehicle category can be employed by the lessee for a broad range of applications, including transportation and construction (ORNL 2012).

F.1.3 Classifying by Application

Alternatively, MHDVs can be classified according to application, which combines features of weight-based and sector-based classes. The previously referenced NRC study classified MHDVs into seven general application categories: tractor-trailers, straight box trucks, straight bucket trucks, refuse trucks, transit buses, motor coaches, and pickup trucks and small vans (NRC 2010). The definitions for these application categories, along with the classes of MHDVs included, are listed in Table F.4.

F.1.4 Important Characteristics of MHDV Use

As described, the types and configurations of MHDVs are quite diverse. For example, Class 8 vehicles include buses, tractor-trailers, and refuse trucks. These vehicles vary significantly in their purpose and use characteristics. The effect of these factors on the suitability of alternate fuel choices and vehicle technologies is significant. Key considerations are whether the vehicle is part of a centrally managed fleet, daily and annual mileage, typical travel speeds and duty cycle, and ownership cycles and resale requirements.

Fleet use. MHDVs are often operated in fleets. Examples of fleets are groups of tractor-trailers used for interstate trucking, utility bucket trucks for line maintenance and emergency response, school buses, trash collection trucks, and cement trucks. Fleets, whether private or public, often benefit from shared vehicle maintenance and refueling stations. This can be quite helpful from the perspective of introducing alternative fuels because the fleet can be supported with minimal investment in refueling infrastructure. To transition a fleet of municipal service vehicles to natural gas, for example, it may be sufficient to install a single natural gas dispenser at the facility where vehicles are stored between uses.

The minimum fleet size for shared services to be economical depends on the application and vehicle class. Drawing on data originally reported in the 2002 VIUS, Table F.5 shows the percentage of MHDVs in fleets of different sizes that rely on different categories of refueling stations—retail gas stations, retail truck stops, a refueling station operated by the fleet owner, or a refueling station operated by some other third party (such as the operator of another nearby fleet)—for their refueling operations. For fleets in the range of 11 to 50 vehicles, roughly a half of all vehicles are fueled at the fleet operator's own facility. In contrast, smaller-sized fleets rely to a much greater extent on retail gas stations. Therefore, in the context of deploying alternative fuels for MHDVs, fleets with more than 11 vehicles appear to be a promising target since any specialized refueling infrastructure can be centralized at the owner's facility, where it will be well utilized by vehicles within the fleet. To introduce alternative fuels with

Table F.4. Generalized MHDV application categories.

Application	Classes	Notes
Tractor-trailer	7, 8	Includes many use types: long haul, port service, full load, less than load, tankers, etc. These trucks may be part of a large fleet or may be independently owned and operated. Since most fuel is burned in long-haul applications, greater considerations are given to this use. Diesel engines are assumed.
Straight truck, box	3–8	Includes all configurations of box trucks, including delivery vans, refrigerated trucks, ambulances, and shuttle vans. In general these trucks are part of a fleet that is managed and maintained centrally. Engines are both gasoline and diesel powered. (The share for gasoline engines was over 40% in 2008.) Generally used for regional hauling, covering approximately 150 miles per day at an average speed of 30 miles per hour.
Straight truck, bucket	3–8	Includes bucket trucks in a range of sizes. Assumed to be centrally managed and maintained as part of a fleet. Typical work includes movement to a site followed by periods of use by auxiliary equipment, such as manipulating the bucket boom. Typically diesel powered.
Refuse truck	7, 8	Large waste-collection vehicles. Assumed to be centrally managed and maintained. The load cycle includes several hundred stops per day. Diesel powered.
Transit bus	8	Transit buses are part of a fleet that is centrally managed and maintained. Urban-use cycles are approximately 150 to 250 miles per day at low speed, with significant electrical load for air-conditioning and lighting. Primarily diesel powered, but increasingly fleets have been converting to natural gas in an effort to improve local air quality. Hybrid buses have been deployed to reduce fuel consumption.
Motor coach	8	Intercity buses. Owned and maintained by service providers, but must travel long distances without refueling. Diesel powered.
Pickup trucks and small vans	2b	Large pickup trucks and small commercial vans. Owned in general by private parties. Typically gasoline powered.

Source: NRC (2010).

an assumed reliance on retail gas stations or truck stops, the dispensers would need to be much more widely deployed, likely resulting in relatively low utilization at any given station.

Table F.6 provides additional insight into the refueling characteristics of MHDVs, in this case listing the primary refueling facility by industrial sector. The most common type of refueling facility for most sectors is the gas station. The for-hire transportation and warehousing sector, in contrast, relies most frequently on truck stops. Still, in several of the sectors, including for-hire transportation and warehousing, agriculture, utilities, vehicle leasing, and mining, nearly 25% or more of all MHDVs refuel at their own facilities, creating greater potential for a transition to alternative fuels.

Combining data from several of these tables, it is possible to develop some rough estimates of the percentages of trucks by

Table F.5. Primary refueling facility by fleet size.

MHDV Fleet Size	*Share of MHDVs by Fleet Size That Refuel At:*			
	Gas Station	Truck Stop	Own Facility	Other Facility
1–5	73.8%	6.1%	18.2%	1.9%
6–10	55.3%	5.7%	35.5%	3.4%
11–20	41.1%	5.1%	48.9%	4.9%
21–50	42.9%	3.7%	49.8%	3.6%
51 or more	48.3%	6.3%	44.4%	1.0%
No fleet	96.4%	1.6%	1.7%	0.3%

Source: ORNL (2012) using data from ESA (2004).

Table F.6. Primary refueling facility by sector.

Application	*Share of MHDVs by Sector That Refuel At:* Gas Station	Truck Stop	Own Facility	Other Facility	Class 7 and 8 Combination Trucks by Sector That Refuel at Own Facility
For-hire or warehousing	33.3%	38.7%	25.8%	2.3%	7.8%
Construction	84.7%	3.3%	9.8%	2.2%	4.1%
Agriculture, forestry, fishing…	62.7%	6.7%	29.4%	1.1%	3.1%
Retail trade	86.6%	3.5%	8.6%	1.2%	1.4%
Waste mgmt., landscaping…	78.2%	3.0%	17.1%	1.6%	1.3%
Manufacturing	81.5%	5.1%	11.9%	1.5%	1.3%
Wholesale trade	76.2%	6.6%	12.0%	5.1%	1.2%
Utilities	72.6%	1.8%	24.3%	1.3%	0.3%
Vehicle leasing or rental	60.2%	1.3%	31.8%	6.8%	1.2%
Personal	98.6%	0.6%	0.7%	0.2%	0.6%
Mining	48.7%	8.5%	34.3%	8.5%	0.6%
All	93.9%	1.8%	3.7%	0.5%	0.7%

Source: ORNL (2012) using data from ESA (2004).

class in each application area that refuel at a facility owned by the fleet operator. For heavy combination trucks in Classes 7 and 8, close to 8% (or approximately 200,000 vehicles) are refueled at a fleet facility. The data do not support the same level of disaggregation for other trucks in Classes 3 through 8. Given the larger number of such vehicles, however, it seems likely that there could be several hundred thousand vehicles each in for-hire transportation, construction, and agriculture that are fueled primarily at fleet operators' facilities.

Daily range. Operating range describes the distance from the central facility within which an MHDV must operate on a daily basis. Because some alternative fuels and technologies—most notably natural gas and battery electric—offer more limited range than conventional fuels, quantifying the typical operational range provides insight into the potential applicability of such fuels and technologies for various MHDV classes and applications. As shown in Table F.7, over 70% of medium-duty vehicles (Classes 3 through 6) and 50% of heavy-duty

Table F.7. Operating range and primary refueling by weight class.

Range and Refueling Facility	Class 3–6	Class 7–8
Typical range of operation		
Under 50 miles	61.5%	40.7%
51–100 miles	11.7%	13.5%
101–200 miles	3.2%	6.7%
201–500 miles	1.8%	7.6%
501 miles or more	2.2%	10.4%
Other, not reported, or vehicle not in use	19.6%	18.1%
Primary refueling facility		
Gas station	62.4%	28.4%
Truck stop	7.7%	31.9%
Own facility	27.3%	36.2%
Other nonpublic facility	2.6%	3.5%

Source: ORNL (2012) using data from ESA (2004).

vehicles (Classes 7 and 8) have typical ranges of less than a hundred miles. MHDV applications for which the operating range is relatively modest, and in which vehicles can refuel at a facility owned by the fleet operator, may present some of the most promising MHDV market applications for alternative fuels.

Operational range has additional implications beyond refueling requirements. Consider the potential application of heavy-duty natural gas engines for long-haul transport in tractor-trailers. Should such a vehicle require maintenance en route, the existing service infrastructure in place for diesel-fueled trucks may be of no help. Understanding this to be an issue, Cummins Westport, a maker of both heavy-duty diesel and natural gas engines, provides parts and service for both fuel technologies from its existing network (Cummins Westport, undated b). Access to proper maintenance is also important to maintain the performance of advanced emissions control systems (NRC 2010).

Annual mileage. MHDVs are used heavily and as a result tend to travel more miles per year than passenger vehicles. As indicated earlier, the typical mileage by class ranges from 20,000 miles per year for local utility vehicles to over 200,000 miles per year for tractor-trailers used in long-haul applications. In comparison to passenger cars, then, this amplifies the relative benefit of alternative fuels and vehicle technologies that reduce fuel costs for MHDVs. With more miles traveled each year, fuel-cost savings can accrue more rapidly to help offset increased capital costs associated with the vehicle purchase or conversion. It should be noted, though, that even with the potential for fuel-cost savings, there is still a delicate balance between capital and operating costs for MHDVs since newer technologies may increase system complexity and result in increased maintenance costs.

Duty cycle. The term “duty cycle” refers to the pattern of use of a vehicle over a fixed time period. Duty cycles are as varied as the applications of MHDVs. For example, the duty cycle for a long-haul tractor-trailer may be as simple as driving 6 hours at an average speed of 60 mph. A waste-collection truck, in contrast, might drive to a neighborhood at a moderate speed, and then creep along as workers gather trash in that neighborhood. The crew may repeat this cycle several times throughout a workday, after which the truck delivers its load and returns to its depot. In an NRC study that examined the prospects for alternative fuels and advanced efficiency technologies in different MHDV applications, the assumed typical use cycle for a waste-collection truck was 700 load stops per day over 25 miles, including two trips to the dump, adding an additional 50 miles (NRC 2010). Alternatively, a utility-service bucket truck could travel from a service facility to a location for maintenance. On-site, the vehicle may idle and provide power for the hydraulic equipment supporting the workmen in the bucket. Then the vehicle may move to another maintenance site at moderate speed, repeating the cycle several times over the course of the day. A transit bus may have several different modes of operation, depending on the type of route. If it is serving a business district, it may travel in relatively congested conditions and make frequent stops. If it is assigned to a commuter route, in contrast, it may make relatively few stops separated by relatively long periods of travel at cruising speed (NRC 2010, 2012).

Although the weights of all these vehicles may be similar, the benefits of alternative fuels and other advanced-efficiency technologies are significantly different depending on the duty cycle. The long-haul tractor-trailer spends a large portion of its time at highway cruise speed and will thus benefit more from improved aerodynamics than, say, from hybrid technologies, the principal benefit of which is the recovery of energy during braking. In contrast, hybrid technologies may provide significant benefits to refuse trucks and transit buses, which must stop and start frequently, or to bucket trucks, enabling the conversion of auxiliary equipment to electrical actuation, which is both lighter and easier to maintain.

The duty cycle can also have a major effect on the emissions profile for internal combustion engines. The emissions of diesel engines are highest during periods of high load, as when accelerating the vehicle from a stop. This makes it challenging to develop effective emission control equipment for vehicles that must make many stops and starts, such as transit buses and refuse trucks. Applying cleaner-burning fuels or advanced engine technologies may help reduce emissions in such cases.

Actual duty cycles have been abstracted into short test cycles so that vehicle performance may be evaluated on a common basis in a laboratory environment. These test cycles are the standards by which emissions regulations are benchmarked. The EPA developed the Urban Dynamometer Driving Schedule (UDDS) for light-duty vehicles, for example, which includes both highway and city driving over 23 minutes of activity (EPA 2012a). The UDDS concept has also been applied to heavy-duty vehicles (NRC 2010). A set of schedules has been developed for MHDVs spanning several modes of operation, including a “creep mode,” a “transient mode,” and a “cruise mode,” corresponding to increased average speeds (Clark et al. 2007, NRC 2010). Relevant aspects of the duty cycle are the proportion of time at highway cruise speed, the proportion of time at idle, the proportion of time in a stop–start driving cycle, and the need to power auxiliary loads.

Ownership characteristics and life-cycle cost. Finally, life-cycle ownership costs, including capital, financing, fuel, maintenance, and resale, are an extremely important factor in evaluating alternative fuels and vehicle technologies. Alternative fuels often involve trade-offs in which certain cost components increase but others are reduced. For example, hybrid drivetrains and natural gas vehicles increase the purchase price of the vehicle significantly, adversely affecting both capital and financing costs. However, a hybrid drivetrain reduces fuel consumption, and natural gas vehicles can benefit from a lower-cost fuel. When purchasing new vehicles, owners of MHDVs typically assume that the vehicle will be sold for a resale value at the end of its term of service. Given the small installed base of support for both natural gas and hybrid vehicles, the ability of the purchaser to sell the vehicle could be compromised; diesel MHDVs operated using untraditional fuels such as biodiesel may likewise fetch less on the salvage market. By implication, given the importance of resale in most MHDV life-cycle cost computations, developing alternative fuels that substitute or may be blended with existing diesel is important. Many tax incentives and other programs at the federal and state levels attempt to change the mathematics behind ownership costs by offsetting the incremental life-cycle costs of natural gas and hybrid vehicles (Krupnick 2011).

F.2 Fuels and Vehicle Technologies

Most MHDVs in the United States today operate on diesel, which accounts for almost 90% of the 3 million barrels of fuel consumed by MHDVs each day. Gasoline is the second most common fuel for MHDVs, at around 10%, followed by much smaller shares for LPG, natural gas, and electricity (ORNL 2012). Table F.8 breaks down the amount of different types of fuels used for different categories of MHDVs.

Motivated by concerns over energy security, climate change, and economic efficiency, there are several initiatives in the United States aimed at improving the performance of MHDVs and reducing fuel consumption. The 21st Century Truck Partnership is a cooperative research and development partnership among the DOE, the DOT, the DoD, the EPA, and 15 industry partners with the goal of increasing the ability of trucks to move freight while reducing emissions and fuel consumption (NRC 2012). The National Research Council appointed a special committee to assess fuel economy technologies for medium- and heavy-duty vehicles (NRC 2010). The EPA has several programs, including the Clean Diesel program and the SmartWay freight program (EPA 2012b, SmartTruck 2009). These programs are focused on advanced engine and vehicle technologies and other methods to reduce fuel consumption and improve the environmental performance of MHDVs. For example, the Clean Diesel program focuses on reducing air emissions from diesel engines by working with manufacturers, fleet operators, local and regional officials, and others to encourage the adoption of new emissions control technologies to reduce the contribution of diesel emissions to local and regional air pollution. Alternative fuels provide one means of improving emissions profiles.

In addition to voluntary and collaborative public–private partnerships, the United States is poised for the first time to regulate fuel economy improvements in the medium- and heavy-duty vehicle fleets. The federal government has mandated CAFE standards for light-duty vehicles since the late 1970s, but MHDVs were not previously regulated in the same manner. In May of 2009, however, President Barack Obama directed NHTSA and the EPA to develop the Heavy-Duty National Program, which would specify fuel economy standards for combination tractors, heavy-duty pickup trucks and vans, and vocational vehicles (buses, refuse trucks, utility trucks, etc.). The proposed rulemaking for this program was issued by NHTSA and EPA in November 2010 and was finalized in September 2011. Under the new standards, set to take effect in 2014 and escalate through 2018, combination tractors will ultimately be required to achieve a 20% reduction in fuel consumption and greenhouse gas emissions, heavy-duty pickup trucks and vans will be required to achieve a 15% reduction, and vocational vehicles will be required to achieve a 10% reduction (EPA and NHTSA 2011).

The remainder of this section briefly reviews current diesel and gasoline engines for MHDV applications, discusses

Table F.8. Daily U.S. fuel consumption for highway vehicles, 2010.

Vehicle Type	*1000 Barrels per Day of Gasoline, Diesel, or Gasoline Equivalent*				
	Gasoline	Diesel	LPG	Natural Gas	Electricity
Light vehicles	8,264	190	25	—	—
Transit buses	0.52	31	—	10	0.37
Intercity buses		14	—	—	—
School buses	3.5	31	—	—	—
Class 3-6 trucks	297	363	11	—	—
Class 7-8 trucks	26	2,229	0.10	—	—
Total MHDV	327	2,669	11.1	10	0.37

Source: ORNL (2012).

technologies for improving fuel economy and reducing emissions for diesel- and gasoline-fueled MHDVs, and considers alternative fuels that could substitute for diesel or gasoline in certain applications. It is likely that many of the technical options discussed could be implemented in the near term in order to comply with the new federal standards on MHDV emissions and fuel economy as they phase in between 2014 and 2018.

F.2.1 Conventional Diesel and Gasoline Engines

The diesel engine is a compression-ignition engine in which the fuel is injected into the cylinder late in the compression stroke. The pressure and temperature in the cylinder cause the mixture to ignite. The combustion process moves the cylinder, which extracts work. The volume of air a diesel engine consumes is generally constant at a given engine speed, with power output governed by the amount of fuel injected into the engine. This relates to the reason why older diesel engines emit soot—which is unburned fuel—under high load conditions: more fuel is injected into the engine than can be burned during the expansion stroke of the engine. To increase power, diesel engines are often turbocharged, increasing the mass of air in the cylinder. Modern diesel engines are electronically controlled and use exhaust gas recirculation (EGR) to reduce in-cylinder formation of NO_x. Filters and catalytic converters are used to reduce the emissions of particulates. To meet more recent requirements for NO_x emissions, new engines employ selective catalytic reduction units, mobile versions of the systems used to reduce emissions from power plants. Diesel engines have high compression ratios as compared to gasoline engines, increasing their efficiency.

Gasoline engines, found in many medium-duty vehicles, rely on spark ignition. In a spark-ignition engine, the air and fuel are premixed in the intake manifold and then introduced into the cylinder, compressed, and ignited. Because the air and fuel are premixed, combustion occurs more rapidly than in a diesel engine. Compression ratios are lower than those in diesel engines to avoid the phenomenon of pre-ignition, also known as knocking. A catalytic converter is used to clean unburned fuel, CO, and NO_x from the exhaust stream. In general, the fuel-air mixture must be stoichiometric—that is, containing just enough air to combust the fuel—which requires that the intake air be throttled at light loads, in turn reducing efficiency. As with diesel engines, turbocharging is a technique that can be used to increase power. Additionally, engine manufacturers vary valve and ignition timing as a function of load and engine speed to optimize efficiency, power, and the emission profiles of the engines.

There are several reasons for the prevalence of diesels for MHDVs. Diesel fuel has higher volumetric energy content than gasoline (Hileman et al. 2009) such that more energy can be carried in similarly sized tanks. Diesel engines are also more efficient than gasoline engines, for two reasons: first, as noted, diesel engines have higher compression ratios than gasoline engines, allowing more work to be extracted during the expansion stroke of the engine; second, diesel engines do not throttle the air intake, which can lower efficiency, especially at light loads. The key advantage to diesels, however, is their durability. The lifetime of a properly maintained diesel engine is several decades, whereas a gasoline engine has a much shorter lifetime. This is one of the reasons why the median lifetime of MHDVs—the majority of which are diesel powered—is so long. The estimated median lifetime of 2002 model year trucks, for example, is estimated to be 28 years (ORNL 2012).

Gasoline engines are simpler, less expensive, and require less-expensive emissions control systems. The simplicity of gasoline engines derives from the relatively less-complex fuel-injection system. Diesel engines must withstand greater pressures than gasoline engines, and as such the engines must be heavier and more robust. These factors increase the cost of diesel engines over gasoline engines, which has led to an increased market share in recent years for gasoline-fueled MHDVs for Class 3 through 7 applications (NRC 2010). Advances in gasoline engines have narrowed the gap in fuel economy and durability for many vehicle configurations and uses. This helps to explain the relatively similar volumes of gasoline and diesel consumption for Class 3 through 6 trucks shown earlier.

F.2.2 Advances in Conventional Fuels and Vehicle Technologies

Significant efforts are being made to improve conventional fuels and engine technologies. As noted previously, the goals of the 21st Century Truck Partnership (NRC 2012) and other programs are to improve engine efficiency, improve performance, and reduce emissions. Some potential areas of improvement are detailed in the following.

Ultra-low-sulfur diesel (ULSD). In December 2000, the EPA promulgated rules that on-road diesel fuel in the United States must have a sulfur content of no greater than 15 ppm [Office of Transportation and Air Quality (OTAQ) 2000]. The regulations, phased in from 2006 to 2010, were paired with more-stringent emissions regulations for new trucks beginning with the 2007 model year. While reducing the sulfur content of diesel yields significant emissions benefits on its own, it also enables the use of catalytic converters in diesel trucks, which otherwise would be damaged by higher-sulfur fuels. As the ultra-low-sulfur diesel was phased in, new trucks were then required to include catalytic converters. The implementation of the ULSD and clean diesel truck rules was completed in 2010.

Lighter-weight materials. Weight is a key consideration for MHDVs. Fuel consumption is directly related to the mass of the vehicle because a lighter vehicle requires less energy to accelerate, decelerate, and push uphill. Significant research is underway in developing new structural materials, including carbon fiber, to allow for the construction of lighter-weight trucks while also maintaining safety characteristics. Reduced weight would be most helpful for trucks not used for goods transport—bucket trucks and buses for example—because the saved weight in these cases would not likely be offset with increased load (NRC 2010). Even with freight trucks, though, the net effect of lighter vehicles with heavier loads would be beneficial, reducing the amount of fuel required to transport a ton-mile of goods.

Aerodynamics and rolling resistance. At higher speeds, most of the power of the engine is used to overcome air resistance. For vehicles that routinely travel at high speeds, such as long-haul tractor-trailers and motor coaches, improved aerodynamics can result in significant fuel savings (NRC 2010). For example, many tractor-trailers are now outfitted with fairings to reduce turbulence in the undercarriage of the trailer. Similarly, new single-tire configurations have been developed that reduce rolling resistance, another major consumer of energy at high speeds.

Gasoline direct injection (GDI). GDI is an engine technology in which the gasoline is directly injected into the cylinder prior to ignition by a spark. GDI comes in two types: stoichiometric GDI (S-GDI) and lean-burn GDI. In both cases, the compression ratio can be increased by directly injecting the fuel into the cylinder, improving the efficiency of the engine. In S-GDI, a stoichiometric amount of fuel is added to the air, a requirement for three-way catalytic converters. The S-GDI system results in pumping losses at low loads. Alternatively, pumping losses may be reduced by allowing more air into the cylinder and burning less fuel, but then different and more expensive catalytic converters must be employed (NRC 2010).

Homogeneous charge compression ignition (HCCI). The HCCI combustion process combines aspects of diesel and gasoline engines. A charge of fuel and air is introduced into the engine and is compressed until it auto-ignites (Ravi et al. 2012). In HCCI engines, combustion occurs much faster than in conventional gasoline or diesel engines, reducing the formation of NO_x significantly. Unlike spark-ignition engines, HCCI engines can run lean, reducing throttling losses that compromise efficiency at low load. Compression ratios are higher than in a typical spark-ignition engine, improving efficiency. HCCI engines are under development and require precise control of the fuel mixture and engine characteristics to ensure proper operation.

Hybrid-electric and hybrid-hydraulic drivetrains. The principal benefit of a hybrid drivetrain is the ability to recover and recycle energy that would otherwise be lost during braking. The net effect is to improve fuel economy, especially when the use of the MHDV requires a significant amount of starting and stopping. In a hybrid-electric vehicle, an electric motor is used for traction, and a battery is used for temporary storage of energy. In a hybrid-hydraulic vehicle, hydraulic motors are used for traction, and accumulators are used for the temporary storage of energy. There are many different configurations of hybrid drivetrains, which must be tailored to the specific application of the vehicle. Hybrid drivetrains are more costly, more complex, and potentially less reliable than standard drivetrains, but may offer a number of benefits. These benefits include the ability to reduce engine size; the ability to operate the engine in its optimal zone for improved fuel efficiency and emissions; and, in the case of hybrid-electric, the ability to run auxiliary loads, such as air-conditioning and lighting, from the electric subsystem rather than directly from the engine (NRC 2010, 2012).

F.2.3 Alternative Fuels and Vehicle Technologies

Although accounting for only a small part of the MHDV market today, alternative fuels and engine technologies are in some cases able to offer significant improvements over conventional fuels and engine systems. A few examples are detailed in the following.

Natural gas. Both gasoline and diesel engines have been modified to accept natural gas as a fuel. The natural gas may be carried on the vehicle in either compressed (CNG) or liquefied (LNG) form; the latter, while more costly, also supports improved vehicle range. Engines typically rely on spark ignition and apply many of the same technologies to improve power and reduce emissions, such as turbocharging and EGR. Cummins Westport is now marketing a heavy-duty natural gas engine for the Class 8 tractor-trailer market, and the firm already produces natural gas engines for buses and other markets (Cummins Westport, undated a). The emissions characteristics of natural gas engines are similar to those of new diesel engines, but natural gas, when used in MHDVs, offers simpler emissions compliance. Current market prices for natural gas are well below those for diesel fuel on an energy equivalent basis. The principal barriers to the use of natural gas are increased vehicle costs, the relatively limited range afforded by currently available onboard storage tanks, increased weight due to specialized tanks, the limited availability of natural gas refueling infrastructure, and the limited availability of appropriately trained mechanics [American Trucking Association (ATA) 2009]. Ensuring safety when handling compressed or liquefied natural gas is also a significant concern.

Biofuels. Alternative liquid fuels, discussed in earlier appendices for the light-duty fleet, are also applicable to MHDVs. In areas where it is mandated by law, MHDVs receive the same blends of gasoline and ethanol or diesel and biodiesel as do light-duty vehicles. Refined vegetable oils and synthetic diesel fuels are also generally compatible as blends. Biodiesel, however, has slightly less energy content than petroleum diesel, and it is thermally unstable and cannot be used in colder weather (Hileman et al. 2009).

Hydrogen. The primary focus of research, development, and demonstration efforts for hydrogen is on fuel-cell–powered vehicles, which convert the hydrogen into electricity that in turn powers an electric drivetrain. Hydrogen fuel cells emit only water vapor, thus offering—depending on how the hydrogen is produced—potentially significant environment benefits. Hydrogen fuel-cell vehicles are not yet available for mass market adoption, and there are a number of technical and cost issues still to be resolved. In the absence of readily available hydrogen, natural gas may be substituted as a fuel for fuel-cell–powered vehicles: an auto-thermal reformer can convert the natural gas to streams of carbon dioxide and hydrogen. This process could occur either on the vehicle or at the fueling site. In comparison to electric-only vehicles storing energy in a battery, fuel cells promise much greater vehicle range.

The U.S. Department of Energy, partnering with the Federal Transit Administration (FTA), is evaluating the technical and economic viability of fuel-cell–powered transit vehicles through the National Fuel Cell Bus Program. The program sponsors pilot tests of fuel-cell technologies and infrastructure for single buses or small bus fleets operating in cities across the country [National Renewable Energy Laboratory (NREL) 2010].

Electric. Battery electric replacements for MHDVs are an option in applications where travel distances are short and there is ready access to charging systems. Although costly, battery electric vehicles emit no pollutants locally, a compelling advantage in areas facing significant air quality challenges. One potential application is in port drayage systems, where containers must be moved and stacked within a confined area.

F.3 Market Prospects

Due to the longevity of most MHDVs, the year-over-year market for new vehicles is not especially large. As such, achieving high levels of penetration for alternative fuels and advanced engines and drivetrain technologies in the absence of environmental or policy motivators could take many years. More likely, the mix of different engine, drivetrain, and fuel types in use will continue to diversify, with traditional diesel engines being supplanted in favorable applications with gasoline, natural gas, and other technologies. While a quantitative assessment of the potential for alternative fuel and vehicle technologies is not presented, the key to understanding their applicability lies in the application, fleet, and usage characteristics, as discussed in earlier sections of this appendix. Table F.9 summarizes these characteristics for common MHDV applications.

Table F.9. Summary characteristics for MHDV applications.

Application	Classes	Fleet	Typical Duty Cycle	Typical Fuel	Typical Refueling Location
Tractor-trailer	7, 8	Local, regional, and national	Extended periods at high speed	Diesel	Truck stop, own facility
Straight truck, box	3–8	Local and regional	Urban delivery, moderate average speed	Diesel	Own facility
Straight truck, bucket	3–8	Local and regional	Urban and rural use, significant auxiliary load	Diesel	Own facility
Refuse truck	7, 8	Local	Urban use with frequent stops and creeping at low speed	Diesel	Own facility
Transit bus	7, 8	Local and regional	Urban use with frequent stops at low speed	Diesel but increasingly natural gas	Own facility
Motor coach	8	National	Extended periods at high speed	Diesel	Truck stop
Pickup trucks and small vans	2b	Local	Varied uses	Gasoline or diesel	Gas station

Table F.10. Promising fuels and technologies for MHDV applications.

Application	Hybrid-Electric, Hydraulic	Natural Gas	Biodiesel, Ethanol	Battery Electric	Hydrogen
Tractor-trailer		●	●		●
Straight truck, box	●	●	●		●
Straight truck, bucket	●	●	●		●
Refuse truck	●	●	●		●
Transit bus	●	●	●		●
Motor coach			●		●
Pickup trucks and small vans	●	●	●		●

Notes: For pickup trucks and small vans, hybrid-electric technology is applicable but hybrid-hydraulic is not generally feasible. As shown by the absence of bullets in the battery electric column, electric vehicle technology is not viewed as promising for most medium- and heavy-duty vehicle applications. A possible exception, as suggested previously, is for certain contexts—such as at ports—where the ability of electric vehicles to mitigate severe local air-quality challenges may be highly prized.

While all MHDVs will benefit from general advances in engines and drivetrains, certain technologies and systems are likely to provide more benefits for some applications than for others. Table F.10 summarizes the technologies and fuels that appear to offer the most promise from different MHDV applications based on the considerations discussed in this appendix.

References

ATA. 2009. *White Paper: Is Natural Gas a Viable Alternative to Diesel in the Trucking Industry.* Arlington, Virginia.

Clark, N. N., M. Gautam, W. S. Wayne, D. W. Lyons, and G. J. Thompson. 2007. *Heavy-Duty Vehicle Chassis Dynamometer Testing for Emissions Inventory, Air Quality Modeling, Source Apportionment and Air Toxics Emissions Inventory.* Coordinating Research Council, Inc.

Cummins Westport, Inc. Undated a. Engines: Models. http://www.cumminswestport.com/models (accessed September 30, 2012).

Cummins Westport, Inc. Undated b. Parts & Service. http://www.cumminswestport.com/parts-service (accessed September 17, 2012).

EPA. 2012a. EPA Urban Dynamometer Driving Schedule. http://www.epa.gov/otaq/standards/light-duty/udds.htm (accessed September 17, 2012).

EPA. 2012b. National Clean Diesel Campaign (NCDC). http://www.epa.gov/diesel/ (accessed September 24, 2012).

EPA and NHTSA. 2011. "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule." *Federal Register*, 76 (179).

ESA. 2004. 2002 Economic Census: Vehicle Inventory and Use Survey, Geographic Area Series.

Hileman, J., D. S. Ortiz, J. T. Bartis, H. M. Wong, P. E. Donohoo, M. A. Weiss, and I. A. Waitz. 2009. *Near-Term Feasibility of Alternative Jet Fuels.* RAND Corporation, Santa Monica.

Krupnick, Alan J. 2011. *Will Natural Gas Vehicles Be in Our Future?* Resources for the Future, Washington, D.C.

NRC. 2010. *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.* The National Academies Press, Washington, D.C.

NRC. 2012. *Review of the 21st Century Truck Partnership, Second Report.* The National Academies Press, Washington, D.C.

NREL. 2010. Fuel Cell Transit Bus Evaluations Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration.

ORNL. 2012. *Transportation Energy Data Book*, Edition 31.

OTAQ. 2000. Regulatory Announcement: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.

Ravi, N., H.-H. Liao, A. F. Jungkunz, H. H. Song, and J. C. Gerdes. 2012. "Modeling and Control of Exhaust Recompression HCCI: Split Fuel Injection for Cylinder-individual Combustion Control." *IEEE Control Systems Magazine.*

SmartTruck. 2009. EPA Smart Truck Partnership. http://smarttrucksystems.com/epasmartway.php (accessed September 24, 2012).

APPENDIX G

Population, Economy, and Land Use

One of the more important ways that changes in transportation fuels and vehicle technologies could affect state DOTs is through their effects on vehicle cost and the marginal energy cost of travel, which would in turn influence aggregate volume and mode choice for passenger travel and goods movement. This appendix reviews past trends and future prospects for three additional factors strongly linked to both energy use and travel demand: population growth, economic growth, and land use. The last section in the appendix discusses the anticipated effects of these variables—in isolation or in combination—on the future energy and transportation scenarios developed in Chapter 6. The intent is to ensure that the effects of evolving fuel sources and vehicle technologies on travel behavior are not considered in isolation but rather in concert with broader socio-demographic trends that may affect both energy use and travel patterns.

G.1 Population Growth

This appendix first considers past trends in population growth and projections for how the U.S. population is expected to change and expand in the coming decades.

G.1.1 Historical Population Growth

The United States is currently the third most populated country on earth, accounting for nearly 4.5% of the world's total population (Shrestha and Heisler 2011). The U.S. population has more than doubled in size since 1950, reaching around 309 million people in 2010 (U.S. Census Bureau 2000, 2011). This corresponds to an average annual growth rate of 1.2%. Figure G.1 shows the fairly steady population growth experienced by the United States over the last 60 years.

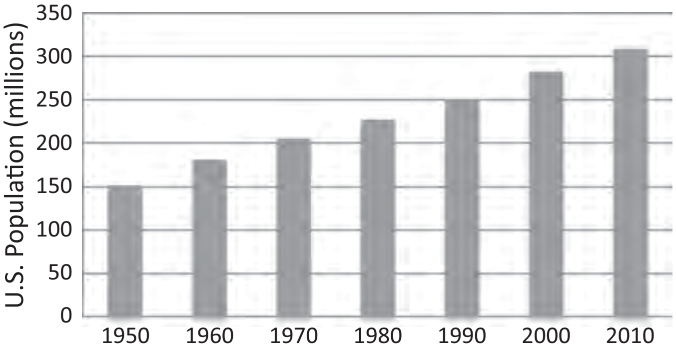
The population changes that have occurred over the previous decades have made the United States one of the most diverse nations on earth. Key demographic factors affecting the size and composition of the U.S. population include:

- **Birth rates.** Birth rates in the decade following World War II rose dramatically, leading to the baby boom era. Since 1950, the long-run birthrate has gradually declined from 24 to about 14 births per 1,000 people per year in 2010. The U.S. Census Bureau predicts that birthrates in the United States will fall slightly lower, to 13 births per 1,000 people, by 2050 (Shrestha and Heisler 2011).
- **Life expectancy.** Advances in medicine and improved living conditions have contributed to longer life expectancies. In 2007, the average life expectancy at birth was 77.9 years (Shrestha and Heisler 2011). The U.S. Census Bureau expects that the average life expectancy will grow to 82.6 years by 2050 (Shrestha 2006).
- **Net immigration.** More people enter the United States than leave each year, further contributing to population growth. The U.S. Census Bureau predicts that net immigration will grow over time, from approximately 800 thousand people per year in 2015 to over 1.2 million people per year in 2060 (U.S. Census Bureau 2012).

G.1.2 Future Population Projections

The U.S. population is expected to continue to undergo structural shifts in the coming decades, as discussed by Cheeseman Day (undated):

- **The U.S. population will continue to grow, but at a declining rate.** Between 1950 and 2010, the U.S. population grew at a rate of 1.2% per year. However, this rate is expected to slow to 0.8% per year over the next 40 years. The U.S. Census Bureau (2009 a, b, c, d) has provided a range of population projections based on assumptions about future net international migration, as shown in Figure G.2. The



Source: Compiled by authors from U.S. Census Bureau (2000, 2011) data.

Figure G.1. U.S. population 1950–2010.

implied rates of U.S. population growth between 2010 and 2050 for the different scenarios range from 0.1% in the zero net-migration case to 1.0% in the highest net-migration case.

- **The U.S. population will be older in the future.** Due to increases in life expectancy, the average age of the population is expected to increase over time.
- **The United States will become more diverse in the future.** Non-Hispanic whites are expected to decline as a share of the U.S. population, while other races are expected to grow at a faster rate. Asian and Pacific Islanders are the fastest growing segments of the population in the United States.

One of the most uncertain factors associated with the magnitude of future growth of the U.S. population is the rate of immigration. Figure G.2 shows several future population projections prepared by the U.S. Census Bureau (2009 a, b, c, d) based on alternate assumptions about net migration rates. Depending on the scenario, the U.S. population could stabilize at around 320 million or could climb to over 450 million by 2050.

The trends just described are at the national scale. However, they have and are likely to continue to play out differently in certain regions of the country. Table G.1 provides regional estimates of the U.S. population in 1950 and 2010 and projections for 2030 developed by the U.S. Census Bureau (1995 and 2005).

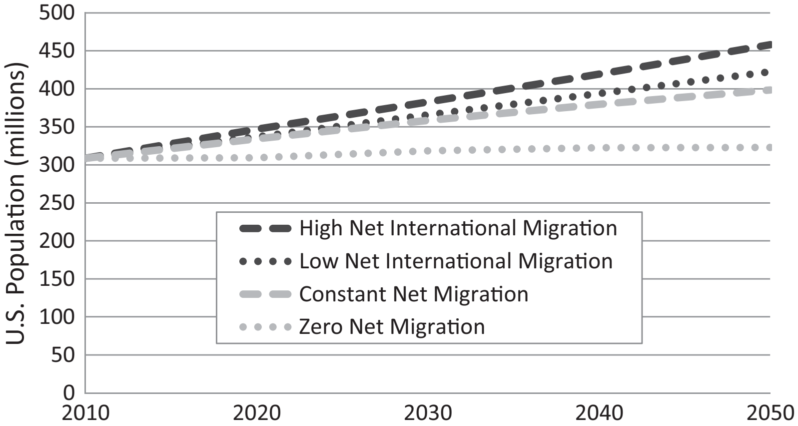
Historically, the western portion of the United States has grown at a faster rate than other parts of the country, followed by the South. The Northeast and Midwest have lagged in population growth. In the future, the western and southern portions of the country are expected to continue to grow faster than other portions of the country, with growth rates in these regions averaging 1.2% per year for the next 20 years.

G.2 Economic Growth

Potentially influential economic trends are now considered. The United States is still slowly emerging from its deepest economic slump since the Great Depression, but the decades since World War II have been generally characterized by economic prosperity. While there have been periods of downturn, they have tended to last only a few years and to be followed by longer periods of growth. More recently, though, the nation has been experiencing several fundamental shifts that are likely to affect future economic growth and in turn transportation demand patterns. These include changes in economic focus, in workforce composition, and in the nation's leadership role within the broader global economy.

G.2.1 Historical Economic Trends

Aggregate economic growth is most often characterized by changes in GDP. This is computed as an estimate of the market value of all final goods and services produced within a country over some specified period of time—typically a quarter or a year. To analyze how changes in GDP and other measures of economic activity change over time, economists



Source: U.S. Census Bureau (2009 a, b, c, d).

Figure G.2. U.S. Census population projections to 2050.

Table G.1. Historical and future population estimates by region.

Region	1950	2010	2030	Historical Annual Rate of Growth (1950–2010)	Projected Annual Rate of Growth (2010–2030)
Northeast	39,478,000	55,785,179	57,671,068	0.6%	0.2%
Midwest	44,461,000	67,391,433	70,497,298	0.7%	0.2%
South	47,197,000	113,583,614	143,269,337	1.5%	1.2%
West	20,190,000	72,175,355	92,146,732	2.1%	1.2%
United States	**151,326,000**	**308,935,581**	**363,584,435**	**1.2%**	**0.8%**

Source: U.S. Census Bureau (1995 and 2005).

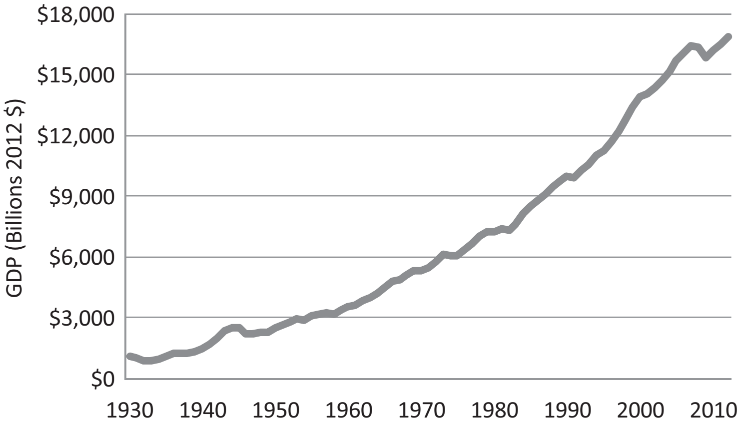
generally put prior-year estimates in real dollars (i.e., adjusted for inflation). Figure G.3 illustrates change in real GDP over time. Over the past 80 years, the U.S. economy has grown by over 1,500%, as measured by the change in real GDP, with an average annual growth rate of about 3.38%. However, growth has slowed more recently, in part due to the severity of the recent recession; over the past two decades (1992–2012), GDP increased by an average annual rate of around 2.51% (computed by authors from BEA 2013).

Another commonly employed term, personal income, differs from GDP in that it excludes economic activity that occurs in the United States that is owned by foreigners and includes U.S. economic activity that occurs in other countries. It represents income received by a country's citizens or residents from all sources, including net earnings, property income, and personal current transfer receipts. Personal income is also adjusted for depreciation and other factors (BEA 2007). When personal income is calculated in per-capita (i.e., per-person) terms, it provides a more useful measure of the income level of individuals in the economy. In the transportation context, broadly speaking, GDP has the more significant impact on demand for goods movement, while personal income has a greater effect on passenger travel demand.

Figure G.4 shows the trend in real per-capita personal income from 1930 to 2011 in the United States, in 2012 dollars adjusting for inflation (computations by authors based on data from BEA 2012 and BLS 2013). Over that time period, per-capita personal income grew by a little less than 400%, from almost $8,500 to $42,400, corresponding to a real annual growth rate of 1.98%. More recently, however, the rate of growth in per-capita personal income has slowed, in part reflecting the severity of the most recent recession; the average real growth rate over the past 20 years (1991–2011) was about 1.2%, while the average real growth rate over the past 10 years (2001–2011) was just 0.5%.

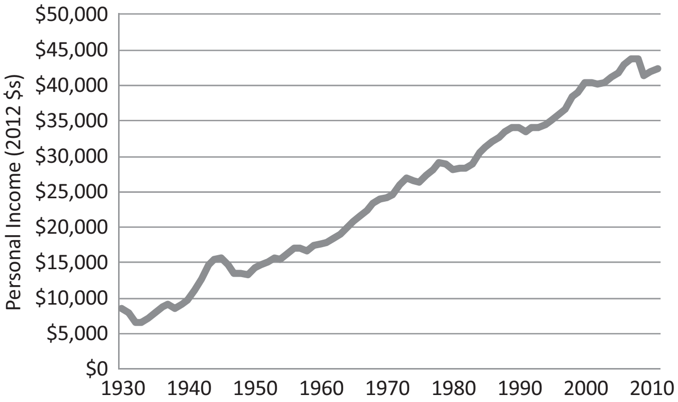
Many factors have contributed to the United States' economic growth. When comparing between countries or between regions within a country, economists often emphasize the following three factors as particularly important:

- **Human capital:** the formal knowledge and skills of the labor force.



Source: BEA (2013).

Figure G.3. Real U.S. GDP, 1930–2012.



Source: Computed by authors from BEA (2012) and BLS (2013).

Figure G.4. Real U.S. per-capita personal income, 1930–2011.

- **Physical capital:** the machines, buildings, and infrastructure that support the production of goods and services.
- **Natural resources:** access to the physical inputs (i.e., timber, oil) used to produce goods and services.

Among these, human capital is perhaps the most important driver of economic growth and, in turn, personal income. For a century, the United States expanded human capital significantly through education. Between 1875 and 1975, the average years of education in the United States increased by seven grades (DeLong, Golden, and Katz 2003), although since then advances in educational attainment have begun to level off. Physical capital and natural resources are generally thought to be secondary drivers of growth relative to human capital. For example, despite dramatic increases in the size of the U.S. economy since World War II, the ratio of physical capital to output has remained relatively constant (DeLong, Golden, and Katz 2003).

G.2.2 Future Economic Growth

Projections of future U.S. economic growth, particularly over the long time horizon considered in this study (30 to 50 years), are highly uncertain. In its most recent reference-case energy projections, the EIA assumes that real U.S. GDP will grow at an annual rate of about 2.5% through 2040 (EIA 2013). Factoring in the EIA's expected annual population growth rate of 0.9%, this would correspond to a growth rate in real per-capita GDP of just under 1.6%. Taking a more optimistic view, Dadush and Stancil (2009) project that the total U.S. economy will grow at a rate of 2.9% per year between 2009 and 2050.

While such forecasts fall in line with historical growth rates, considering a wider range of scenarios seems prudent. Severe economic disruptions in various forms could lead to lower growth rates, while advances in technology or other developments could possibly lift U.S. economic growth to levels that surpass historical rates. It is also the case that economic growth could be distributed unevenly across the country. Following the recent recession, for example, smaller cities in the oil and gas producing regions of the country have experienced the strongest records of economic growth, while sprawling metropolises and their smaller-city counterparts in the Sunbelt region have faced the greatest struggles (Florida 2012).

G.3 Land Use Patterns

Finally are considered past and potential future trends in land use, which is a term used to describe the purposes served by different parcels of land in an area. At the broadest level, land is often categorized as being either urbanized or undeveloped. Urbanized land includes at least moderate development that can involve residential, commercial, or industrial uses. Undeveloped land, in contrast, has little if any physical construction and may include parkland, cropland, forests, wilderness areas, and the like. Within a large country such as the United States, the vast majority of land is undeveloped rather than urbanized. Out of about 2.26 billion acres across the country, only around 66 million, or about 3%, were urbanized as of 1997. The pace of development has been rapid, though, with a four-fold increase over the second half of the twentieth century (Lubowski et al. 2002).

Of the nation's remaining open land, other major categories are roughly 671 million acres of forestland; 614 million acres of grassland, pasture, and rangeland; 408 million acres of cropland; 313 million acres of special-use land such as parks and wildlife areas; and 197 million acres of miscellaneous nature such as tundra or swamps (Nickerson, Ebel, and Borchers 2011). The website NationalAtlas.gov (2013) reports that the federal government owns about 650 million acres—roughly 30% of the nation's land area—which is reserved for national parks, national forests, national wildlife refuges, military reserves, and other public-interest uses.

Another common differentiation of land use patterns is between urban, suburban, and rural. The U.S. Census Bureau began defining metropolitan statistical areas (MSAs)—which include both urban and suburban populations—in 1910. Each MSA includes a densely developed central city area along with moderately dense communities around the central city. Taken together, center cities and their surrounding suburbs of a specified minimum density are described as urbanized, whereas areas falling outside of an MSA are generally described as rural. Most MSA boundaries have changed over the years with the spread of urbanization; that is, land that was once classified as rural may be reclassified as urbanized with the introduction of new development.

This discussion is concerned with both the rate of development and the characteristics of the resulting land-use patterns.

Of particular interest are the density of development (e.g., population or jobs per square mile) and degree to which different land uses (e.g., residential, commercial, and industrial) are either mixed or segregated from one another. These characteristics have significant implications for both total travel demand and mode choice.

G.3.1 Historical Land-Use Trends

Before World War II, most of the U.S. population lived in rural areas. By 1950, however, more Americans lived in metropolitan areas than in rural areas; by 2000, the share of Americans in metropolitan areas had risen to 80% (Hobbs and Stoops 2002).

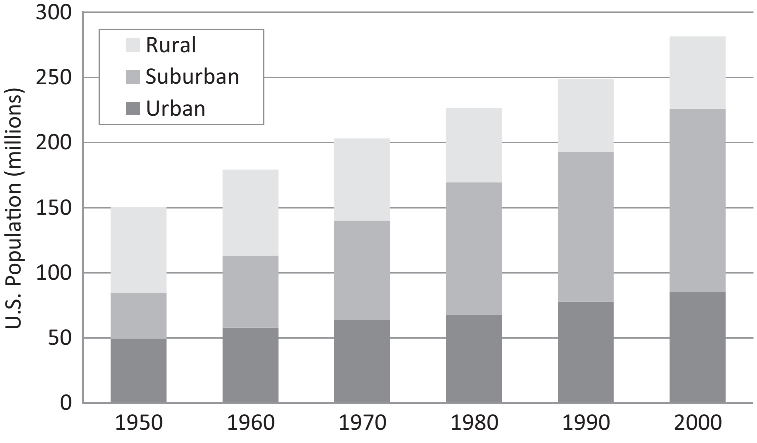
Increasing urbanization, however, did not mean that Americans were flocking to the center cities, where the vast majority of metropolitan dwellers had lived before the war. Rather, Americans were drawn to the suburbs. In 1950, only 23% of Americans lived in areas characterized as suburban. By 2000, as shown in Figure G.5, that proportion had grown to half of the U.S. population.

Many factors contributed to the rapid increase in suburbanization following World War II. These include the Government Issue (GI) Bill that gave returning veterans access to inexpensive mortgages to purchase houses, the emergence of development companies (such as the famous Levittown) that sprung up to take advantage of greater interest in home ownership, the post-war baby boom that created a desire for larger homes in which to raise growing families, the federal mortgage interest deduction that made home ownership more affordable, the Federal Housing Administration's practice of "red-lining" that made it difficult to obtain mortgages for center city housing, the creation of the Interstate highway system that made commuting throughout a metropolitan area easier, and the phenomenon of "white flight" from cities to suburbs following desegregation of urban school systems. While none of these policies or trends was initiated with the specific aim of creating suburbanization, in concert they had that effect.

This major shift toward suburbanization has been intertwined with trends in housing construction, density, and the location of employers, all of which have affected how Americans travel. Before 1920, the shares of housing built in center cities, suburbs, and rural areas were roughly equal; in the 1940s, about 80% of housing was built in the center city and suburbs. By the 1960s, more than half of new housing units were in suburbs, and by the 1990s, 60% were in the suburbs (Williams 2004).

Suburbanization was accompanied by an increase in the development of single-family houses as opposed to multifamily buildings, as well as a trend toward the design of larger single-family houses. In 1974 (the earliest year for which figures are available), just over half of all housing units built were single-family houses; by 2000, the share had risen to about 80% (U.S. Census Bureau, undated). In 1950, the size of an average new house was 983 square feet; by 2000 it was 2,057 square feet [National Association of Home Builders (NAHB) 2006]. For single-family homes, average size has increased from 1,695 square feet in 1974 to 2,504 square feet in 2012 (U.S. Census Bureau, undated).

A key effect of suburbanization is the decline in density of the urbanized area as a whole. In 1940, the average population density of a metropolitan area (including both center city and suburbs) was 8,654 persons per square mile. By 2000, that had fallen to 5,581 persons per square mile (Giuliano, Agarwal, and Redfearn 2008; Kim 2007). Density gradients—a measure of the rate at which population density declines with distance from the center—have also become less steep



Source: Data from Hobbs and Stoops (2002).

Figure G.5. U.S. population by urban, suburban, and rural areas, 1950–2000.

due to suburbanization and the gradual expansion of metropolitan area boundaries (Kim 2007). Another result of the trend toward suburbanization is that the conversion of undeveloped land has occurred more rapidly than the population has grown; from 1960 to 2000, urbanized population grew by 80%, while urbanized land area grew by 130% (Nelson 2004).

Following World War II, there began a shift toward the decentralization of employment locations as well. In 1950, the share of employment in the central county of metropolitan areas was between 45% and 50%; by the early 1990s, that share had declined to just 40% (Glaeser et al. 2001). Prevailing wisdom is that the workforce suburbanized and then employers followed, although this is clearly a two-way process.

While employment decentralization has occurred across the board in American cities, there is much diversity between metropolitan areas. Some areas have edge cities—high concentrations of suburban office and retail space—while others have more dispersed employment. The dominant employment sector also has some impact on the form and patterns of decentralization; cities with higher shares of service employment (such as banking) tend to be more centralized than those with higher shares of manufacturing (Glaeser et al. 2001).

While these trends describe most of the post-war twentieth century, there is some evidence that certain trends have slowed more recently. Two-thirds of the 100 largest central cities added population in the first decade of the 2000s, helping to offset previous declines (Brookings Institution 2010). By 2008, housing prices per square foot were 40% to 200% higher for many urban areas than their suburban counterparts (Leinberger 2008). However, decentralization continues to be the dominant trend.

G.3.2 Future Land-Use Trends

The future trajectory of development patterns in the United States is difficult to predict. Many observers have viewed decentralization as an unsustainable trend in the long run based on the externalities associated with automotive travel. The mortgage meltdown of 2008 provided some ammunition to this argument, albeit from a financial standpoint rather than an environmental one. The recession of 2008 was brought on in large part by overextension in the for-sale housing market—prices rose too quickly, too many new homes were built, prospective homeowners bought houses they could not realistically afford because mortgages were so readily available, and banks resold bundles of sub-prime mortgages as high-quality securities.

Future historians may look at the housing crisis and ensuing recession as a key turning point in American land-use trends, the way that the end of World War II ushered in its own significant shifts. Some futurists argue that our economic geography is undergoing profound changes. Older industrial cities, in this view, will continue their decline, previous boom cities whose growth relied largely on the real estate market itself will retrench, exurban areas with large amounts of single-family housing in single-use zoning will evolve into slums, and cities that successfully recentralize and attract knowledge workers will thrive (Myers and Gearin 2001, Leinberger 2008, Florida 2009). In terms of what this would mean for land use, much new development could take place along smart growth principles: more compact housing types, built to a greater extent near transit services, and in mixed-use communities that combine housing with employment and retail.

However, it is also possible that the strong decentralization trends of the second half of the twentieth century may continue, given the slow pace of land use change and the institutional factors that make higher-density development difficult to build in many center cities and inner-ring suburbs. Established communities often resist adding additional housing or office space, fearing declines in property values and increased traffic; developers are accustomed to working with large suburban parcels of land and do not wish to take on the additional requirements that infill development often entails; and the regional planning that can help areas grow in a more compact fashion is often undermined by local land-use controls, since zoning is typically a local prerogative (Downs 2005).

It is also possible that the country could remain in a kind of holding pattern in which it stays mired in sluggish economic conditions and largely retains the land use patterns in existence today. It might be that the expected growth in population fails to emerge; immigration could slow because there are fewer jobs available, and people might have fewer children if unemployment remains high. Instead of forming new households, the future could witness more intergenerational households, in which adult children continue to live with their parents even as they have children themselves. This could lead to more overcrowding, defined as people sharing housing units that were built for a smaller number of occupants. Home ownership might also decline, leading to reduced demand for new houses. A recent analysis has already found that Americans are moving less now than at any point since World War II (Frey 2009).

These are not either-or scenarios; some metropolitan regions could go one direction, developing more along pre–World War II models, while others could continue to decentralize or stagnate. The trends described in the preceding section generally held true for most metropolitan areas in the country, but there are always exceptions—places that for one reason or another remained more centralized than the average. For the purposes of the scenarios in this report, however, the broadest trends and how they would affect transportation are of most interest.

These scenarios assume that the United States recovers from the current recession eventually and continues growing in some fashion. However, some observers think that higher and more volatile oil prices, coupled perhaps with unsustainable government deficits or environmental crises, could lead to much more drastic changes in American life. Several recent books describe this prospect as a type of urban collapse, in which extremely high-priced or unavailable petroleum means that urban areas cannot feed their populations or function as economic centers (Heinberg 2003, Kunstler 2005). Others see a more optimistic future, but still one in which more expensive gasoline leads to a radical restructuring of cities, more local production of food, and far less long-distance transport of goods and people (Newman, Beatley, and Boyer 2008; Steiner 2009).

By nature, revolutionary change is more difficult to predict than evolutionary change, given that it is based on sharp dislocation rather than long-term trends. The changes described in the preceding paragraph are revolutionary, although none of the authors make hard-and-fast predictions about the pace of change, and some acknowledge that even widespread decline may take generations, not just a few years. The United States has certainly seen large-scale population migrations in the past, in some cases involving rapid growth due to economic opportunity (San Francisco grew 25-fold in 2 years during the gold rush) and in other cases involving mass departures based on economic hardship (about 2.5 million people left drought-ridden Midwestern farmlands in the 1930s dust bowl). So such major changes in population—and with them, land use—are not unprecedented, but neither are they easy to predict.

G.4 Potential Effects on Energy and Transportation

This final section explores how future changes in population, the economy, and land use—individually or in concert—affect specific energy and transportation factors included in the scenarios developed in this study. The discussion draws on principled reasoning and findings from the literature, as appropriate. As a general rule, the effects on transportation tend to be more direct and better studied; in contrast, the potential effects of changes in population, economy, and land use on some of the energy factors of interest, such as the future mix of different fuel types, are more speculative.

Note that some of the studies referenced in this section rely on the economic concept of elasticities to report their results. A measure of elasticity provides a ratio that indicates how a percentage change in one variable of interest relates to a percentage change in another variable. For example, if the elasticity of fuel consumption with respect to changes in the price of fuel is estimated as −0.2, this indicates that a 10% increase in the cost of fuel should trigger a 2% reduction in fuel consumption. Economic analyses often further differentiate between short-run elasticities (measuring changes that occur within a year or so) and longer-run elasticities (measuring changes that unfold over a few years or more). Longer-run elasticities can differ significantly from short-run elasticities because they allow more time for individuals and firms to alter decisions or behaviors in response to the change (for example, to purchase a more fuel-efficient vehicle in response to higher fuel prices).

G.4.1 Effects on Fuels and Vehicle Technologies

The future transportation energy scenarios developed for this study encompass the price of oil, conventional-vehicle fuel economy, the mix of alternative fuels in use, vehicle cost premiums, and the marginal per-mile energy cost of travel. Of these factors, the logical effects on the price of oil are most clear, even if they are likely to be quite modest. The potential effects on other factors are much more speculative.

Price of oil. Population growth and economic expansion both correlate with increased travel, translating to greater aggregate fuel consumption. For example, based on their review of relevant studies, Goodwin, Dargay, and Hanly (2004) estimate that a 10% increase in average income leads to a 4% increase in fuel consumption over the short term and a 10% increase over the longer term. (The elasticity is higher over the longer term because higher incomes enable households to purchase more vehicles and to choose models that substitute greater size, power, and acceleration for fuel economy, but these purchase decisions unfold over multiple years.) Greater fuel consumption in turn puts upward pressure on the price of oil.

In contrast, denser land-use patterns and greater mixing of land uses, as discussed at greater length subsequently, are associated with reduced vehicle travel. This could help reduce aggregate fuel consumption and in turn ease pressure on oil prices. Note, however, that oil is traded on a world market. As a result, changes in U.S. demand for oil stemming from future changes in population, economy, and land use may have only a modest influence on oil prices given the rapid increase in oil consumption within many of the emerging economies around the world.

Vehicle fuel economy. The effects of population, economy, and land use on vehicle fuel economy are uncertain but not likely to be significant. For example, if growth in population or the economy leads to additional vehicle travel and higher oil prices, this could result in increased demand for vehicles with higher fuel economy. On the other hand, rising incomes in the past have often resulted in the purchase of faster and more powerful vehicles with lower fuel economy. In the coming years, however, as a result of significantly more-stringent CAFE standards, new vehicles will have to meet progressively higher levels of fuel economy, culminating in an average of 54.5 miles per gallon by 2025. In the context of rapidly escalating CAFE requirements, it is not clear that changes in population, the economy, or land use will have much additional effect.

Alternative fuels. As with fuel economy, likely effects on the use of alternative fuels are also speculative. If changes in population or economy result in higher oil prices, this could make alternative fuels comparatively more attractive. As noted previously, however, any effects on gasoline or diesel costs are likely to be muted in the context of broader worldwide trends in supply and demand. It is also possible that denser land use could enable greater adoption of electric vehicles, even with their current range limitations.

Vehicle cost. One could make plausible arguments about how changes in population, the economy, or land use might influence vehicle cost. For example, a combination of high population growth and high economic growth, as described previously, might lead to rising oil prices, in turn increasing demand for alternative fuels. A robust economy, in turn, could allow for increased investment in fuel and vehicle technology research and development, which might lead to breakthroughs that reduce the premiums for, say, electric or hydrogen vehicles. As another example, a trend toward increased land-use density might lead residents to purchase smaller, and often more affordable, vehicles because they are easier to maneuver and park in dense urban areas. On the other hand, the uptake rate for electric vehicles, which entail significant cost premiums, could be higher in urban areas where range limitations are less constraining to typical travel patterns. In short, there is significant uncertainty regarding whether and how future trends in population, the economy, and land use might affect vehicle cost, and little in the way of available evidence to clarify expectations.

Marginal cost of travel. Following this logical sequence, growth in population and the economy could result in increased fuel demand and higher oil prices. Higher prices for gasoline and diesel would in turn provide an incentive for consumers to purchase more fuel-efficient models, potentially reducing the marginal cost of travel. Higher prices could also trigger greater research and development funding for alternative fuels and vehicle technologies. If such investments led to breakthroughs that significantly reduce the vehicle premium costs associated with electric, natural gas, or hydrogen fuel-cell vehicles, in turn stimulating mass market adoption, this could also help reduce the marginal cost of travel. While such technologies currently involve much higher vehicle purchase prices, they promise much lower per-mile energy costs in return. In contrast, a shift to higher land-use density could increase the marginal cost of travel. This is because higher population and employment density generally leads to increased levels of traffic congestion (Sorensen et al. 2008), and more congested travel conditions can greatly reduce vehicle fuel economy (Barth and Boriboonsomsin 2009). This could be offset, however, if greater land-use density enabled increased adoption of limited-range electric vehicles or stimulated the purchase of smaller cars more generally. Here again, then, there is considerable uncertainty.

G.4.2 Effects on Travel Demand

In contrast to energy factors, for which the causal relationships are much less clear, the interactions between population, the economy, land use, and travel patterns have been studied extensively and are therefore easier to anticipate. Here are discussed how changes in these variables would be likely to influence future passenger vehicle travel, truck travel, and mode share for transit and other non-automotive alternatives.

Passenger vehicle travel. When the population grows, total passenger vehicle travel generally expands as well. There are, however, important variations in travel behavior among different demographic groups that could moderate the overall effect of population growth on travel. For example, retired persons, recent immigrants, and those in lower-income households tend to drive less than their younger, more acculturated, or more affluent counterparts (Santos et al. 2011). If population growth stems mainly from longer life expectancies, higher rates of immigration, or a higher birth rate among lower-income families than among the wealthy, then the growth in vehicle travel could be less, proportionately, than the increase in population would initially suggest.

The relationship between the economy and the demand for transportation is well documented. Increases in personal income, which tend to rise in proportion to GDP, are associated with an increase in vehicle ownership and overall personal travel (Santos et al. 2011). Drawing on the literature on income elasticities and travel, Goodwin, Dargay, and Hanly (2004) suggest that a 10% increase or decrease in average income will cause the vehicle miles traveled to grow or decline by 2% in the short run and by 5% over the longer run. It is worth noting, however, that increases in VMT are not strictly caused by economic growth. Rather, the relationship can work in both directions, with some additional travel resulting from economic growth and some economic growth produced by greater travel (Pozdena 2009).

There has been considerable attention to the relationship between land use and travel as well. The evidence suggests that three aspects of local land-use affect travel in consistent and measurable ways:

- **Density.** This attribute, which refers to the number of people living or working within a given area and can be characterized with such measures as dwelling units per acre or jobs per hectare, is known to have a strong effect on individual travel behavior. Higher levels of density generally correlate with reduced automobility and increased use of alternative modes such as transit, walking, and biking. Density has been shown to affect travel at both the local and regional level.

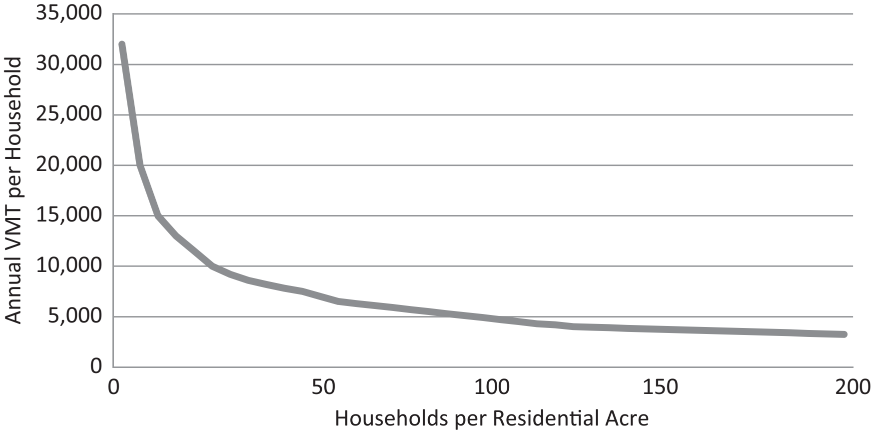
- **Mixing of land uses.** This describes the degree to which residential, commercial, retail, and other land uses have been located within close proximity of one another, which can help reduce the distances between the origins and destinations for some trips. The mixing of land uses is complex to measure, and most studies have focused on the neighborhood level. While available evidence suggests that greater mixing of land uses can help reduce per-capita passenger vehicle travel, the effect does not appear to be as strong as that of overall density.
- **Centralization.** This term relates to the percentage of employment or residences that are located in the center city as opposed to the outskirts. Broadly speaking, regions can be centralized, with a high concentration in the center city; decentralized, with few or no such concentrations; or multi-centric, with multiple smaller centers scattered throughout a region. At the regional level, some studies have found that higher degrees of centralization are associated with reduced per-capita vehicle travel.

While the broad findings outlined are generally consistent across many studies, two caveats should be noted. First, the study of land use and travel interactions presents a self-selection bias problem. That is, it is methodologically challenging to determine whether individuals in higher-density, mixed-use areas travel less by car in response to the environment in which they are situated, or instead if individuals who prefer to drive less choose to move to such neighborhoods because they provide better non-automotive travel alternatives. Some recent research has examined this question, and one study found that neighborhood characteristics are more important predictors of behavior than self-selection (Cao 2009), but this remains an area of ongoing inquiry.

Second, the results of any efforts to modify land use patterns with the aim of reducing VMT may take decades to unfold. As one recent review notes, "VMT savings will be slow to develop, however, if only because the existing building stock is highly durable; therefore, opportunities to build more compactly are limited largely to new housing as it is built to accommodate a growing population and to replace the small percentage of existing units that are scrapped each year" (TRB 2009, p. 5–6).

Still, it is clear that higher densities, mixed use, and centrality are associated with lower VMT. Higher densities and mixed uses lead to shorter and fewer driving trips, in part because origins and destinations are closer together. The aforementioned TRB review estimated that doubling residential density across a metropolitan area could lower household VMT by about 5% to 12% (TRB 2009); if coupled with higher employment density, significant public transportation improvements, greater mixing of uses, and demand management strategies, the reduction could be as much as 25%. Greater centrality, in turn, can reduce VMT by enabling more trips to be taken on transit; one study of over 100 urbanized areas found that a doubling in centrality was associated with a 15% reduction in VMT (Bento et al. 2005).

To illustrate the potential effects of land use on travel behavior, Figure G.6 graphs housing density against VMT per household for a sampling of smaller neighborhoods drawn from three cities in the United States: Chicago, San Francisco, and Los Angeles. Despite the varying land-use patterns of these three cities, there is a generally consistent relationship between density and VMT when viewed at the neighborhood level (Holtzclaw et al. 2002).



Source: Based on data from Holtzclaw et al. (2002, Figure 5).

Figure G.6. Relationship between residential density and VMT.

An analysis of land use and transportation at the regional scale by van de Coevering and Schwanen (2006), which looked at many of the same cities examined in an earlier study by Newman and Kenworthy (1989), found that higher regional density was associated with fewer vehicle miles traveled and fewer commute trips by car. Study results also indicated that higher employment density in the center city is associated with lower VMT, although this effect was weaker, and that a greater concentration of residents in the center city is associated with higher use of transit.

Although most prior work has focused on residential density, employment density can also affect travel behavior. One study by Chatman (2003) found that for each additional 10,000 employees within a square mile, average per-capita vehicle travel declines by about a half mile per day; for each additional 1,000 employees per square mile, the probability that an employee will drive to work rather than relying on an alternate mode declines by about 3%.

Use of transit. Growth in the population should lead to more travel, including more trips by transit and other alternative modes, but this does not necessarily result in a greater mode share for transit. As noted earlier, though, travel behavior varies among different segments of the population. For instance, transit use tends to be higher among lower-income groups (Santos et al. 2011) and recent immigrants. Thus, higher birthrates among lower-income families or higher-than-expected rates of immigration could contribute to an increased mode share for transit.

Growth in the economy also leads to increased travel, although here again there are potentially conflicting effects on transit mode share. Assuming that increases in social prosperity are broadly distributed, the mode share for transit could decrease; evidence from the literature indicates that as real income levels rise, individuals are less likely to rely on transit and more likely to drive (Santos et al. 2011). On the other hand, recent decades have witnessed growing economic inequality, accompanied by declines in inflation-adjusted income for many lower- and middle-income families. If this pattern persists, reduced income among a sizable share of the U.S. population could translate to an increase in mode share for transit and other non-automotive modes of travel.

Turning to land use, both density and the mixing of uses are known to have an effect on mode split. In denser areas, origins and destinations are often closer together, making it possible to choose non-automotive modes for a greater share of trips. Higher density also increases the pool of potential transit users within a given area or corridor, making if more financially feasible to develop faster transit options such as subways, light rail, and bus rapid transit with dedicated right-of-way. Finally, traffic congestion is generally more intense and parking rates can be considerably higher in dense urban areas, making transit more attractive in comparison (Sorensen et al. 2008).

With respect to the mixing of land uses, most studies have focused at the neighborhood level, where it is easier to develop suitable metrics. Ewing and Cervero (2001) reviewed 14 studies that assessed the impact of neighborhood-scale land use. While the studies looked at slightly different variables, they all compared the travel behavior of residents of neighborhoods with more traditional land-use patterns (mixed uses, good transit service, and pedestrian-friendly infrastructure) to those of suburban neighborhoods (exclusively residential, less transit service, and not pedestrian-friendly) with similar socio-economic demographics. The residents of traditional neighborhoods made fewer trips, shorter trips, and used transit and nonmotorized modes at higher levels.

Freight trucking. Holding other factors constant, a larger population will consume more goods and services, in turn leading to additional truck travel. Growth in the economy, likewise, results in additional trade flows and greater demand for goods movement via trucks and other modes. Bennathan, Fraser, and Thompson (1992), for example, used cross-sectional data for different developed countries to derive estimates of the elasticity of truck travel with respect to changes in GDP. Their results indicate an elasticity of approximately 1.02, suggesting that freight VMT increases one-for-one with GDP. The effects of changes in land use on truck travel, in contrast, are less clear. On the one hand, the reduction in distances between origins and destinations associated with higher density could reduce the length of some truck trips. On the other hand, trucking is typically the most efficient mode for goods movement within an urban context; as such, a shift toward larger and denser metropolitan regions might conceivably act to increase the overall mode share for trucking.

References

Barth, M. and K. Boriboonsomsin. 2009 (Fall). "Traffic Congestion and Greenhouse Gases." *Access*, 35: 2–9.

BEA. 2007. *Measuring the Economy: A Primer on GDP and the National Income and Product Accounts.*

BEA. 2012. SA1-3 Personal income summary. http://www.bea.gov/iTable/iTable.cfm?ReqID=70&step=1&isuri=1&acrdn=4 (accessed March 18, 2013).

BEA. 2013. Current-Dollar and Real Gross Domestic Product. National Economic Accounts. http://www.bea.gov/national/ (accessed March 18, 2013).

Bento, A. M., M. L. Cropper, A. M. Mobarak and K. Vinha. 2005. "The Effects of Urban Spatial Structure on Travel Demand in the United States." *Review of Economics and Statistics*, 873: 466–478.

BLS. 2013. Consumer Price Index: All Urban Consumers – (CPI-U). ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt (accessed March 18, 2013).

Bennathan, E., J. Fraser, and L. S. Thompson. 1992. *What Determines Demand for Freight Transport?* WPS 998. Infrastructure and Urban Development Department, The World Bank.

Brookings Institution. 2010. *State of Metropolitan America: On the Front Lines of Demographic Transformation.* Brookings Institution Metropolitan Policy Program. Washington, D.C.

Cao, X. 2009. "Disentangling the Influence of Neighborhood Type and Self-Selection on Driving Behavior: an Application of Sample Selection Model." *Transportation*, 36 (2): 207–222.

Chatman, D. 2003. "How Density and Mixed Uses at the Workplace Affect Personal Commercial Travel and Commute Mode Choice." *Transportation Research Record: Journal of the Transportation Research Board, No. 1831:* 193–201. Transportation Research Board of the National Academies, Washington, D.C.

Cheeseman Day, J. Undated. *National Population Projections.* http://www.census.gov/prod/1/pop/profile/95/2_ps.pdf (accessed March 18, 2013).

Dadush, U. and B. Stancil. 2009. "The G20 in 2050." *International Economic Bulletin.* http://www.carnegieendowment.org/publications/index.cfm?fa=view&id=24195 (accessed March 18, 2013).

DeLong, J. B., C. Golden, and L. F. Katz. 2003. "Sustaining U.S. Economic Growth." In: H. J. Aaron, J. M. Lindsay, and P. S. Nivola (eds.), *Agenda for the Nation.* Brookings Institution Press, Washington, D.C.

Downs, A. 2005. "Smart Growth: Why We Discuss It More than We Do It." *Journal of the American Planning Association*, 71 (4): 367–378.

EIA. 2013. *Annual Energy Outlook 2013.*

Ewing, R. and R. Cervero. 2001. "Travel and the Built Environment: A Synthesis." *Transportation Research Record: Journal of the Transportation Research Board, No. 1780:* 87–114. Transportation Research Board of the National Academies, Washington, D.C.

Florida, R.. 2009. "How the Crash Will Reshape America." *The Atlantic.* http://www.theatlantic.com/magazine/archive/2009/03/how-the-crash-will-reshape-america/307293/ (accessed March 18, 2013).

Florida, R. 2012. "The Uneven Geography of U.S. Economic Growth." *The Atlantic Cities.* http://www.theatlanticcities.com/jobs-and-economy/2012/10/uneven-geography-economic-growth/3067/ (accessed March 18, 2013).

Frey, W. H. 2009. *The Great American Migration Slowdown: Regional and Metropolitan Dimensions.* Brookings Institution, Washington, D.C.

Giuliano, G., A. Agarwal and C. Redfearn. 2008. "Metropolitan Spatial Trends in Employment and Housing: Literature Review." Paper prepared for the Committee on the Relationships among Development Patterns, Vehicle Miles Traveled, and Energy Consumption of the Transportation Research Board and the Division on Engineering and Physical Sciences of the National Academies, Washington, D.C.

Glaeser, E. L., M. E. Kahn, R. Arnott, and C. Mayer. 2001. "Decentralized Employment and the Transformation of the American City [with Comments]." *Brookings-Wharton Papers on Urban Affairs*, pp. 1–63.

Goodwin, P., J. Dargay, and M. Hanly. 2004. "Elasticity of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review." *Transport Reviews*, 24 (3): 275–292.

Heinberg, R. 2003. *The Party's Over: Oil, War, and the Fate of Industrial Societies.* New Society Publishers.

Hobbs, F. and N. Stoops. 2002. *Demographic Trends in the 20th Century.* CENSR-4. U.S. Department of Commerce.

Holtzclaw, J., R. Clear, H. Dittmar, D. Goldstein, and P. Haas. 2002. "Location Efficiency: Neighborhood and Socioeconomic Characteristics Determine Auto Ownership and Use-Studies of Chicago, Los Angeles, and San Francisco." *Transportation Planning and Technology*, 25 (1): 1–27.

Kim, S. 2007. "Changes in the Nature of Urban Spatial Structure in the United States, 1890–2000." *Journal of Regional Science*, 47 (2): 273–287.

Kuntsler, J. H. 2005. *The Long Emergency: Surviving the Converging Catastrophes of the Twenty-First Century.* Atlantic Monthly Press.

Leinberger, C. B. 2008. "The Next Slum?" *The Atlantic.* http://www.theatlantic.com/magazine/archive/2008/03/the-next-slum/306653/ (accessed March 18, 2013).

Lubowski, R. N., M. Vesterby, S. Bucholtz, A. Baez, and M. J. Roberts. 2002. "Major Uses of Land in the United States." Economic Information Bulletin No. (EIB-14). Economic Research Service, U.S. Department of Agriculture.

Myers, D. and E. Gearin. 2001. "Current Preferences and Future Demand for Denser Residential Environments." *Housing Policy Debate*, 12 (4): 633–659.

NAHB. 2006. Housing Facts, Figures and Trends. Washington, D.C.

NationalAtlas.gov. 2013. Federal Lands and Indian Reservations. http://nationalatlas.gov/printable/fedlands.html (accessed March 15, 2013).

Nelson, A. C. 2004. *Toward a New Metropolis: The Opportunity to Rebuild America.* Brookings Institution, Washington, D.C.

Newman, P., T. Beatley, and H. Boyer. 2008. *Resilient Cities: Responding to Peak Oil and Climate Change.* Island Press.

Newman, P. and J. Kenworthy. 1989. "Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey." *Journal of the American Planning Association*, 55 (1): 24–37.

Nickerson, C., R. Ebel, and A. Borchers. 2011. "Major Land Uses in the United States, 2007." Economic Information Bulletin No. EIB-89. Economic Research Service, U.S. Department of Agriculture.

Pozdena, R. 2009. "Driving the Economy: Automotive Travel, Economic Growth, and the Risks of Global Warming Regulations." Working Paper. Cascade Policy Institute, Portland.

Santos, A., N. McGuckin, H. Y. Nakamoto, D. Gray, and S. Liss. 2011. Summary of Travel Trends: 2009 National Household Travel Survey. Federal Highway Administration.

Shrestha, L. B. 2006 (May 5). *The Changing Demographic Profile of the United States.* Report to Congress. Congressional Research Service.

Shrestha, L. B. and E. J. Heisler. 2011 (March 31). *The Changing Demographic Profile of the United States (Update).* Report to Congress. Congressional Research Service.

Sorensen, P., M. Wachs, E. Y. Min, A. Kofner, L. Ecola, M. Hanson, A. Yoh, T. Light, and J. Griffin. 2008. *Moving Los Angeles: Short-Term Policy Options for Improving Transportation.* RAND Corporation, Santa Monica.

Steiner, C. 2009. *$20 Per Gallon: How the Inevitable Rise in the Price of Gasoline Will Change Our Lives for the Better.* Grand Central Publishing.

TRB. 2009. *Special Report 298: Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and* CO_2 *Emissions*. Transportation Research Board of the National Academies, Washington, D.C.

U.S. Census Bureau. Undated. Table Q-6. New Privately Owned Housing Units Completed in the United States, by Intent and Design. Characteristics of New Housing. http://www.census.gov/construction/nrc/pdf/compsusintenta.pdf (accessed March 21, 2013).

U.S. Census Bureau. 1995. Intercensal Estimates of the Total Resident Population of States: 1950 to 1960. Population Estimates. http://www.census.gov/popest/data/state/asrh/1980s/tables/st5060ts.txt (accessed March 20, 2013).

U.S. Census Bureau. 2000. Historical National Population Estimates: July 1, 1900 to July 1, 1999. Population Estimates. http://www.census.gov/popest/data/national/totals/pre-1980/tables/popclockest.txt (accessed March 18, 2013).

U.S. Census Bureau. 2005. Table 6: Interim Projections: Total Population for Regions, Divisions, and States: 2000 to 2030. 2005 Interim

State Population Projections. http://www.census.gov/population/projections/data/state/projectionsagesex.html (accessed March 20, 2013).

U.S. Census Bureau. 2009a. Table 1-C. Projections of the Population and Components of Change for the United States: 2010 to 2050 Constant Net International Migration Series (NP2009-T1-C). 2009 National Population Projections (Supplemental): Summary Tables: Constant Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009cnmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2009b. Table 1-H. Projections of the Population and Components of Change for the United States: 2010 to 2050 High Net International Migration Series (NP2009-T1-H). 2009 National Population Projections (Supplemental): Summary Tables: High Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009hnmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2009c. Table 1-L. Projections of the Population and Components of Change for the United States: 2010 to 2050 Low Net International Migration Series (NP2009-T1-L). 2009 National Population Projections (Supplemental): Summary Tables: Low Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009lnmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2009d. Table 1-Z. Projections of the Population and Components of Change for the United States: 2010 to 2050 Zero Net International Migration Series (NP2009-T1-Z). 2009 National Population Projections (Supplemental): Summary Tables: Zero Net International Migration Series. http://www.census.gov/population/projections/data/national/2009/2009znmsSumTabs.html (accessed March 20, 2013).

U.S. Census Bureau. 2011. Table 1. Intercensal Estimates of the Resident Population by Sex and Age for the United States: April 1, 2000 to July 1, 2010. US-EST00INT-01. Population Estimates. http://www.census.gov/popest/data/intercensal/national/nat2010.html (accessed March 18, 2013).

U.S. Census Bureau. 2012. Table 1. Projections of the Population and Components of Change for the United States: 2015 to 2060 (NP2012-T1). 2012 National Population Projections: Summary Tables. http://www.census.gov/population/projections/data/national/2012/summarytables.html (accessed March 18, 2013).

van de Coevering, P. and T. Schwanen. 2006. "Re-evaluating the Impact of Urban Form on Travel Patterns in Europe and North-America." *Transport Policy*, 1 3(3): 229–239.

Williams, B. T. 2004. *These Old Houses: 2001.* H121/04-1. U.S. Census Bureau; Office of Policy Development and Research, U.S. Department of Housing and Urban Development; and Economics and Statistics Administration, U.S. Department of Commerce.

APPENDIX H

Energy, Climate, and Transportation Funding Policies

To support the development of future transportation energy scenarios for this study, the preceding appendix considered past trends and future prospects for several broad socio-economic factors strongly linked to both energy use and travel demand—namely population, the economy, and land use. At the same time, future policy choices relating to energy, climate, and transportation funding may likewise exert significant influence on future energy and transportation outcomes. This appendix discusses current policy challenges along with potential policy responses being considered or debated at the federal level and in many states across the country. The material serves as background information for the federal policy elements of the future scenarios developed in Chapter 5, and it also offers an introduction to some of the strategies that states might find helpful in preparing for and responding to an uncertain energy future.

Note that there is some overlap between energy and transportation funding policies, most notably with respect to fuel taxes. Given the critical importance of fuel-tax revenue to state DOTs, however, it is helpful to discuss the two policy areas separately. The first section in this appendix thus focuses on ongoing policy debates relating to energy and climate change, while the second examines transportation funding and investment challenges and policy options. The final section considers the potential implications for policy options discussed throughout the chapter on the future transportation energy scenarios developed for the study.

H.1 Energy and Climate Policies

Energy and climate policies can be motivated by several objectives, such as reducing the cost of energy, improving energy security (reducing the amount of energy that must be imported from volatile and potentially hostile nations around the world), and reducing GHG emissions produced through the combustion of fossil fuels to mitigate climate change (Burger et al. 2009). High and volatile gasoline prices over the past several years have led to broadly shared concerns regarding the cost of energy. At the same time, ongoing conflicts and strife in the Middle East—the source of much of the world's petroleum—have translated into increased interest in policies to promote greater energy independence. (Note that some commentators choose to distinguish between the amount of energy that the United States imports as a whole, including from neighbors such as Canada and Mexico, and the amount that it imports from potentially hostile regimes in the Middle East and elsewhere, with the latter being viewed as most critical from the perspective of energy security.)

In contrast, policies aimed primarily at reducing greenhouse gas emissions—for example, by taxing carbon—remain much more controversial within the United States, particularly in the context of a still weakened economy. What is clear, however, is that any policies intended to achieve significant reductions in GHG emissions will need to encompass the transportation sector, which accounts for about 27% of all U.S. emissions (EPA 2011).

Certain policy options can be helpful in addressing energy cost, energy security, and climate mitigation simultaneously. For instance, policies aimed at increasing vehicle fuel economy will reduce the amount that consumers must spend on fuel per mile of travel and decrease aggregate fuel consumption for the nation as a whole, in turn reducing oil imports and greenhouse gas emissions from the transportation sector. Other policies, however, involve trade-offs. Boosting domestic oil production, for example, may reduce energy costs and promote greater energy independence, but possibly at the cost of greater GHG emissions. (Any increase in supply should in theory reduce price and in turn stimulate greater consumption of oil, though other countries may choose to moderate their petroleum production in response to U.S. production levels.) Levying higher fuel taxes or introducing carbon taxes, in contrast, would reduce demand—thus decreasing oil imports and GHG emissions—but would also increase the end-user cost that consumers pay for gasoline and diesel.

Policies involving such trade-offs are almost invariably controversial.

In this section are surveyed available policies—including some that have already been widely implemented and others that have only been discussed—for promoting the goals of reducing energy cost, promoting energy independence, or reducing GHG emissions. These can be broadly divided between policies that seek to expand domestic energy sources (supply-side policies) and policies that seek to reduce demand through greater fuel economy or by promoting the development and adoption of alternative fuels and vehicles (demand-side policies). Within the latter category, the discussion further distinguishes between regulatory approaches, subsidies, and pricing (taxation) policies. After discussing the range of potential policies, the section closes with commentary on current debates and the potential directions in which energy and climate policy could evolve in future decades.

H.1.1 Policies to Boost Domestic Energy Production

Policies in this category may focus on increasing the domestic production of petroleum and natural gas from both conventional and emerging sources such as bitumen or oil sands, shale oil (also known as tight oil), shale gas, coal-to-liquid fuel, and gas-to-liquid fuel (for further discussion see Chapter 3 and Appendix A). One potential strategy would be to remove current restrictions on areas open to energy development. For example, oil producers are not currently allowed to drill in the coastal waters off of many states, or on certain protected public lands such as the Alaskan National Wildlife Refuge. Likewise, the government could relax certain environmental and safety-related permitting requirements that act to constrain the pace of domestic petroleum and natural gas development. The government could also provide further tax incentives for exploration and development, as well as continue to subsidize ongoing research into unconventional fossil-based energy sources.

Active policy intervention to boost U.S. production of fossil fuels may in fact prove unnecessary. U.S. and North American production of both petroleum and natural gas have surged in recent years based on the development of improved technologies for enhancing recovery from existing wells and exploiting tight oil and shale gas resources. Recent projections by the IEA suggest that the United States could become the largest global oil producer by 2020 and—due in part to more-stringent fuel economy standards—a net oil exporter by 2030 (IEA 2012).

To the extent that domestic fossil-fuel production, and in turn world production, is increased, it should have some effect on lowering fuel prices. Yet the benefits may be limited by the fact that oil is traded on the world market and world demand is expected to increase dramatically with the continued growth of China, India, and other emerging nations. At the same time, other major oil producers around the world may choose to lower production rates in response to changes in U.S. supply in order to maintain higher prices. If global demand outpaces global supply, oil prices could still rise. Further, as illustrated most recently by the Deepwater Horizon spill in the Gulf of Mexico, there are significant environmental risks associated with drilling and transporting petroleum and other fossil fuels. Finally, if increased U.S. production succeeds in helping to lower world prices, it should also translate to greater overall demand, problematic from the perspective of reducing GHG emissions to mitigate climate change.

H.1.2 Reducing Petroleum Use and GHG Emissions Through Regulatory Mandates

Regulatory mandates govern the quantity and qualities of goods or harmful wastes produced by individual firms or an industry as a whole. Current federal mandates to reduce the demand for petroleum include CAFE standards, which have recently been harmonized with GHG emissions standards, along with RFSs; analogous mandates have also been developed at the state level.

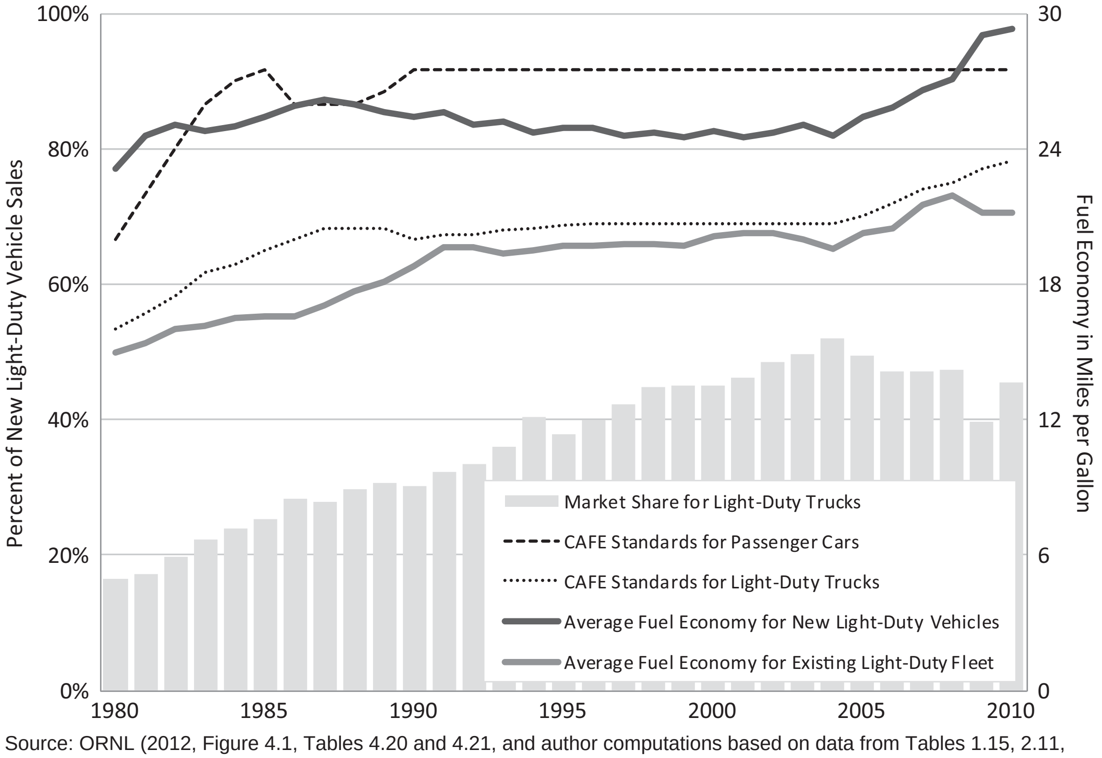
CAFE and GHG emissions standards. CAFE standards, in essence, require that the fleet of vehicles sold by auto manufacturers each year achieves specified average fuel economy standards. Firms that fail to meet the standards are subject to significant fines based on (a) the amount by which their fleet falls short of the specified fuel economy goal, and (b) the number of vehicles that they sell for the year. In the past, CAFE standards were separate for passenger cars and light-duty trucks, with the former being more stringent; more recent standards also factor in the vehicle's size (wheel-base footprint) in determining the applicable fuel economy target.

The EPA has traditionally been charged with measuring the fuel economy for different vehicle models, while NHTSA administers the overall program. With the most recent CAFE rulemakings—issued for model years 2012 to 2016 in April of 2010 and for model years 2017 to 2025 in August of 2012 (EPA 2012c)—federal fuel economy standards have been integrated or harmonized with GHG emissions standards determined by the EPA under authority of the Clean Air Act (CAA) along with the state of California, which holds a waiver to set its own emissions standards under the CAA.

CAFE standards were first adopted in the United States in 1975 as part of the Energy Policy and Conservation Act (EPCA). The Middle East oil embargo of 1973–1974 caused a major economic shock in the United States, highlighting the relative inefficiency of many American cars. At the time, the fuel economy of new cars had experienced a steady decline, from 14.8 mpg in model year 1967 to 12.9 mpg in 1974. Some gas guzzlers attained only 6 or 8 mpg. This shift had been driven at least in part by the availability of relatively inexpensive gasoline during the 1960s and early 1970s. CAFE standards offered a strategy to reverse this trend by requiring the production of cars with greater fuel economy levels, in turn reducing the nation's need to rely on foreign, and potentially volatile, sources of oil. In the intervening decades, energy independence has remained a key motivation underlying CAFE standards. In more recent years, given that GHG emissions vary in proportion to fuel consumption, stricter CAFE standards have also been viewed as a potentially powerful tool to help mitigate the threat of climate change. This additional objective of climate mitigation is now formalized with the harmonization of CAFE standards with EPA and California GHG emissions standards.

In the initial legislation, standards for passenger vehicles were set at 18 mpg by 1978, 20 mpg by 1980, and 27.5 mpg by 1985, with the goal of doubling overall fuel economy within 10 years. For much of the subsequent period, while standards were increased modestly on a few occasions, most efforts to increase fuel economy standards were blocked in Congress. Thus CAFE standards remained relatively static throughout the late 1980s, 1990s, and early 2000s. Over this same period, there was a significant rise in the market share for light-duty trucks (i.e., pickup trucks, sport utility vehicles, and minivans), which have been subject to lower CAFE standards than passenger vehicles. With the failure to further increase CAFE standards combined with a dramatic shift in vehicle purchase preferences, the average fuel economy of light-duty vehicles on the road increased only modestly over the past several decades, as shown in Figure H.1.

In just the past few years, however, with increasing oil prices and greater concerns about climate change, CAFE standards have been revised with much more demanding goals. Light-duty truck standards were amended in 2006, although the 9th Circuit Court of Appeals overturned the rules as not being sufficiently strict and directed NHTSA to implement further revisions. In December 2007, Congress passed the Energy Independence and Security Act (EISA) of 2007, calling for ratable increases in fuel economy from 2011 through 2020, culminating in an average of 35 mpg for all passenger cars and light-duty trucks by 2020. In May 2009, President Obama proposed a new national fuel economy program adopting uniform federal standards to regulate both fuel economy and GHG emissions while preserving the legal authorities of NHTSA, the EPA, and California (which had separately been pursuing a waiver under the CAA to set its own GHG emission standards). The resulting rules, issued by NHTSA and the EPA in April 2010, specify an average fuel economy of 35.5 mpg (39 mpg for passenger cars and 30 mpg for light-duty trucks)



Source: ORNL (2012, Figure 4.1, Tables 4.20 and 4.21, and author computations based on data from Tables 1.15, 2.11, and 3.7). Note that the dip in estimated average fuel economy for the existing light-duty fleet following 2007 is an artifact of changes in the way that the FHWA estimates annual vehicle miles of travel, as documented by ORNL (2012, Table 3.7).

Figure H.1. CAFE standards and light-duty fleet fuel economy, 1980–2010.

by 2016, accelerating the pace of improvement stemming from the 2007 EISA bill. Next, in July of 2011, the Obama administration announced an agreement with California and 13 large automakers to increase average fuel economy to 54.5 mpg by 2025, with the final rulemaking issued in August of 2012. The feasibility of this target is supported by a series of studies of advanced vehicle and powertrain technologies (e.g., Kasseris and Heywood 2007; Burke and Zhao 2010; NRC 2010; Burke, Zhao, and Miller 2011; Cheah and Heywood 2011), which indicate that it should be possible to achieve 60 mpg in midsize cars at reasonable cost.

President Obama's proposal in May of 2009 also directed NHTSA and the EPA to develop the Heavy-Duty National Program, which would for the first time specify fuel economy standards for combination tractors (the semi-trucks that typically pull trailers), heavy-duty pickup trucks and vans, and vocational vehicles (buses, refuse trucks, utility trucks, etc.). The proposed rulemaking for this program was issued by NHTSA and the EPA in November 2010 and finalized in September of 2011 (EPA 2012b). Under the standards, which take effect in 2014 and escalate through 2018, combination tractors will be required to achieve a 20% reduction in fuel consumption and greenhouse gas emissions, heavy-duty pickup trucks and vans will be required to achieve a 15% reduction, and vocational vehicles will be required to achieve a 10% reduction.

Many studies have examined the effects of CAFE standards as well as the prospects for instituting more-stringent future standards (e.g., Greene 1997, GAO 2000, NRC 2002, CBO 2003). Most agree that the program has been successful in reducing aggregate U.S. oil consumption. The NRC study, for example, found that CAFE standards were responsible for reducing oil use by about 2.8 million barrels per day as of the early 2000s (NRC 2002).

On the other hand, CAFE standards have been subject to considerable critique as well. Perhaps the most significant concern is that CAFE standards led auto manufacturers to produce smaller vehicles, which in turn created greater safety risks for motorists. Along these lines, the NRC study estimated, though not with full panel consensus, that CAFE standards contributed to an additional 1,300 to 2,600 traffic deaths in 1993 (NRC 2002). Based on safety concerns, and as mandated by the 2007 EISA, the most recent CAFE standards differentiate not only between passenger cars and light-duty trucks, but also between cars or trucks of different sizes as measured by vehicle footprint. The effect of linking fuel economy targets to vehicle footprint is that it motivates automakers to achieve the standards by making lighter and more efficient vehicles rather than by making smaller vehicles. The logic for this shift, as demonstrated in a recent analysis by Kahane (2012), is that safety outcomes in traffic collisions correlate with vehicle size—smaller vehicles are less safe, other factors held constant—rather than with vehicle weight.

Another concern is that CAFE standards have not been as effective as possible in reducing the nation's petroleum use, in part because the standards remained largely static between 1985 and the middle of the first decade of the 2000s. Finally, some have examined the question of whether fuel economy might be improved more cost-effectively through other policy options such as increased fuel taxes (e.g., CBO 2003).

Renewable fuel standards. As an additional means of reducing oil consumption and GHG emissions, the United States has adopted a national renewable fuel standard for ethanol and biodiesel. The first such standard, RFS1, was established under the Energy Policy Act of 2005 and called for at least 7.5 billion gallons of biofuels to be used each year in the United States by 2011. A revised and more demanding set of standards, RFS2, was developed in compliance with EISA. Finalized in February 2010, RFS2 defines four categories of renewable fuels: cellulosic biofuel, biomass-based diesel, advanced biofuels, and other renewable fuel. Fuels from each category must meet different standards for GHG reductions to qualify—cellulosic biofuels, for instance, must demonstrate a 60% reduction over the petroleum baseline—and there are separate volumetric targets for each category (EPA 2013a). In aggregate, RFS2 calls for biofuel use in the United States to increase from 11.1 billion gallons in 2009 to 36.0 billion gallons in 2022.

The method for enforcing RFS2 is complicated, involving the use of unique renewable identification numbers (RINs) attached to each gallon of qualifying biofuel produced in or imported into the country. RINs are transferred with intermediate fuel purchase transactions, and ultimately retail fuel blenders are required to accumulate a certain number of RINs—in essence, biofuel credits—in proportion to the total volume of fuel that they sell (referred to as their renewable volume obligation, or RVO). If blenders accumulate more RINs than they need in a given year, they can trade their extra credits to other blenders who have fallen short of their goals. Alternatively, blenders can hold on to the extra credits to use against the following year's requirements. If the renewable fuel mandate increases the overall cost of producing fuel—that is, if the price of biofuels exceeds the price of petroleum—blenders are expected to pass most of the additional costs along to consumers (Schnepf and Yacobucci 2010).

Related to the concept of renewable fuel standards is the prospect of implementing low-carbon fuel standards. Yeh and Sperling (2010) provide further discussion of this idea.

H.1.3 Reducing Petroleum Use and GHG Emissions Through Subsidies

Along with core investment in research and development, the U.S. government also encourages the production and adoption of advanced vehicle technologies and alternative fuels through subsidies provided to producers and consumers.

Tax credits for electric vehicles and plug-in hybrids. The federal government, along with some states, currently offers subsidies (rebates in the form of tax credits) for the purchase of electric or plug-in hybrid vehicles. The subsidies are intended to help early adopters defray the higher initial cost of such vehicles in comparison to conventional internal combustion engine technology. The federal tax credits were authorized in the Energy Improvement and Extension Act of 2008 and the American Clean Energy and Security Act of 2009. The subsidies are directed toward battery electric (such as the Nissan Leaf) and plug-in hybrid (such as the Chevy Volt) vehicles, which draw energy from a traction battery that stores at least 5 kWh of electricity and uses an off-board source of energy to recharge the battery. The tax credit for such vehicles is $2,500 plus $417 for each kWh of storage over 5 kWh up to a maximum of $7,500, and credit is only available on models from a given manufacturer until that manufacturer has sold 200,000 qualifying vehicles. The federal government is also subsidizing, through the end of 2013, up to 30% of the cost of installing home-based alternative-fueling infrastructure (capped at $1,000) and larger public refueling installations (capped at $30,000); this program encompasses electric charging infrastructure along with other alternative fuels such as natural gas, propane, and ethanol (EERE 2013).

Previously the federal government offered tax credits of up to $3,400 for hybrid vehicles like the Toyota Prius, but those tax credits expired in December of 2010. Many perceive that such subsidies helped the initial adoption rate for hybrid vehicles, and it is possible that subsidies will have a similar effect on initial sales for early electric and plug-in hybrids such as the Volt and the Leaf.

Some states have provided additional subsidies for advanced vehicle purchases. Among the more generous examples, California offers a $5,000 purchase rebate for battery electrics and $3,000 for plug-in hybrid vehicles, Oregon offers up to $5,000 for plug-in hybrid vehicles, and New Jersey offers up to $4,000 for battery electric vehicles. Many other states offer smaller rebates.

Car Allowance Rebate System (cash for clunkers program). The 2009 cash for clunkers program, which offered rebates to consumers who traded in an older vehicle with lower fuel economy for a new vehicle with higher fuel economy, provides another recent example of federal subsidies for the purchase of cleaner vehicles. The program was part of the economic stimulus package and sought to support struggling auto makers while simultaneously encouraging sales of more fuel-efficient models. Depending on the difference in fuel economy between the vehicle purchased and the vehicle traded in, the subsidy varied between $2,500 and $4,500. The program lasted several months and was well received, with the allocated funding of $3 billion being spent rapidly. The average fuel economy of the trade-in vehicles in was 15.8 mpg, while the average fuel economy of the purchased vehicles was 24.8 mpg, representing a prospective fuel savings of 36%. Yet analysis by several economists indicated that as a means of reducing GHG emissions, the program was very expensive, costing about $400 to $500 per ton of CO_2 equivalent emissions (Knittel 2009).

Ethanol subsidies. For a period of three decades, the United States subsidized the production of corn-based ethanol to blend into gasoline. The most recent subsidy, a tax credit of 45 cents per gallon, expired at the end of 2011. Owing in part to the nation's renewable fuel standard, however, business prospects for ethanol producers remain strong. In October 2010, the EPA increased the maximum amount of ethanol that can be blended into gasoline from 10% to 15% for use in cars of model year 2001 and later. This was an important ruling for the ethanol industry because it significantly increased the potential size of their market. There are also about nine million flex-fuel vehicles in the United States that can use E85 (blends of up to 85% ethanol), but most use much lower blends given the limited availability of E85 and—perhaps even more importantly—the cost and inconvenience of reduced vehicle range stemming from the lower energy content of ethanol versus gasoline. With more modest blends of 10% or 15%, however, governmental subsidization has clearly played an important role in boosting the production and consumption of ethanol.

H.1.4 Reducing Petroleum Use and GHG Emissions Through Taxes and Fees

The third demand-side policy approach, often referred to as "pricing," is to apply taxes or fees that are structured to encourage consumers to adopt conventional vehicles with higher fuel economy or to shift to alternate-fuel vehicles. Although subsidies can also be viewed as a form of pricing incentives, the focus here is on the use of taxes or fees that penalize certain vehicle and fuel choices—a potentially effective but also more controversial policy approach.

Feebate programs. Although direct vehicle subsidies, as described previously, appear to be successful in stimulating more rapid adoption, they are also quite costly to maintain over the long run. In a period of growing fiscal austerity, it is unclear that federal or state governments will have sufficient resources to offer pure rebates on an ongoing basis. Another option that might be considered, then, is a feebate program, under which consumers who purchase vehicles with lower fuel economy must pay a fee, and consumers who purchase more fuel-economical models or alternative-fuel vehicles receive a rebate. The fees paid by the former group offset the rebates provided to the latter, allowing the program to be revenue neutral to the government.

While the feebate concept has been studied thoroughly, there is limited experience with actual application (Bunch and Greene 2010, German and Meszler 2010). Only France and

Canada have implemented feebate programs, while Ireland, Germany, and the United States have in certain cases applied fees to vehicles with lower fuel economy without offering the corresponding rebates for vehicles with higher fuel economy.

Taxes on gasoline and diesel. Increasing current motor-fuel excise taxes on gasoline and diesel would provide an incentive for motorists to reduce total travel or to purchase vehicles with greater fuel economy or alternative-fuel vehicles. The federal government currently levies an 18.4 cents-per-gallon tax for gasoline and a 24.4 cents-per-gallon tax for diesel. States also collect excise fuel taxes and in some cases charge additional sales taxes on the purchase price of gasoline and diesel. According to recent calculations by API, the average motorist paid a total of 48.8 cents per gallon in federal and state taxes on gasoline as of January 2013, and a total of 54.4 cents per gallon on diesel (API 2013).

The majority of this tax burden is based on federal and state excise taxes as opposed to sales taxes. Because excise taxes are levied on a cents-per-gallon basis, the revenue—measured in real dollars per mile of travel—declines over time with inflation and fuel economy improvements. Over the past several decades, however, despite the fact that the United States has the lowest fuel taxes of any industrial country, elected officials have grown increasingly reluctant to take on the unpopular task of instituting fuel-tax increases to offset inflation and fuel economy gains. For example, federal fuel taxes were last raised in 1993, and many states have likewise not increased fuel taxes for many years. As a result, fuel-tax revenue, adjusted for inflation and fuel economy, has fallen precipitously. Fischer, Harrington, and Parry (2007), for example, estimate that real fuel-tax revenue per mile of travel has declined by about 40% since 1960. With reduced real rates, fuel taxes are no longer as effective at influencing traveler behavior or at raising necessary highway revenue.

If the purchase price of gasoline and diesel were raised by instituting substantial motor-fuel excise tax increases, consumers would be likely to invest in more fuel-efficient conventional vehicles or alternative-fuel vehicles and change their travel behavior to reduce their consumption of oil. Because a fuel-tax increase would represent a permanent increase in the retail cost of fuel, it would tend to induce greater efforts at conservation than similarly sized transitory price increases generated by oil market fluctuations. It would also create greater opportunities for the emergence of cost-competitive alternative-fuel vehicle options; that is, such options would then be competing against reliably more expensive gas and diesel. The next section discusses fuel taxes at greater length in the context of highway revenue sources.

Pricing greenhouse gas emissions. From a theoretical perspective, many economists view pricing policies as a more efficient means for reducing GHG emissions than regulatory mandates such as CAFE standards (Fischer, Harrington, and Parry 2007). However, note that, as Greene, German, and Delucchi (2008) argue, consumers do not always act in an economically rational manner, potentially undermining the case made by economists for pricing.

The idea behind pricing carbon dioxide and other GHGs (often described as carbon pricing, carbon fees, or carbon taxes) is that the incentives embodied in pricing can motivate emission reductions at lower overall societal cost given the flexibility in how the emissions can be reduced. Two policies involving carbon pricing have been considered to date: carbon fees and carbon cap and trade.

Carbon fees involve a direct tax on the emission of GHGs into the atmosphere in order to create a strong financial incentive for reducing emissions. Such fees could in theory be imposed when fuels are extracted from the earth, when they are imported, when they are processed, or when they are consumed. From an economic perspective, the level of the fee would ideally approximate the damages caused by the emissions, although in practice this is extremely difficult to quantify. An important effect of carbon fees would be to level the playing field such that cleaner fuels (i.e., fuels that produce less GHGs) or conservation technologies could better compete in the marketplace. From the perspective of mitigating climate change, one of the main drawbacks of carbon fees is that the approach does not provide for a specific limit on overall emissions.

In contrast, a cap-and-trade policy would not impose direct costs on the carbon content of fuels; rather, it would place a limit (the cap) on overall GHG emissions. Allowances would then be distributed, either for free or via auction, that grant the holder rights to emit a certain amount of GHGs. For example, an allowance might entitle a company to emit 1 ton of CO_2 or to sell fuel that, once combusted, would result in 1 ton of CO_2 emissions. Companies would then be free to buy and sell allowances as needed. If it were expensive for one company to reduce its GHG emissions, that company could purchase allowances from another company that could reduce its emissions at lower cost. It is this ability to trade permits, in the view of economists, that promotes greater overall economic efficiency. As years pass, the number of permits would be gradually reduced, resulting in corresponding overall reductions in GHG emissions.

The CAA employed cap-and-trade policy to reduce emissions that contributed to acid rain. Title IV of the act set a goal of reducing SO_x emissions from power plants by 10 million tons per year below 1980 levels. Phase I began in 1995, and data show that emissions were reduced by roughly 40%. Phase II began in 2000 and further constrained emissions from over 2,000 power plants (EPA 2012a). In 2005, the EPA implemented the Clean Air Interstate Rule to reduce SO_x and NO_x from power plants whose emissions drift from one state to another. This rule also relies on a cap-and-trade system to reduce these emissions by 70% (EPA 2013b).

In recent U.S. debates, cap-and-trade policy has been favored over carbon fees due to the perceived successes of cap-and-trade policies for acid rain. Additionally, unlike carbon fees, for which the resulting emissions reductions would be difficult to predict, a cap-and-trade system offers greater certainty in actual emissions reductions. In 2009 the U.S. House of Representatives passed H.R. 2454, American Clean Energy and Security Act of 2009. This bill would have used cap and trade to reduce greenhouse gas emissions as part of an overall attempt to create clean jobs, promote energy independence, and reduce global warming. The bill was not passed by the Senate, however, and therefore did not become law (Govtrack, undated). Absent more aggressive federal action, the state of California has now implemented its own multi-sector carbon cap-and-trade program (CARB 2013), while the Eastern Seaboard's Regional Greenhouse Gas Initiative has established a cap-and-trade program for electric power. Other multi-state efforts to explore and develop cap-and-trade programs are the Western Climate Initiative and the Midwestern Greenhouse Gas Reduction Accord (UCS 2012).

Either form of carbon pricing—carbon taxes or cap and trade—would ultimately increase the cost of emitting GHGs based on the combustion of fossil fuels. From the perspective of motorists, the effect would be to increase the cost, in cents per mile, of driving. The magnitude of the effect would depend on (a) the cost of greenhouse gases (typically expressed as \$/metric ton of CO_2 equivalent) based on either the tax or the market price for trading emissions permits, (b) the amount of GHG emissions created by producing, transporting, and consuming each unit of the fuel (i.e., well-to-wheels emissions), and (c) the vehicle's fuel economy. An electric vehicle running entirely on renewably generated power, for example, would face no additional cost, while a conventional vehicle with poor fuel economy would face higher costs.

Even with today's conventional vehicles, however, the overall effect of pricing greenhouse gas emissions on the cost of driving is expected to be rather modest. To illustrate, Table H.1 computes how carbon pricing, under several cost-per-ton scenarios, could affect the marginal cost of driving a conventional gasoline-powered vehicle. Per EPA (2010) estimates, the calculations assume that each gallon of gas produces 11,294 grams of CO_2-equivalent emissions on a well-to-wheels basis. At this rate, it takes 88.5 gallons to produce a metric ton of emissions. To estimate how a tax on greenhouse gas emissions could affect the per-mile cost of driving a gasoline-powered vehicle, then, one simply calculates the cost of emissions (in \$/metric ton per CO_2 equivalent) divided by 88.5 gallons divided by the vehicle's fuel economy measured in miles per gallon.

In Table H.1, this calculation is provided for a vehicle that averages 27 miles per gallon (corresponding roughly to CAFE standards for passenger vehicles over much of the past 25 years) and for a vehicle that averages 54.5 miles per gallon (corresponding to the target average vehicle fuel economy in 2025 under the recent CAFE revisions). To put the cost of emissions in context, the table also estimates the per-mile cost of gas to fuel the car as well as the per-mile cost of federal and state fuel taxes. These latter calculations assume a purchase price of \$4 per gallon, including \$3.50 for the fuel itself and another 50 cents in federal and state taxes [close to the average tax burden reported by API (2013)].

As shown in Table H.1, any change in the marginal cost of driving that would result from pricing GHG emissions could prove to be quite modest. For both the \$10 and \$20 per-ton scenarios, the incremental cost of GHGs would remain substantially lower than the cost associated with fuel taxes or fuel itself. Still, even a small increase in the cost of driving would provide some incentive for travelers to purchase vehicles with higher fuel economy or to switch to lower-carbon alternative fuels.

H.1.5 Future Energy and Climate Policy Directions

U.S. climate and energy policy over the past several decades could be described as conflicted, a reflection of the seemingly inevitable competition among stakeholder interests seeking to influence policy choices based on their own goals. On one hand, for example, the federal government provides considerable research and development funding to support the emergence of cleaner energy and fuel sources and technologies, in turn reducing dependence on foreign oil and mitigating climate change. On the other hand, the United States also continues to subsidize oil exploration and the development of unconventional fossil fuels such as oil sands, shale oil, and

Table H.1. Effect of carbon pricing on cost of driving with gasoline.

	Marginal Cost in Cents/Mile				
Miles per Gallon	**Gasoline at \$3.50/gallon**	**Gas Taxes at \$0.50/gallon**	**GHGs at \$10/ton CO_2 Equivalent**	**GHGs at \$20/ton CO_2 Equivalent**	**GHGs at \$100/ton CO_2 Equivalent**
27	12.96	1.85	0.42	0.84	4.18
54.5	6.42	0.92	0.21	0.41	2.07

coal-to-liquid fuel that, while supporting the goal of energy independence, could severely undermine efforts to mitigate climate change.

U.S. policy could also be characterized as being relatively moderate, in the following sense. Most federal energy and climate policies to date—for example, investment in research and development, CAFE standards, renewable fuel standards, and tax credits for ethanol production and electric vehicle purchases—have involved either subsidies or regulations on industry. In contrast, the federal government has generally eschewed the more controversial—though potentially more effective—approach of structuring taxes or fees with the aim of influencing consumer behavior, although certain states such as California have begun to move in this direction. The future trajectory of energy and climate policy in the United States thus rests on two key issues that remain very much unresolved, with strongly divergent views among different elements of the electorate.

Relative prioritization of policy goals. With anticipated increases in U.S. oil and natural gas production, energy security concerns appear to be receding. What remains unresolved, however, is whether the nation's policies should aim primarily at low energy costs or instead focus more strongly on climate change. Some policy options such as CAFE standards can simultaneously reduce the energy cost of travel and mitigate climate change. Many other policies, however, such as support for petroleum production or the application of carbon pricing, involve trade-offs between the goals of reducing energy cost and climate mitigation. Should a greater degree of agreement regarding the relative prioritization of these goals emerge—perhaps in response to changing economic conditions or new information about climate change—it could set the stage for significant shifts in federal energy and climate policies.

Application of pricing policies. This leads to the second question of whether the application of pricing to achieve energy and climate goals will achieve broader adoption among states or at the federal level. Carbon pricing, for instance, could support even more rapid progress toward energy independence and climate change mitigation, but to date this idea has proven too divisive to gain sufficient support for federal implementation.

H.2 Transportation Funding and Investment Policy

The discussion now turns to transportation funding and investment policy. Similar to energy and climate policy, choices about how to raise and spend transportation funds can exert a strong influence on both energy consumption and travel behavior. This section begins with an overview of principles and themes that have guided transportation revenue and investment policies in the United States over much of the past century. It then looks at more recent shifts in highway and transit funding over the past several decades. The overarching story is that certain of these recent trends—most notably the steady shift from fuel taxes and other user fees to greater reliance on general sources of revenue—could make it difficult to sustain adequate funding in the coming decades, in turn prompting decision makers to consider major reforms in transportation funding policy. The section concludes by examining ongoing revenue policy debates and exploring how potential shifts in funding mechanisms and investment choices could affect energy use and travel demand in the coming decades.

H.2.1 Historical Themes in Transportation Revenue and Investment

Roads and transit systems are typically planned and funded by the public sector based on revenue raised at federal, state, and local levels. Common funding sources are user fees (e.g., fuel taxes or transit fares) and various general revenue sources (e.g., property taxes and sales taxes). Looking back over much of the past century, several themes in surface transportation funding and investment can be discerned: strong adherence to the principle that users of the transportation system should pay for its construction and upkeep, a willingness to increase taxes and fees as needed to improve transportation systems, the hypothecation of transportation revenue, and the diversification of funding sources.

Adoption of the user-pays/user-benefits principle. The evolution of highway funding policy in the United States has been guided by the principle that those who benefit from the road network should pay, in proportion to use, for building and maintaining the system (Wachs 2003). In the early 1900s, as the adoption of cars and trucks began to accelerate, demand for new roads to serve these vehicles grew rapidly. With most households not yet owning vehicles, it was generally viewed as fair to ask those who used the system to pay for its development and maintenance, as opposed to relying on general revenue sources (Brown et al. 1999).

While tolls were one way to levy usage fees, broad application of tolling would have led to high administrative costs, congested traffic surrounding toll plazas, and the difficulty of preventing theft of toll-box revenue. Searching for a more efficient alternative to tolls, in 1919 the state of Oregon pioneered the application of motor-fuel taxes to raise highway revenue. Fuel-tax collections, like tolls, would be paid by those who used the road network, and further would vary in rough proportion to the amount of travel. At the same time, collecting fuel taxes from a small number of fuel wholesalers would be much cheaper and easier to enforce than collecting tolls from individual drivers on different stretches of road.

These proved to be compelling advantages; the federal government first levied fuel taxes in the 1930s, and by 1940 all of the states had followed Oregon's lead (Brown et al. 1999). In the intervening decades, fuel taxes evolved to become the most significant source of highway revenue; in 2004, for example, federal and state motor-fuel excise taxes collectively generated roughly $68 billion, representing about 64% of all highway user fees and about 50% of all highway revenues (TRB 2006).

The principle that transportation should be funded by those who directly benefit from the system has analogs in the funding of local roads and transit systems. Many local governments, for example, have relied on property taxes to help pay for the local road network. Although property taxes are not related to direct use, the logic is that property owners benefit—through enhanced land values—from access provided by local roads. Local transit systems, in turn, have historically relied on user fees, in the form of transit fares, to help fund operations and capital improvements.

Increasing taxes and fees as needed. Throughout much of the past century, federal and state fuel taxes, typically levied on a cents-per-gallon basis, were periodically raised to account for inflation and, in more recent decades, improved fuel economy. Initially set at 1 cent per gallon in 1932, for example, the federal excise tax on gasoline has been increased nine times in the intervening years—most recently in 1993—and currently stands at 18.4 cents per gallon. Many states, in turn, have instituted similar fuel-tax increases as needed or have indexed their fuel taxes to increase with inflation. Other revenue sources, such as registration fees and transit fares, have also been periodically increased. Still others, such as property and income taxes, increase automatically with inflation.

Hypothecation of transportation revenue. To garner public support for levying and increasing fuel taxes to pay for roads, the federal government and most states have chosen to hypothecate (dedicate) fuel-tax revenue for transportation investments. In essence, this represents a pact between road users and the government that fuel taxes will be treated as a user fee; road users agreed to fund the road network through fuel taxes, and the government in turn agrees to invest the resulting revenue in construction and maintenance projects that benefit road users. With the Highway Revenue Act of 1956, Congress created the federal Highway Trust Fund account to serve as a repository for federal fuel-tax receipts, which are in turn allocated to states to fund the Interstate highway system and other federal-aid highways. Many states and local areas have likewise created dedicated accounts for allocating revenue from fuel taxes and other funding sources to investments in roads or transit systems, which is an arrangement that is relatively rare outside of the United States.

Diversification of funding sources. To augment fuel taxes and transit fares, federal, state, and local governments have gradually broadened the set of revenue sources for funding surface transportation. In addition to excise taxes on gasoline and diesel fuel, for example, the HTF receives funding from taxes on the sale of trucks, trailers, and truck tires, along with an annual heavy-vehicle use fee for trucks. States and local governments rely on an even more diverse set of revenue mechanisms (Cambridge Systematics et al. 2006). These include (a) direct user fees such as tolls, weight-distance truck tolls, container fees, and transit park-and-ride fees; (b) indirect user fees such as sales taxes on motor fuels, license and registration fees, vehicle personal property taxes, vehicle sales taxes, taxes on automotive parts and supplies, vehicle lease taxes, and rental car taxes or surcharges; (c) beneficiary taxes or fees such as property taxes, development impact fees, special assessment districts, and transit advertising, leases, and concessions; and (d) general revenue sources such as income taxes, sales taxes, general obligation bonds, and taxes on tobacco, alcohol, and gaming.

H.2.2 Recent Trends in Highway Funding

Historical reliance on federal and state fuel taxes hypothecated for highway investment provided stable and sufficient funding to develop the Interstate system, an engineering feat that contributed enormously to the nation's economic growth and prosperity. The past few decades, however, have been marked by several significant shifts in highway funding. These include diminished emphasis on fuel-tax revenue, devolution of funding responsibility, and reduced reliance on user fees overall.

Decline in motor-fuel tax revenue in relation to travel. The ability of excise motor-fuel taxes to raise sufficient revenue has been increasingly undermined, in recent years, by structural and political limitations. Most fuel taxes are levied on a cents-per-gallon basis and must be raised periodically to offset the effects of inflation and improved fuel economy. Beginning with the tax revolts of the late 1970s, however, voter sentiment has hardened against tax increases in any form, and elected officials have correspondingly grown less willing to take on the politically unpopular task of raising fuel taxes. Federal fuel taxes, for example, were last increased in 1993, and many other states have allowed their fuel taxes to stagnate as well. As of 2010, based on the most recent available data from the FHWA, 19 states had not increased their excise fuel-tax rates for gasoline or diesel since the 1990s, while another six states had not raised their rates since the 1980s or earlier (OHPI 2011).

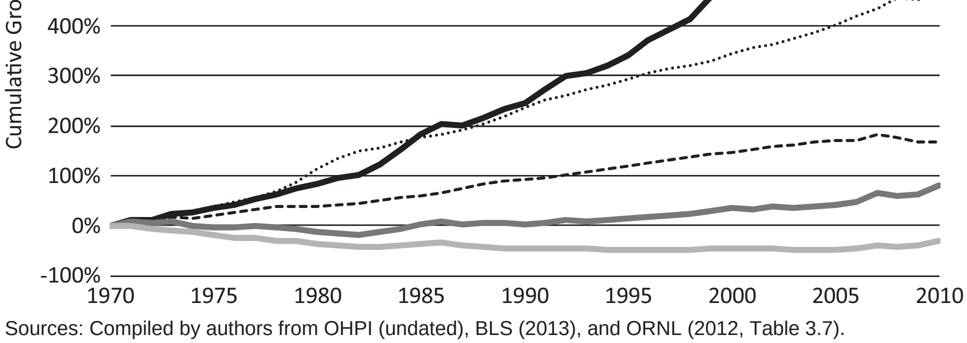
Failure to increase per-gallon fuel taxes to offset inflation leads, over time, to the erosion of real revenue per gallon of fuel. Since they were last increased in 1993, federal excise fuel taxes have lost more than a third of their value due to inflation (NSTIFC 2009). The effects of inflation have been further compounded by gains in vehicle fuel economy, which reduce the amount of revenue collected per mile of vehicle travel. Between 1970 and 2010, for example, total travel on the nation's roads increased by about 167%, while total fuel consumed by on-road vehicles increased by just 92% (ORNL 2012, Tables 1.15 and 3.7). Recent projections from EIA, which factor in more-stringent corporate average fuel economy standards along with a modest shift to alternative fuels in the coming years, are that growth in VMT will outpace growth in gasoline and diesel consumption to an even greater extent in future decades (EIA 2013).

The effects of inflation and improved fuel economy, along with the failure to increase fuel taxes to account for these factors, have combined to reduce real fuel-tax revenue per mile of travel. Given the significant share of highway revenue generated by federal and state fuel taxes, this has in turn undermined total highway revenue, in real terms, in relation to total travel. Figure H.2 illustrates the growth, over the past four decades, in total nominal highway revenue (all sources of federal, state, and local user fees along with general revenue and bond sale proceeds directed toward highway spending), the consumer price index (as a measure of inflation), VMT, real revenue (adjusted for growth in the CPI), and real revenue per mile of travel (adjusted for CPI and VMT).

Between 1970 and 2010, as shown in the figure, while total nominal revenue has increased by nearly 900%, cumulative inflation as measured by the CPI has exceeded 450%, and total VMT has increased by almost 170%. Combining these factors together, real revenue per mile of travel declined by nearly 50% between 1970 and the middle of the first decade of the 2000s.

In just the past few years, real revenue per VMT has rebounded somewhat due to both a decrease in VMT and a rapid increase in nominal revenue, but these outcomes may prove ephemeral. The recent decline in VMT reflects actual reductions in travel based on spiking fuel prices followed by the deep recession as well as a change in the way that the FHWA computes VMT (per notes provided with ORNL 2012, Table 3.7). Turning to the funding side of the equation, in 2008 and 2009, Congress transferred a total of $15 billion from the general fund to the HTF in order to keep it solvent. Then, beginning in 2009, under ARRA (also known as "the stimulus"), Congress directed tens of billions of additional dollars to transportation programs to help rejuvenate the economy. Given the current federal focus on debt reduction, the prospects for significant future injections of general revenue to shore up transportation programs seem limited. Assuming that total travel rebounds with the economy in the coming years, then, the measure of real revenue per VMT could decline again to the level of the middle of the first decade of this century—that is, a roughly 50% reduction from 1970.

Devolution of funding responsibility. One effect of the failure to increase federal and state fuel taxes commensurate with inflation and fuel economy gains has been to shift a greater responsibility for transportation funding to local jurisdictions (Goldman and Wachs 2003). Over the past half century, since the inception of the Interstate highway system, both the federal and state shares of highway funding have generally declined, while the local share has risen. Through the 1960s and early 1970s, at the height of the Interstate construction era, federal and state governments provided about 80%



Sources: Compiled by authors from OHPI (undated), BLS (2013), and ORNL (2012, Table 3.7).

Figure H.2. Growth in highway revenue, inflation, and VMT, 1970–2010.

of all highway revenue, with local governments accounting for the remaining 20%. By the middle of the first decade of the 2000s, with the erosion in fuel-tax revenues and preceding the actions of Congress to shore up the HTF with transfers of general revenue, the share of highway funding provided at the federal and state levels had decreased to about 72%, while the local share had grown to 28% (computations based on data from OHPI, undated). Note, however, that the increasing share of local highway funding has not been sufficient to offset the overall decrease in total funding in relation to travel; as indicated previously, real highway revenue adjusted for total VMT has fallen considerably over the past four decades.

Reduced reliance on user fees. Another effect of diminishing federal and state fuel taxes, given the significant share of total highway revenue for which they account, has been reduced overall reliance on user fees. Based on analysis of FHWA data, user fees accounted for more than 78% of all highway revenue in 1960, for about 60% in 1980, and for just under 50% in 2010 (OHPI 1997, 2012). This decline appears to reflect a reduction in the share of fuel-tax revenue at the federal and state levels combined with an increased share of general revenue stemming from state and local sources.

Search for alternative revenue sources. As the erosion of real fuel-tax revenue in relation to VMT has accelerated, decision makers and analysts have sought to identify alternative revenue mechanisms to replace or augment fuel taxes. Examples of discussions in this vein are those found in Whitty (2003), TRB (2006), Cambridge Systematics et al. (2006), NSTPRSC (2007), and NSTIFC (2009). Although the particulars vary from one study to the next, most of these analyses have identified various forms of direct user fees—for example, facility-based tolls, mileage-based user fees, weight-distance truck tolls, and congestion tolls—as being among the more promising longer-term revenue mechanisms to pursue. One can characterize user fees as being equitable in the sense that they align the costs of paying for roads with the benefits received from use of the roads, and they also encourage more efficient use of the road network by creating a financial incentive for drivers to forgo their least-valued trips (Wachs 2003). A key drawback of direct user fees, however, is that they often face more challenging public acceptance barriers in comparison to sales taxes, general obligation bonds, and other forms of general revenue. This explains, in part, why the recent trend in highway finance has been toward greater reliance on general revenue rather than on user fees.

H.2.3 Recent Trends in Transit Funding

As with roads and highways, current transit revenue mechanisms may face challenges in their ability to provide a sustainable and expanding source of funding in the coming decades. Most transit services were privately provided during the early 1900s and were largely reliant on fare-box revenue to fund capital investments and operations. Following World War II, however, as automobile ownership accelerated and the relative attractiveness of transit deteriorated, privately provided transit services became less viable. Recognizing that transit still represented a valuable service for many residents, the public sector began to assume control of many local transit systems. Since that shift, though fare-box revenue has remained an important source of income, there has been significant growth in public subsidization of transit services by all levels of government. And in contrast to the highway sector, growth in transit funding has exceeded growth in ridership—in other words, per-passenger subsidies have been rising. With fiscal challenges faced at all levels of government, it is not clear that this trend will continue indefinitely.

Significant and increasing public subsidies. Between 1988 and 2010, based on data from APTA, the share of annual transit capital and operating expenses derived from user fees (transit fares) and other direct sources of agency revenue (such as advertising and concessions) has declined from about 33% to just under 26% (APTA 2012, Table 71). Remaining funds are provided, in roughly even shares, by federal, state, and local subsidies. As of the early 1980s, most federal subsidies flow through the Mass Transit Account within the HTF, which receives approximately 15% of HTF revenue.

Growth in transit funding relative to ridership. In contrast to the decline in real highway revenue relative to vehicle travel, transit funding has increased faster than ridership in recent decades. Based on data from APTA and BLS, transit ridership measured in passenger miles has increased by about 31% since 1996, while total transit capital and operating expenditures have increased, in real terms, by about 57% over the same period (APTA 2012, Tables 3 and 56; BLS 2013). At first blush this seems encouraging; transit funding has increased faster than ridership, suggesting that transit operators should not be facing financial difficulties. In fact, the data hint at two troubling trends. Closer examination of APTA data reveals that, since the mid-1990s, total annual transit expenditures in real terms (APTA 2012, Table 56, adjusted for inflation based on BLS 2013) have increased faster than transit capacity as measured by vehicle revenue miles (APTA 2012, Table 9), which has in turn risen faster than ridership in passenger miles (APTA 2012, Table 3). In other words, the cost of providing each unit of transit capacity is increasing, in real terms, while the level of ridership supported by each unit of capacity is decreasing.

With roughly three-quarters of all transit revenue now stemming from federal, state, or local subsidies, these numbers portend challenges in securing adequate transit revenue in the future. With intense ongoing debate over the federal debt, and with budgetary shortfalls already confronting many states and local areas, voters and elected officials may consider the allocation of increasingly scarce general revenues from a broad range of potential public investments. Assessment of the relative costs and benefits of alternate investment choices could factor into this debate.

H.2.4 Recent Trends in Highway and Transit Investment

Examination of surface transportation investments over the past several decades reveals several important trends: insufficient overall investment, increased diversion of federal highway revenue to other uses, disproportionate investment in transit relative to use, and diminished investment in bus service relative to other modes of transit.

Insufficient overall investment. Relatively recent estimates suggest that the gap between projected federal, state, and local revenue and the amount needed to maintain the nation's transportation networks in their current conditions falls in the range of $57 billion to $118 billion per year, while the shortfall in funding needed to substantially improve the networks falls in the range of $113 billion to $185 billion per year (NSTIFC 2009). Absent new sources of funding, the prospects for meeting these needs are bleak. As noted previously, insufficient federal fuel-tax revenue led the Congress, in 2008 and 2009, to transfer a total $15 billion in general revenue to keep the HTF solvent; in the later stimulus bills, Congress provided further infusions of general funds into the federal surface transportation program. At the state level, where budgets must be balanced each year, many transportation projects have simply been put on hold in the face of growing revenue shortfalls.

Diversion of federal highway revenue. When the HTF was established in 1956 to fund the Interstate system, federal excise fuel taxes on gasoline and diesel were designated as the main source of HTF funding. (Additional truck-related fees were hypothecated to the HTF.) In the intervening decades, through a series of federal transportation bills, the share of HTF funds directed to non-highway uses—including transit, air quality mitigation, and bicycle and pedestrian improvements—has gradually grown. Based on analysis of a study by the GAO (2009) documenting HTF expenditures in fiscal years 2004 through 2008, Poole and Moore (2010) recently estimated that as much as 25% of HTF funds may be allocated to projects not directly related to highway and bridge capacity, maintenance, operations, and safety. Setting aside debates over the merits of such projects, Poole and Moore argue that the diversion of fuel-tax revenue for other modes has made it more difficult to secure the support of road user groups for increasing federal fuel taxes to keep pace with inflation and total vehicle travel.

Disproportionate investment in transit relative to use. Total U.S. investment in highways greatly exceeds total investment in transit. In 2010, for example, highway expenditures across all levels of government—inclusive of capital outlays, maintenance and traffic services, administration and research, safety and law enforcement, interest on debt, and bond retirements—totaled around $205 billion (OHPI 2012), while total transit investments in the same year were about $55.6 billion (APTA 2012, Table 56). On the other hand, transit receives a disproportionately large amount of funding relative to its use. Table H.2, based on data from the 2009 National Household Travel Survey (see Santos et al. 2011), compares the mode share for private automobiles and transit in terms of person trips and person miles for total travel and commute travel. As shown, the ratio of personal vehicle travel to transit travel ranges from 25 to 1 to 59 to 1, depending on the metric one uses, while the ratio of highway investment to transit investment is closer to 3.7 to 1.

The disproportionate investment in transit relative to mode share stems from the fact that many decision makers view transit as an attractive and politically viable strategy for addressing a spectrum of worthy social objectives. These include providing mobility for those unable to drive, enhancing access to employment, enabling denser development and more livable communities, easing traffic congestion, reducing reliance on foreign oil, and limiting the emissions of harmful greenhouse gases and local air pollutants (Taylor 2010). However, the ability of transit to deliver on some of these aims depends on ridership levels, which to date remain weak in many cities.

Declining emphasis on bus transit. Within the context of transit, a final trend worth noting is the diminishing share of investment devoted to bus service. Over the past two decades, according to APTA, the share of transit investment devoted

Table H.2. Mode share for personal vehicles and transit.

Mode	Person Trips		Person Miles	
	Total	Commute	Total	Commute
Private vehicle	83.4%	91.4%	88.4%	94.5%
Transit	1.9%	3.7%	1.5%	2.6%
Private vehicle-to-transit ratio	44:1	25:1	59:1	36:1

Source: Santos et al. (2011, Tables 9 and 12).

to bus service has declined from about 50% to about 42% (APTA 2012, Table 57). The combined share of investment in commuter, heavy, and light rail has grown slightly during this period, while the share devoted to demand-responsive transit (also known as paratransit) has increased dramatically, expanding from 3% to 11%. The shifts in funding have been mirrored by shifts in ridership as well. Since 1992, the share of transit passenger miles served by bus has declined from about 51% to less than 39%. The combined share for rail transit modes has risen from 47% to about 55% over this same period, while the share for other transit modes has gained just a few percentage points (APTA 2012, Table 4).

H.2.5 Future Funding and Investment Policy Options

As noted previously, growing gaps between transportation investment needs and available revenue—owing in large part to the decline in real fuel-tax revenue in relation to total travel—have prompted discussion of a broad range of alternate policy directions for the future. This section briefly reviews some of the ideas and concepts under debate. Note that many of the strategies that states might choose for increasing revenue are discussed at greater length in Appendix I and summarized in Chapter 7.

Federal, state, local, and private roles in funding transportation. Failure to increase federal and state fuel taxes to keep pace with inflation and improved fuel economy has led to an increased role for local governments in funding transportation investments. With the Interstate system now largely complete, some might argue that a shift toward greater local responsibility is appropriate. Under this line of reasoning, local officials are in a better position to judge what investments will be most helpful, and residents will be more willing accept revenue measures when they know that the money will be invested in local improvements and that they can hold their officials responsible.

Yet there are at least three significant drawbacks to increased reliance on local revenue sources. First, much of the Interstate system is reaching the end of its 50-year design life and will soon need to be completely rebuilt, a task of national importance that is likely to be far more expensive than the initial construction (Regan and Brown 2011). Second, greater reliance on local resources has to date corresponded with reductions in total revenue relative to total travel; that is, increases in local funding have been insufficient to offset overall reductions in state and especially federal funding. Third, following recent trends, increased devolution of funding responsibility to local areas is likely to result in greater reliance on general revenue sources such as sales taxes. In comparison to fuel taxes and other forms of user fees, general revenue sources are less equitable (payments are not aligned with benefits received) and do not promote economically efficient use of the system (Wachs 2003).

Absent sufficient public funding, it is also possible that private industry (most likely through PPPs) could take a greater role in financing and operating transportation facilities in the United States. This could include developing and operating new private tollways or transit facilities, for example, or contracting with public agencies to operate existing systems.

Level of funding. The decline in real highway funding relative to vehicle travel has diminished the capacity of transportation agencies to provide new infrastructure where needed and to maintain existing facilities. For transit systems, in contrast, increasing subsidies have outpaced growth in ridership. Still, the overall pattern in surface transportation can be described as one of increasing disinvestment (Cambridge Systematics et al. 2006), and the question is whether voters will continue to support this trajectory. On one hand, strong arguments can be made that the nation's investment in a world-class transportation network in prior decades has been a key underpinning of its economic prosperity and that further investment will be critical in ensuring continued success in the future. On the other hand, constituencies favoring lower taxes and smaller government have gained greater political influence of late, reducing the likelihood of significant increases in the level of public investment for at least the near term. Over the longer term, it is difficult to predict whether leaders will continue to focus on austerity or instead ask the public to invest more in transportation with the aim of promoting continued economic growth.

Funding mechanisms. The United States has traditionally relied heavily on user fees, such as fuel taxes, tolls, and transit fares, to fund transportation investments and operations. With the failure in recent decades to increase federal and state fuel taxes to keep pace with inflation and improved fuel economy, the proportion of transportation funds derived from general sources has increased. Yet recent technical innovations are now enabling the development of systems to meter travel and levy more-precise road-use fees based on some combination of vehicle attributes, distance, time, and location of travel (e.g., electronic tolling, mileage-based user fees, congestion tolls, and weight-distance truck tolls), and interest among elected officials in these alternatives appears to be growing (Sorensen and Taylor 2006). Similarly for transit systems, the proliferation of electronic fare media now makes it possible to structure rates based on such factors as time and distance of travel, and this could in turn promote greater ridership as well as enhanced cost recovery (Wachs 1981, Cervero and Wachs 1982).

Despite the potential benefits of more precise user fees—specifically, their ability to align costs with benefits and promote more efficient system use—and the availability of enabling technology, it remains uncertain whether decision makers will adopt such an approach or instead allow a continued shift toward general sources of revenue to fund transportation. The recent success of numerous local transportation funding initiatives across the country, many of which have relied on sales taxes and general obligation bonds (Goldman and Wachs 2003), suggests that the public views general revenue as an acceptable source for transportation funding; in contrast, innovative transportation funding mechanisms such as congestion tolls and mileage-based user fees remain controversial.

Investment in roads versus transit. While the United States invests less in transit than it does in roads, transit systems still receive a disproportionate share of transportation funding in relation to the ratio between transit ridership and automotive travel. This can be explained, in part, by the fact that transit represents a relatively uncontroversial means for addressing numerous social and economic goals. Yet the ability of transit to deliver on many of these goals depends on a high level of ridership, which has yet to be achieved in many U.S. cities and is even less common in suburban and rural areas. At the same time, the state of repair for roadways is rapidly deteriorating in many states, leading some to argue that the share of road use fees (e.g., from federal fuel taxes) currently allocated to fund transit should be reduced or eliminated (Poole and Moore 2010). Looking forward, it is unclear—particularly if one assumes continued shortfalls in available transportation funding—whether the nation will continue to increase funding for transit or instead shift a greater percentage of revenue to the road network.

H.3 Potential Effects on Energy and Transportation

This final section summarizes the anticipated direct and indirect effects of various energy, climate, and transportation funding and investment policies on core elements of the future scenarios developed in Chapter 5. The discussion focuses first on the impacts for fuels and vehicle technologies and then examines potential implications for broader trends in travel demand.

H.3.1 Effects on Fuels and Vehicle Technologies

Elements of the future scenarios related to fuels and vehicle technologies include the price of oil, conventional vehicle fuel economy, use of alternative fuels, vehicle cost, and the marginal cost of driving.

Price of oil. The price of oil is governed by the interaction of global trends in supply and demand. As such, U.S. policy choices are likely to have only a moderate effect on price. With that caveat in mind, policies intended to expand supply or reduce demand should still have some effect on decreasing the underlying price of oil, while policies that restrict supply or increase demand should have the reverse effect. Policies that tax the consumption of oil products represent a special case. While such taxes will reduce the demand for oil, in turn putting downward pressure on the underlying price, the addition of the taxes has the net effect of increasing prices for end users. The analysis here considers the end-user perspective.

Following this logic, any policies to expand domestic oil production (e.g., the expansion of offshore drilling or further development of oil sands, shale oil, or coal to liquids) should reduce price. Policy choices that could reduce price through reductions in demand include CAFE standards, subsidies or feebate programs to encourage the purchase of alternative-fuel vehicles or conventional vehicles with higher fuel economy, renewable fuel subsidies or standards, reduced total investment in transportation (by limiting capacity for additional travel), increased funding for transit (by encouraging mode shift), and the application of tolls or MBUFs that raise the marginal cost of travel. Policies that could result in increasing demand, and in turn price, include boosting total transportation investment or shifting a greater share of funding to highways (either of which would increase capacity for additional travel and potentially stimulate greater economic growth, which in turn increases the demand for oil) and reducing the cost of travel by relying on general revenue sources, as opposed to user fees, to fund highways. Finally, the application of carbon taxes (or alternatively carbon cap and trade) or higher fuel taxes would reduce demand for oil and, in turn, the underlying price, but still result in higher prices for the end user.

Vehicle fuel economy. More rapid adoption of vehicles with greater fuel economy can be promoted via regulation, as with CAFE standards, or through government incentives such as vehicle subsidies or feebate programs. Additionally, policies that would result in increasing the price of gasoline or diesel—notably carbon taxes or fuel taxes—create an incentive for consumers to adopt vehicles with higher fuel economy. Policies that would reduce the price of fuel to the end user, in contrast, would undermine efforts to encourage a transition to vehicles with greater fuel economy. These include expanded domestic oil production and a transition from fuel taxes to tolling, MBUFs, or general revenue sources, any of which would eliminate the current incentive for more fuel-efficient vehicles embodied in fuel taxes.

Alternative fuels. Policies that result in either decreasing the purchase price of gasoline and diesel or speeding the adoption of conventional vehicles with higher fuel economy would make it harder to develop cost-competitive alternative-fuel models. These include expanded oil production, CAFE standards, and transitioning from fuel taxes to tolling, MBUFs, or general revenue to fund highways. Policies that mandate or incentivize the production and consumption of alternative fuels or increase the cost of conventional fuels, in contrast, should support greater adoption of alternative-fuel technologies. Renewable fuel standards, renewable fuel subsidies, carbon pricing, and higher fuel taxes on gasoline and diesel fall into this category. Note that the effect of clean vehicle subsidies and feebate programs depends on whether the incentives focus solely on alternative-fuel models or instead encompass conventional vehicles with much higher fuel economy as well.

Vehicle cost. Few of the policies described in this appendix are expected to directly affect the cost of new vehicles, which will depend more on the evolution of specific vehicle technologies as summarized in Chapter 3 and discussed at greater length in Appendices A, B, C, D, E, and F. The recent adoption of more-stringent CAFE standards, however, is expected to result in the application of advanced fuel-saving technologies that will increase the average price for new vehicles. Vehicle subsidies or feebate programs, in contrast, should reduce the purchase price (if not the production cost) of conventional vehicles with higher fuel economy or alternative-fuel vehicles.

Marginal cost of driving. Policies that either decrease the cost of fuel or lead to improved fuel economy will in turn lower the marginal cost of driving. These include expanded oil production, CAFE standards, renewable fuel subsides, clean vehicle subsidies, feebate programs, and a shift from fuel taxes to general revenue sources for highway funding. In contrast, policies that would increase the cost of fuel, including carbon taxes and higher fuel taxes, should raise the marginal cost of travel. A transition from fuel taxes to tolls or MBUFs would also increase the marginal cost of travel over time as fleet fuel economy improves. The effect of renewable fuel standards is unclear, ultimately depending on whether it proves possible to produce ethanol and biodiesel more cheaply than gasoline and diesel.

H.3.2 Effects on Travel Demand

Elements of the future scenarios related to travel demand include growth in personal vehicle travel, growth in transit ridership, and growth in truck travel.

Passenger vehicle travel. Policies that reduce the cost of vehicles, reduce the marginal cost of driving (by either improving fuel economy or reducing the purchase price of fuel), or increase available road capacity will tend to promote automobility. Options in this vein include efforts to expand fossil-fuel production, renewable fuel subsidies, clean vehicle subsidies, feebate programs, increasing total investment in transportation capacity, investing a greater share of revenue in highways, and shifting to greater reliance on general revenue rather than user fees to fund highways. CAFE standards have a conflicting effect, increasing the cost of vehicles but also reducing the marginal cost of travel through improved fuel economy. However, economic practicability is one of the criteria used to set CAFE standards (NHTSA, undated), and as a result they tend to be structured such that the savings through improved fuel economy will more than offset the vehicle purchase premium. As such, it is reasonable to expect that CAFE standards, on balance, will also tend to promote greater automotive travel. In contrast, policies that would restrict the growth in automotive travel—either by increasing the marginal cost of driving or by limiting capacity expansion—include carbon pricing, reducing overall transportation investment, devoting a greater percentage of transportation funds to support transit rather than roads, and relying to a greater extent on fuel taxes, tolls, or MBUFs to raise highway revenue. The effect of renewable fuel standards remains unclear and will ultimately depend on whether biofuels can be produced at lower cost than fossil fuels.

Use of transit. As a general rule, the effects on transit use of the policy choices discussed in this appendix should be opposite to the effects on automotive travel; that is, policies that support increased growth in automobility will tend to constrain growth in transit use, while policies that limit automotive growth will tend to promote greater use of transit. The main exceptions to this rule involve the overall level of investment in transportation capacity. Increased total investment (without regard to specific allocation among modes) may increase both automotive travel and transit demand, while reduced total investment may undermine growth in both modes.

Freight trucking. The effects on trucking of the energy, climate, and transportation funding and investment policies considered in this appendix should be broadly similar to the effects on personal automotive travel.

References

API. 2013. Motor Fuel Taxes. Oil & Natural Gas Overview. http://www.api.org/statistics/fueltaxes/ (accessed March 22, 2013).

APTA. 2012. Appendix A: Historical Tables. *2012 Public Transportation Fact Book.* Washington, D.C.

BLS. 2013. Consumer Price Index: All Urban Consumers—(CPI-U). ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt (accessed March 18, 2013).

Brown, J., M. DiFrancia, M. C. Hill, P. Law, J. Olson, B. D. Taylor, M. Wachs, and A. Weinstein. 1999. *The Future of California Highway Finance.* California Policy Research Center, Berkeley.

Bunch, D. S. and D. L. Greene. 2010. *Potential Design, Implementation, and Benefits of a Feebate Program for New Passenger Vehicles in California.* Institute of Transportation Studies, University of California, Davis.

Burger, N., L. Ecola, T. Light, and M. Toman. 2009. *Evaluating Options for U.S. Greenhouse-Gas Mitigation Using Multiple Criteria.* RAND Corporation, Santa Monica.

Burke, A. F. and H. Zhao. 2010. Projected Fuel Consumption Characteristics of Hybrid and Fuel Cell Vehicles for 2015–2045. Presented at the Electric Vehicle Symposium 25, Shenzhen, China.

Burke, A. F., H. Zhao, and M. Miller. 2011. "Technologies for the Alternative Fuel/Vehicle Pathways – Vehicle Technology, Design, Fuel Economy, and Cost." In *STEPS Book*, Institute of Transportation Studies, University of California, Davis.

Cambridge Systematics, Mercator Advisors, A. E. Pisarski, and M. Wachs. 2006. *NCHRP Web-Only Document 102: Future Financing Options to Meet Highway and Transit Needs.* Transportation Research Board of the National Academies, Washington, D.C.

CARB. 2013. Cap-and-Trade Program. http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm (accessed March 22, 2013).

CBO. 2003. *The Economic Costs of Fuel Economy Standards Versus a Gasoline Tax.*

Cervero, R. and M. Wachs. 1982. "An Answer to the Transit Crisis: The Case for Distance-Based Fares." *Journal of Contemporary Studies*, 5 (2): 59–70.

Cheah, L. and J. Heywood. 2011. "Meeting U.S. Passenger Vehicle Fuel Economy Standards in 2016 and Beyond." *Energy Policy*, 39 (1): 454–466.

EERE. 2013. Alternative Fuel Infrastructure Tax Credit. Alternative Fuels Data Center. http://www.afdc.energy.gov/laws/law/US/10513 (accessed March 22, 2013).

EIA. 2013. *Annual Energy Outlook 2013.*

EPA. 2010. *2005 Petroleum Baseline Lifecycle GHG (Greenhouse Gas) Calculations 1/29/2010.* EPA-HQ-OAR-2005-0161.

EPA. 2011. *Inventory of Greenhouse Gas Emissions and Sinks: 1990–2009.* EPA 430-R-12-001.

EPA. 2012a. Acid Rain Program. Clean Air Markets. http://www.epa.gov/airmarkets/progsregs/arp/basic.html (accessed March 22, 2013).

EPA. 2012b. Regulations and Standards: Heavy-Duty. Transportation and Climate. http://www.epa.gov/otaq/climate/regs-heavy-duty.htm (accessed March 22, 2013).

EPA. 2012c. Regulations and Standards: Light-Duty. Transportation and Climate. http://www.epa.gov/otaq/climate/regs-light-duty.htm (accessed March 22, 2013).

EPA. 2013a. Renewable Fuels: Regulations & Standards. Fuels and Fuel Additives. http://www.epa.gov/oms/fuels/renewablefuels/regulations.htm (accessed March 22, 2013).

EPA. 2013b. Clean Air Interstate Rule (CAIR). Clean Air Markets. http://www.epa.gov/airmarkets/progsregs/cair/index.html (accessed March 22, 2013).

Fischer, C., W. Harrington, and I. W. H. Parry. 2007. "Should Automobile Fuel Economy (CAFE) Standards Be Tightened?" *Energy Journal*, 28 (1): 1–29.

GAO. 2000. *Automobile Fuel Economy: Potential Effects of Increasing the Corporate Average Fuel Economy Standards.*

GAO. 2009. *Highway Trust Fund Expenditures on Purposes Other than Construction and Maintenance of Highways and Bridges during Fiscal Years 2004–2008.* GAO-09-729R.

German, J. and D. Meszler. 2010. *Best Practices for Feebate Program Design and Implementation.* International Council on Clean Transportation, Washington, D.C.

Goldman, T. and M. Wachs. 2003. "A Quiet Revolution in Transportation Finance." *Transportation Quarterly*, 57 (1): 19–32.

Govtrack. Undated. H.R. 2454 (111th): American Clean Energy and Security Act of 2009. http://www.govtrack.us/congress/bill.xpd?bill=h111-2454 (accessed April 19, 2011).

Greene, D. L. 1997. *Why CAFE Worked.* Oakridge National Laboratory.

Greene, D. L., J. German, and M. Delucchi. 2008. "Fuel Economy: The Case for Market Failure." In D. Sperling and J. Cannon, eds., *Reducing Climate Impacts in the Transportation Sector.* Springer Press.

IEA. 2012. *World Energy Outlook 2012.*

Kahane, C. J. 2012. *Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTV – Final Report.* DOT HS 811 665. National Highway Traffic Safety Administration.

Kasseris, E. and J. Heywood. 2007. "Comparative Analysis of Automotive Powertrain Choices for the Next 25 Years." Paper 2007-01-1605, presented at SAE World Congress & Exhibition, Detroit, Michigan.

Knittel, C. 2009. *The Implied Cost of Carbon Dioxide under the Cash for Clunkers Program.* Institute of Transportation Studies, University of California, Davis.

NHTSA. Undated. CAFE Overview – Frequently Asked Questions. http://www.nhtsa.gov/cars/rules/cafe/overview.htm (accessed November 8, 2011).

NRC. 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards.* The National Academies Press, Washington, D.C.

NRC. 2010. *Assessment of Fuel Economy Technologies for Light-Duty Vehicles.* The National Academies Press, Washington, D.C.

NSTIFC. 2009. *Paying Our Way: A New Framework for Transportation Finance.* Report of the National Surface Transportation Infrastructure Financing Commission. Washington, D.C.

NSTPRSC. 2007. *Transportation for Tomorrow.* Report of the National Surface Transportation Policy and Revenue Study Commission. Washington, D.C.

OHPI. Undated. Total Receipts for Highways, by Government Unit 1945–2010. Highway Statistics 2010. http://www.fhwa.dot.gov/policyinformation/statistics/2010/2010recchrt.cfm (accessed March 25, 2013).

OHPI. 1997. Table HF-210. Funding for Highways, All Units of Government, 1921–1995. Highway Statistics Summary to 1995. http://www.fhwa.dot.gov/ohim/summary95/section4.html (accessed March 25, 2013).

OHPI. 2011. Table MF-121T. Tax Rates on Motor Fuel – 2010. Highway Statistics 2010. http://www.fhwa.dot.gov/policyinformation/statistics/2010/mf121t.cfm (accessed March 25, 2013).

OHPI. 2012. Table HF-10. Funding for Highways and Disposition of Highway-User Revenues, All Units of Government, 2010. Highway Statistics 2010. http://www.fhwa.dot.gov/policyinformation/statistics/2010/hf10.cfm (accessed March 25, 2013).

ORNL. 2012. *Transportation Energy Data Book*, Edition 31. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Poole, R. W. and A. T. Moore. 2010. *Restoring Trust in the Highway Trust Fund.* Policy Study 386. Reason Foundation, Los Angeles.

Regan, E. and S. Brown. 2011 (Spring). "Building the Case for Tolling the Interstates." *Tollways*, pp. 6–21.

Santos, A., N. McGuckin, H. Y. Nakamoto, D. Gray, and S. Liss. 2011. Summary of Travel Trends: 2009 National Household Travel Survey. Federal Highway Administration.

Schnepf, R. and B. D. Yacobucci. 2010. Renewable Fuel Standard (RFS): Overview and Issues. Congressional Research Service.

Sorensen, P. and B. D. Taylor. 2006. "Innovations in Road Finance: Examining the Growth in Electronic Tolling." *Public Works Management & Policy*, 11 (2): 110–125.

Taylor, B. D. 2010 (October 17–19). "Balancing New Infrastructure Investments with Improved Operations: How Can We Get the Most Transit Bang for the Subsidy Buck?" Presented at the 20th Annual UCLA Arrowhead Symposium: The Transportation—Land Use—Environment Connection. Infrastructure Investment for Sustainable Growth. Lake Arrowhead, California.

TRB. 2006. *Special Report 285: The Fuel Tax and Alternatives for Transportation.* Transportation Research Board of the National Academies, Washington, D.C.

UCS. 2012. Existing Cap-and-Trade Programs to Cut Global Warming Emissions. Global Warming. http://www.ucsusa.org/global_warming/solutions/big_picture_solutions/regional-cap-and-trade.html (accessed March 22, 2013).

Wachs, M. 1981. "Pricing Urban Transportation: A Critique of Current Policy." *Journal of the American Planning Association*, 47 (3): 243–251.

Wachs, M. 2003. *Improving Efficiency and Equity in Transportation Finance.* The Brookings Institution, Washington, D.C.

Whitty, J. M. 2003. *Road User Fee Task Force: Report to the 72nd Oregon Legislative Assembly on the Possible Alternatives to the Current System of Taxing Highway Use Through Motor Vehicle Fuel Taxes.* Oregon Department of Transportation.

Yeh, S. and D. Sperling. 2010. "Low Carbon Fuel Standards: Implementation Scenarios and Challenges." *Energy Policy*, 38 (11): 6955–6965.

APPENDIX I

Strategies to Sustain or Increase Revenue

This appendix presents detailed assessments of strategic directions that states might choose to pursue with the principal aim of maintaining or enhancing available transportation revenue. The possibilities include direct user fees (e.g., tolls, mileage-based user fees, and weight-distance truck fees), indirect marginal-cost user fees (e.g., fuel taxes), indirect fixed-cost user fees (e.g., vehicle sales taxes and registration fees), value capture and beneficiary fees (e.g., tax increment financing, special assessment fees, and developer impact fees), general revenue sources (e.g., portions of sales taxes and income taxes dedicated to transportation funding), and private capital (various forms of public–private partnerships).

I.1 Direct User Fees (Tolls or Mileage-Based User Fees)

Direct user fees offer a mechanism for raising transportation revenue in which travelers pay charges based on actual system use (e.g., based on the distance that they travel or on the specific facilities that they use). Relative to other funding mechanisms, user fees offer two key advantages: they promote more efficient system use and they fairly align the costs of constructing and maintaining the system with the benefits afforded by system use (NSTIFC 2009).

I.1.1 Supportive Policies

Frequently discussed forms of direct user fees are tolling, MBUFs, and weight-distance truck fees. In the transit arena, passenger fares that vary with distance of travel and potentially time of travel can also be viewed as direct user fees. While some of these mechanisms have a long history (e.g., tolling has existed for centuries), recent technology advances now make it possible to implement various forms of direct user fees with much greater efficiency (Sorensen and Taylor 2006).

Facility tolls. Tolls are often employed in the United States to fund the construction and maintenance of bridges and tunnels. Toll roads (typically limited-access facilities) are also common in some areas of the country, such as the Northeast, Florida, Texas, and Southern California. With the decline of fuel-tax revenue in recent decades, tolling has increasingly been used to fund new capacity; in the past decade, about a third of all new limited-access lane miles have been tolled, and tolls are often mentioned as a potential revenue source for funding truck-only facilities (NSTIFC 2009). One option for states to enhance available revenue for building and maintaining the broader transportation network as a whole would be to introduce tolling on currently untolled highways and major arterials. Because electronic tolling relies on the installation of roadside or gantry-mounted readers, its application would likely be constrained to only the most heavily traveled segments in the road network.

Mileage-based user fees. In response to more fuel-efficient conventional vehicles and the anticipated adoption of alternative-fuel vehicles, both of which will further erode the viability of continued reliance on gas and diesel taxes, decision makers have begun to consider the idea of transitioning to MBUFs (see, e.g., NSTIFC 2009). The state of Oregon, for example, is currently developing legislation to implement MBUFs for electric vehicles beginning in 2015 (Whitty 2011). While MBUFs are conceptually similar to tolling, they could be applied across the entire road network—not just on the most heavily traveled segments. Multiple options for implementing MBUFs are possible (see Sorensen et al. 2009; Sorensen, Wachs, and Ecola 2010). At the simple end of the spectrum, it would be possible to read a vehicle's odometer each year to record and charge for total mileage. In a more sophisticated approach, vehicles could be equipped with GPS-enabled devices capable of metering distance traveled by time and location. This would allow the system to charge for in-state miles but not out-of-state miles, for example, or to charge for travel on public roads but not on private roads. (It would also allow the system to charge higher fees for peak-hour travel in congested areas; this possibility is discussed separately in the section on congestion pricing policies.)

Although MBUFs offer many policy advantages, such as the ability to effectively toll the entire road network, the concept also faces significant challenges relating to the cost of implementing and administering a system to levy mileage fees (Rufalo 2011; Sorensen, Wachs, and Ecola 2010) and public acceptance (Baker and Goodin 2010, Hanley and Kuhl 2011). Oregon and Minnesota are currently exploring a range of innovative MBUF system-design strategies to overcome these challenges (Sorensen, Ecola, and Wachs, 2012).

Weight-distance truck fees. Weight-distance truck fees represent a variation of MBUFs in which the per-mile charge increases with vehicle weight to reflect the additional road damages caused by truck travel. To account for such damages with precision, the per-mile fee should vary with axle weight (with higher charges for heavier axle loads) and the type of road being traversed (with higher charges for more lightly engineered local or rural roads that suffer greater damage from truck travel). In practice, however, most weight-distance truck fees are based simply on distance and gross vehicle weight. While weight-distance truck fees have been employed by a large number of states, the traditional implementation approach—reliant on manual record keeping—proved quite cumbersome. This led many states to discontinue this approach; only Oregon, New York, Kentucky, and New Mexico still levy weight-distance truck fees (NSTIFC 2009). Over the past decade, however, advanced telecommunication technologies have been employed to develop automated weight-distance truck fees in such countries as Switzerland, Austria, Germany, the Czech Republic, Slovakia, and New Zealand, making this form of tolling much more efficient (Sorensen et al. 2009). Oregon, likewise, has conducted trials of a system to automate the state's existing weight-distance tolls.

Other direct user fees. As noted previously, transit fares that vary by distance traveled and potentially by time of travel can also be viewed as direct user fees. This review focuses, however, on direct user fees for passenger vehicle and truck travel. Transit fares are not commonly employed as a source of state DOT revenue.

Assumed policies for assessing direct user fees. The following sections that assess direct user fees assume that states would implement either expanded tolling on highways and other major thoroughfares or mileage-based user fees for passenger vehicles and would additionally implement weight-distance tolls for trucks. The fees would not, however, be structured to vary with vehicle emissions characteristics or with the time and location of travel. (Emissions fees and congestion tolls are discussed separately with other strategic policy options.)

I.1.2 Intended Mitigation Effects

Direct user fees could be quite effective in helping to address some of the challenges for state DOTs that may arise with alternate energy futures.

Increasing transportation revenue—highly effective. As discussed in Chapter 6, total vehicle travel is expected to grow much more rapidly than fuel consumption in the coming decades (EIA 2013). As such, a transition from fuel taxes to a system of user fees based on travel distance, even if structured to be initially revenue neutral, would create a more sustainable revenue stream that continues to increase in proportion to funding needs. And in the case of weight-distance truck fees, it is quite possible that the initial shift would not be revenue neutral. Rather, a careful cost allocation model could show that truck user fees should be increased to reflect the aggregate burden from trucks on the road network (NSTIFC 2009). Direct user fees could therefore be a very effective alternative to continued reliance on fuel taxes.

Reducing DOT costs—highly effective. Instituting weight-distance truck fees that vary with axle weight and the type of road traveled should be very effective in motivating trucking firms to adopt vehicle configurations and select routes to minimize damage to the road network, and in turn charges owed (Small, Winston, and Evans 1989). It could also have the effect of shifting some freight from trucking to rail. Because a disproportionate amount of road damage is caused by trucks with heavy axle loads (NSTIFC 2009), this strategy should be highly effective in reducing costs associated with road maintenance and repair.

Reducing traffic congestion—moderately effective. In contrast to many other revenue options, direct user fees would increase the marginal cost of travel and, in turn, help constrain the growth in passenger vehicle and truck travel. Regarding the latter, studies have indicated that the share of road use revenue generated by trucks through diesel taxes and other user fees is not commensurate with the burden that trucks impose on the system (for discussion see TRB 1996 and NSTIFC 2009). Assuming that a shift from fuel taxes to direct user fees would be informed by a careful highway cost allocation study to determine appropriate rates, a switch to weight-distance truck fees could result in a considerably higher tax burden for the trucking industry. Given tight profit margins and the possibility of switching to other modes for certain products, this could in turn act to significantly reduce the growth in trucking.

Given that the relationship between total travel and traffic congestion is nonlinear, even small reductions in vehicle travel can produce large effects in reducing traffic congestion (Downs 2004). Yet the types of user fees discussed here would not vary by time and location to create more specifically targeted incentives to reduce peak-hour traffic in congested locations. (Such fee structures are instead discussed under the category of congestion pricing.) This ultimately limits their effectiveness in terms of achieving significant and lasting congestion reductions.

Improving safety outcomes—moderately effective. Vehicle crashes and fatalities vary in proportion to total travel. By acting to help reduce passenger vehicle and truck travel, direct user fees should likewise have a beneficial effect on safety.

I.1.3 Intended Shaping Effects

The main intent of direct user fees is to raise transportation revenue in an efficient and equitable manner. Such fees would not be intended to exert significant influence in shaping evolving patterns of energy use.

I.1.4 Other Effects

Among the broad range of potential transportation revenue mechanisms, direct user fees are generally viewed favorably in terms of their ability to promote more efficient system use and to fairly align the costs and benefits of travel (Wachs 2003, NSTIFC 2009).

Economy—highly positive. When the costs charged for traveling are lower than the costs imposed by that travel, drivers and businesses will rationally over-consume road space—that is, they will choose to make at least some trips for which the net social benefits are exceeded by the net social costs (Downs 2004). Imposing direct user fees to more accurately reflect the cost associated with travel, in contrast, creates an incentive for drivers to ration their least-valued trips, in turn promoting more economically efficient use of the system (Wachs 2003). At the same time, they would provide more revenue for strategic capacity investments to address congested bottlenecks in the current road network that act to constrain economic productivity. Direct user fees should thus have a highly positive effect on economic growth and productivity.

Environment and public health—moderately positive (uncertain). Direct user fees should have some effect on reducing vehicle travel and traffic congestion, as discussed previously. This could help reduce harmful GHG emissions; improve air quality; and promote greater use of transit, walking, and biking, offering both environmental and public health benefits. On the other hand, existing fuel taxes create an incentive for purchasing more fuel-efficient vehicles, whereas tolls, MBUFs, and weight-distance truck fees lack such an incentive. Indeed, a shift from fuel taxes to MBUFs, for example, would result in reduced total road-use charges for vehicles with very poor fuel economy (Weatherford 2011). This would tend to counteract some of the benefits of reduced overall vehicle travel. It is difficult to estimate the comparative magnitude of such effects, however, leading to a rating of moderately positive but uncertain.

Equity—highly positive. Direct user fees can be described as promoting greater fairness in transportation funding by more accurately aligning the costs and benefits of travel (NSTIFC 2009). Additionally, in terms of the relative distribution of the tax burden, research by Weatherford (2011) demonstrates that road use charges based on miles of travel would be less regressive than fuel taxes—in other words, shifting from fuel taxes to MBUFs would generally benefit lower-income drivers.

I.1.5 Barriers

The preceding text indicates that a shift to more direct user fees would offer many benefits. The fact that such mechanisms are not more widely employed already suggests that they also face considerable barriers.

Low public support—significant barrier. Most public opinion research about the concept of MBUFs indicates that the public does not understand the problems faced by continued reliance on fuel taxes, does not understand the potential benefits of MBUFs, and has very low initial support for the concept. [As indicated by the work of Hanley and Kuhl (2011), however, support for MBUFs rises with greater understanding of how such a system would work.] The trucking industry, in turn, is extremely skeptical of distance-based charging, instead preferring to raise additional transportation revenue by increasing fuel taxes (Roth 2011). This position is understandable if one assumes (a) that the fees paid by the trucking industry through fuel taxes and other user charges may not fully reflect the costs imposed by truck travel (TRB 1996, Parry 2006, NSTIFC 2009), and (b) that trucking fees might be increased through a switch to weight-distance truck fees. In short, with both poorly informed opposition to MBUFs among the public at large and well-informed opposition to weight-distance tolls in the trucking industry, gaining public acceptance for a switch to direct user fees represents a significant challenge.

Technical risk—moderate barrier. The technology for distance-based road-use fees has been demonstrated in U.S. trials and implemented in international road pricing programs. Still there are some risks. One is that the system could prove to be more expensive to build, operate, and enforce than anticipated; another is that similar systems developed in different states would not be interoperable, creating challenges in collecting road use fees for out-of-state travel (Sorensen, Wachs, and Ecola 2010).

Enabling legislation—significant barrier. Any state wishing to implement MBUFs or weight-distance truck fees would almost certainly need enabling legislation. (The sole exceptions, for weight-distance truck fees, are Oregon, New York, Kentucky, and New Mexico, which already levy this form of trucking fee.) A decision to expand tolling across the Interstate system could require enabling federal legislation, potentially representing an even greater barrier.

I.1.6 Required Lead Time

Although the concept of direct user fees is rather easy to explain, the systems required to implement this form of charging are technically complex (Sorensen et al. 2009). As such, it is reasonable to assume that a period of 5 to 10 years would be needed to explore, plan, and implement any of the direct user-fee options discussed in this section. Once implemented, however, the effects on revenue and travel behavior would occur rather quickly.

I.1.7 Qualifications

The forms of direct user fees discussed in this section should work equally well and be equally helpful for all states regardless of geographic and demographic differences.

I.2 Indirect Marginal-Cost User Fees (Fuel Taxes)

Marginal-cost indirect user fees represent another potential transportation funding approach. Like direct user fees, they vary in proportion to system use (hence “marginal cost”). As such, they promote more economically efficient travel choices, and they also more fairly align the costs and benefits of using the transportation system (Wachs 2003). On the other hand, marginal-cost indirect user fees do not accurately mirror actual travel patterns and thus may be somewhat imprecise in their distribution of costs on system users.

I.2.1 Supportive Policies

Federal and state excise motor-fuel taxes on gasoline and diesel are the most commonly employed form of marginal-cost indirect user fees in the United States, and one could envision the application of similar taxes on alternate fuels in the future. Container fees represent another potential option for goods movement. Finally, taxes on tires and other vehicle parts and supplies also fall under this category.

Excise motor-fuel taxes. Federal and state excise taxes on gasoline and diesel consumption combine to provide almost two-thirds of all highway user fees and about half of all highway revenue in the United States (TRB 2006). Fuel taxes offer numerous advantages as a highway funding mechanism, including low administrative cost, low evasion rates, reasonable alignment of the tax burden with system use (variations in vehicle fuel economy prevent more precise alignment), and a modest incentive for the purchase of vehicles with greater fuel economy. The main drawback of fuel taxes is that they are typically levied on a cents-per-gallon basis and, as a result, must be periodically increased to offset inflation and fuel economy improvements. While a few states have indexed their fuel taxes to increase automatically, most states and the federal government rely on fixed per-gallon rates that require either legislative action or voter approval to increase. This has proven to be politically difficult in recent years, and as a result fuel-tax revenues—expressed in real dollars per mile of travel—have eroded considerably. The strategy considered here, then, would be for states to either increase or index their fuel taxes to reverse this trend.

Taxes on other transportation fuels. Looking forward to the introduction and increasing adoption of alternative fuels in the transportation sector, states might consider the application of analogous excise taxes on these alternative fuels to collect highway revenue. Green, for example, has suggested the concept of an “indexed energy user fee” that could be applied to multiple fuel types based on their embodied energy content and indexed to increase with average fleet fuel economy along with inflation in highway construction and maintenance costs (Green 2011). Though appealing, this concept faces at least two challenges. First, some potential fuels, such as natural gas and electricity, have alternate uses outside of transportation. This means that to collect fees related strictly to road use—that is, to apply the taxes only on the amount of fuel used to power a vehicle—the taxes would need to be collected at the retail level rather than at the wholesale level. This in turn would entail higher administrative costs. Second, at least some of the alternative-fuel options, including electricity, hydrogen, and natural gas, could allow for home refueling or even home production. At a minimum this could require the installation of multiple meters at a home to distinguish between different uses for, say, electricity or natural gas. Even more challenging, some users might be able to avoid fees entirely. For example, an owner of an electric vehicle could in theory charge a vehicle from battery storage connected to off-grid photovoltaics. In sum, an effort to embed road use charges in alternate fuels could prove more expensive, less effective, and ultimately less equitable (in terms of ensuring that all drivers pay their fair share) than the current system of taxes for gasoline and diesel.

Container fees. A parallel option to raise revenue for investment in goods movement facilities is to impose a fee on the transportation of shipping containers (NSTIFC 2009). This would likely be easier to implement at ports than at state crossings, however, thus limiting the number of states for which it would be a viable option. Note that from the perspective of a port seeking to raise its own revenue, a container fee might be viewed as a direct user fee given that each container requires roughly the same effort to process. From the perspective of a state, however, container fees would not reflect the amount of subsequent travel on the road network, if any, and would thus represent a more indirect user fee.

Other policies. In addition to taxing fuel, it is also possible to tax other vehicle parts and supplies that wear out in proportion to use. Owners of heavy-duty trucks, for example, pay federal taxes on the purchase of new tires, the proceeds of which are deposited into the HTF. Many states have levied similar taxes on tires, motor oil, and other parts and supplies (Cambridge Systematics et al. 2006).

Assumed policies for assessing marginal-cost indirect user fees. The assessments that follow address a scenario in which states would institute sufficiently large fuel-tax increases to offset losses in past decades due to inflation and improved fuel economy. Depending on the state, such increases could be as high as an additional 25 to 50 cents per gallon. While this would produce significantly more transportation revenue, retail fuel prices would still remain far lower than in many European nations, for example, where fuel-tax rates equate to several dollars per gallon and the resulting proceeds are treated as general revenue. In the scenario considered, states would also index their fuel taxes to keep pace with a combined measure of inflation and improved fuel economy, thus ensuring a sustainable revenue stream moving forward. States might also include fees on other parts and supplies that need to be periodically replaced based on usage patterns, and port states could conduct analyses to determine whether it would be possible to levy container fees to help fund goods movement projects without stimulating a shift in trade volume to other ports in other states. Given the challenges outlined previously, the scenario does not assume that states would apply transportation taxes on any alternative fuels that allow for at-home production or refueling.

I.2.2 Intended Mitigation Effects

The main intent of the policies discussed in this section would be to increase revenue, in turn helping to address potential increases in the cost of construction and maintenance. Additionally, increased fuel taxes would help reduce traffic congestion, improve safety outcomes, and reduce emissions of harmful local air pollutants and greenhouse gases.

Increasing transportation revenue—highly effective (uncertain). In prior decades, fuel taxes provided sufficient revenue to construct the Interstate system and support local road networks. If raised to offset prior losses due to inflation and fuel economy gains, they could again provide enough revenue to meet investment needs. Container fees, if and where applied, could help fund much-needed goods movement projects. Over the longer term, however, a shift to greater reliance on alternative fuels that would be more difficult to tax is possible, and this could undermine the ability of fuel taxes to provide a sustainable revenue source. Given this possibility, the rating of highly effective is described as uncertain.

Reducing DOT costs—moderately effective. As noted previously, greater reliance on user fees should have the effect of reducing overall travel. Because road damage varies to some degree with total travel, this should in turn reduce the level of required repair and maintenance activities. On the other hand, indirect user fees such as fuel taxes do not provide specific encouragement for reducing the types of trips—trucks with heavy axle loads on lightly engineered routes—that can cause the greatest damages to the road network. As such, this strategy is rated as only moderately effective in reducing DOT maintenance and operations costs.

Reducing traffic congestion—moderately effective. Here again, increased fuel taxes should stimulate an overall reduction in total vehicle travel, in turn helping to reduce traffic congestion. Fuel taxes would not, however, create a specific incentive for the reduction of peak-hour travel in congested areas (in comparison to, say, congestion tolls); this ultimately limits their effectiveness in reducing traffic congestion (Downs 2004).

Improving safety outcomes—moderately effective. Traffic crashes and fatalities are generally proportional to total vehicle travel. Anticipated reductions in vehicle travel based on higher fuel taxes should therefore translate into improved safety outcomes as well.

Improving air quality—moderately effective. Higher fuel taxes would help reduce harmful air pollutant emissions in several ways. First, they would reduce total vehicle travel and, in turn, emissions. Second, they would have some effect on reducing traffic congestion, which in many cases would lead to reduced emissions per mile of travel. Third, they would create an incentive for the purchase of newer vehicles with higher fuel economy, and such vehicles often meet more-stringent emission control standards as well.

Reducing GHG emissions—highly effective. GHG emissions vary directly with the combustion of gasoline and diesel. Taxing these two fuels, therefore, represents one of the most effective ways for reducing GHGs in the transportation sector (NSTIFC 2009). Drivers may respond to increased fuel taxes through some combination of reducing travel and purchasing cars with higher fuel economy; both of these actions reduce fuel consumption and, in turn, greenhouse gas emissions. Finally, it is possible that higher fuel taxes could accelerate the shift to alternative fuels with potentially lower carbon footprints such as electricity or hydrogen.

I.2.3 Intended Shaping Effects

While a core motivation for increasing fuel taxes is to provide more revenue, fuel taxes would also promote reduced oil consumption and perhaps make alternative-fuel options more cost-competitive.

Reducing oil consumption—moderately effective. By increasing the purchase price of gasoline and diesel, higher fuel taxes would create a strong financial incentive for the purchase of more fuel-efficient vehicles, in turn reducing aggregate oil consumption (CBO 2002). In contrast to fuel price swings due to market volatility, drivers recognize that fuel taxes represent a permanent surcharge on the price of gas and diesel; thus, the savings from purchasing a vehicle with higher fuel economy will continue over time. However, even with an additional tax of 25 to 50 cents, as envisioned for this assessment, fuel prices would remain far below the level seen in other countries. Additionally, the most recent revisions to CAFE standards already require vehicle manufacturers to achieve significant gains in average vehicle fuel economy by 2025. Against this backdrop, the marginal effect of higher fuel taxes on promoting further improvements in fuel economy is likely to be modest.

Promoting adoption of lower-carbon alternative fuels—moderately effective (uncertain). Increasing the cost of gasoline and diesel through higher fuel taxes would also increase the relative attractiveness of alternative-fuel vehicles. Still, it is expected that most emerging vehicle technologies reliant on alternative sources of energy will entail a significant premium for many years to come. Additionally, the question of which technologies will emerge as market competitors remains unclear. For this reason, the policy is rated as moderately effective with a significant degree of uncertainty.

I.2.4 Other Effects

The marginal-cost indirect user fees considered here should have broadly positive effects with respect to the economy, environment, and equity.

Economy—highly positive. Higher fuel taxes, to the extent that they better reflect the costs of providing and maintaining roads, engender more economically efficient use of the existing network by creating an incentive for drivers to ration their least-valued trips (Wachs 2003). Additionally, the resulting revenue stream can be used to improve the road network, one of the key historical underpinnings of the nation's economic success through the 20th century. In similar fashion, container fees, if included in the mix of indirect user fees, would provide much-needed revenue for freight projects to reduce bottlenecks and improve the efficiency of the goods movement (NSTIFC 2009).

Environment and public health—highly positive. As noted previously, fuel taxes should be moderately effective in reducing criteria pollutants and highly effective in reducing greenhouse gases. Additionally, container fees, if applied, would create a revenue source that could be used to fund not only freight capacity improvements but also environmental remediation projects to improve air and water quality in the vicinity of ports. All of these should lead to positive environmental and public health outcomes.

Equity—moderately positive (uncertain). Fuel taxes (like most taxes) are regressive with respect to income; that is, their burden falls more heavily on lower-income drivers. On the other hand, because the tax burden varies in proportion to total travel, fuel taxes result in a relatively fair alignment of the costs and benefits of road use. And in contrast to other common transportation revenue options such as dedicated sales taxes, those who do not drive—including many in lower-income households—are not required to pay for the road network. For these reasons, fuel taxes can be viewed as promoting greater equity in transportation finance (Wachs 2003). Yet the degree to which fuel taxes align costs and benefits may be undermined in the future. With the recent establishment of much more stringent CAFE standards through 2025, new vehicles will exhibit much higher fuel economy. At the same time, a variety of alternative-fuel vehicles are now reaching the market or are poised to do so in the near future. Owners of such vehicles, which are more likely to be purchased by upper- and middle-income households, will either pay less in fuel taxes per mile of travel or no fuel taxes whatsoever. Thus, the ability of fuel taxes to fairly align the costs and benefits of road use may be increasingly undermined in the future, to the detriment of owners of older vehicles with lower fuel economy—including a proportionally larger share of lower-income households.

I.2.5 Barriers

The main challenge to increasing fuel taxes is the current degree of public opposition to higher taxes in any form. Efforts to institute container fees, if pursued, would likely face similar challenges from stakeholders in the goods movement industry. Enabling state legislation could also be needed.

Low public support—moderate barrier (uncertain). Opposition to higher taxes in any form—with few distinctions drawn in the public debate between user fees and general revenues—has grown acute in recent decades. Over much of the past century, however, both the federal government and states have been generally willing to increase fuel taxes as needed to pay for highway construction and maintenance. It is plausible to argue that the public, confronted by ever-deteriorating road conditions, may at some point return to the perspective that investing in the nation's transportation network is a worthy endeavor, with fuel taxes representing a sensible approach for raising the necessary funds. Low public support is thus rated as a moderate rather than a significant barrier; whether such an attitudinal shift will occur, however, is also uncertain. Turning to the goods movement arena, it is reasonable to expect that many stakeholders would prefer not to pay container fees. Yet freight stakeholders also recognize the economic costs associated with delays and unreliable transport times due to capacity constraints. Provided that revenue from container fees, if and where levied, would be devoted to freight improvements, opposition to container fees could prove to be more muted.

Enabling legislation—moderate barrier. All states already levy some form of fuel taxes, but increasing the rate is likely to require legislative action in most states. Container fees, if pursued, would likely require enabling legislation as well.

I.2.6 Required Lead Time

States already levy fuel taxes. Assuming that public support for increased fuel taxes can be secured, it should be possible to institute the increases with little delay. The effects in terms of boosting available revenue would be immediate, while the secondary effects on traveler choice (e.g., to reduce travel or to purchase vehicles with greater fuel economy) would become apparent within a few years. While container fees are much less common than fuel taxes, they are not particularly complex in concept. It thus seems reasonable to assume that container fees could be planned, implemented, and begin to produce revenue within a 5-year window.

I.2.7 Qualifications

Increasing fuel taxes would be valuable for most states, but especially for those that do not currently index their fuel taxes and have not increased the per-gallon rates for many years. Container fees would mainly be applicable for states with major port facilities or international border-crossing points along major goods-movement corridors.

I.3 Indirect Fixed-Cost User Fees (Registration Fees)

Fixed-cost indirect user fees—including vehicle sales taxes and registration fees—represent another common approach for raising transportation revenue. Such fees account for a significant share of state highway funding. In 2010, states collected almost $23 billion in taxes on motor vehicles and motor carriers, equal to about three-quarters of the $30 billion that they collected on state motor-fuel taxes (OHPI 2012). Such taxes are related to use of the transportation network and thus fall into the general category of user fees. Unlike direct user fees and marginal-cost indirect user fees, however, the amount paid in vehicle sales taxes and registration fees does not depend on the amount one travels. Rather, these are fixed fees that may be paid a single time (as with sales tax on a new vehicle) or annually (as with license and registration fees). As such, though they may be quite adequate for raising revenue, they do not perform particularly well with respect to fairly allocating the costs associated with building and maintaining the road network based on actual use. Rather, the effect will be for those who travel more to be subsidized by those who travel less.

I.3.1 Supportive Policies

Vehicle sales taxes and registration fees are the most commonly employed revenue mechanisms in this category, as noted, although these have been structured in different ways by different states. License and title fees are also levied in some states, although these do not typically yield significant revenue.

Vehicle sales taxes. Many states collect sales taxes on vehicle purchases, just as they do with the sales of other goods, and these are treated as general revenue. A smaller number of states collect excise taxes on vehicle sales, which are dedicated to transportation. The federal government collects a similar fee on the sales of commercial trucks and trailers to help fund the HTF (Cambridge Systematics et al. 2006).

Vehicle registration fees. All states levy some form of vehicle registration fees, which typically vary by vehicle class. For light-duty vehicles, some states levy a flat fee, some levy a fee based on vehicle weight, and some levy a fee that accounts for a combination of age, weight, horsepower, and value. For heavy-duty vehicles, fees are typically based on weight according to a classification system that varies from one state to the next. Personal property taxes on vehicles have been levied by a few states, such as California, Kansas, and Virginia. While these act, in effect, as registration fees, federal tax code allows tax payers to itemize state personal property taxes on their income returns; the same does not hold for vehicle registration fees. This approach has therefore provided states with a mechanism for increasing transportation revenue in a way that mitigates the net increase in combined federal and state taxes for their residents (Cambridge Systematics et al. 2006).

Other policies. Many states also assess fees for vehicle titles and driver licenses. These, however, generate relatively little revenue, which is often used to cover administrative expenses rather than to fund highway investments (Cambridge Systematics et al. 2006).

Assumed policies for assessing marginal-cost indirect user fees. The following assessments assume that states would institute large increases in vehicle registration fees—sufficient to cover a major share of current transportation funding shortfalls—for both light-duty vehicles and commercial trucks. For light-duty vehicles, the fees would be structured to vary with vehicle age, weight, and value. The purpose of including age in the calculation is that older vehicles tend to be driven fewer miles each year than newer vehicles (Santos et al. 2011, Table 22). Weight, in turn, relates to the amount of wear and tear that a vehicle imposes on the roadways. Finally, factoring in the value of the vehicle is intended to reduce the burden on lower-income drivers, who tend to own lower-valued vehicles, and should thus promote improved equity outcomes. For trucks, the fees would be based on some measure of size, weight, and axle configuration to reflect the amount of wear on the road network likely to be caused by use of the trucks. Excise taxes on new vehicle sales are not assumed in the assessment because, unlike annual registration fees, they do not represent an ongoing revenue stream that persists for as long as the vehicle is being used in the state.

I.3.2 Intended Mitigation Effects

The main intent of higher registration fees would be to increase revenue, which would in turn help to address potential increases in the costs of construction and maintenance. Indirectly, it is possible that they could have a modest effect in reducing traffic congestion and vehicle crashes.

Increasing transportation revenue—highly effective. Registration fees already constitute a significant share of state transportation revenue (OHPI 2012); if raised significantly, they could certainly provide enough revenue to address current funding shortfalls.

Reducing DOT costs—moderately effective. As described next, it is possible that higher registration fees, by discouraging vehicle ownership, could lead to reduced overall travel, which in turn could reduce road maintenance needs. Additionally, if the registration fees for trucks are structured to account for axle-weight loads, they could encourage motor carriers to adopt vehicle configurations with lighter axle loads, which would reduce the wear and tear on pavement, in turn reducing required maintenance activities.

Reducing traffic congestion—moderately effective (uncertain). It is possible, though uncertain, that higher registration fees could exert downward pressure on the growth in vehicle travel, and in turn on traffic congestion. By increasing the annual costs associated with owning an automobile, higher registration fees should have the effect of reducing average vehicle ownership rates. Vehicle ownership, in turn, correlates strongly with total household vehicle travel (Giuliano and Dargay 2006). On the other hand, if higher registration fees are paired with reduced reliance on fuel taxes over time, then the reduced marginal cost of travel is likely to promote increased travel for vehicles that have been registered. The net effect of these opposing influences is uncertain.

Improving safety outcomes—moderately effective (uncertain). If higher registration fees lead to reductions in total travel, this should also reduce the incidence of vehicle crashes.

I.3.3 Intended Shaping Effects

The main objective of indirect user fees is to raise revenue; they would not be expected to exert a significant shaping influence on evolving energy patterns.

I.3.4 Other Effects

The anticipated effects of higher registration fees on the economy, environment, and equity range from neutral to moderately positive.

Economy—moderately positive. By boosting available revenue, higher registration fees could help stimulate economic growth through investments in transportation aimed at alleviating congestion and improving mobility for passenger travel and goods movement. The effect would not be as strong, however, as with marginal-cost indirect user fees (e.g., gas taxes) or direct user fees (e.g., tolls or mileage-based user fees). Both of these alternatives discourage lower-valued trips and thus promote more efficient use of the road network (Wachs 2003, NSTIFC 2009). Additionally, either tolling or mileage-based user fees would provide an opportunity to collect better data about where travel demand is highest (Sorensen, Wachs, and Ecola 2010), allowing for the selection of improvement projects that would yield the greatest economic returns on investment. Thus, registration fees are rated as only moderately positive in comparison to these other alternative revenue sources.

Environment and public health—neutral (uncertain). Should higher registration fees lead to decreased vehicle ownership and, in turn, vehicle travel, this should have some effect on reducing emissions and promoting more walking, biking, and transit use. On the other hand, if the fees are determined in part by the value of the vehicle, which would help reduce the burden on lower-income drivers, this would result in an incentive for keeping older, and more-polluting, vehicles on the road for a longer time. These two factors—potentially fewer vehicles, but also potentially more polluting vehicles—will tend to cancel each other out, although the exact interplay would depend on programmatic implementation details. The combined effect on the environment and public health is therefore rated as neutral but uncertain. Note that it would be possible to impose sales or registration fees based on the environmental performance of a vehicle, leading to more unambiguously positive effects; this is considered separately under the strategy of pricing vehicles to achieve environmental aims and is not assumed here.

Equity—moderately positive. As envisioned for the purpose of this assessment, increasing registration fees would perform moderately well in terms of equity. As a user fee, registration fees would ensure that those who own vehicles and use the roads would play a role in helping to fund expansion and maintenance, whereas those who do not own vehicles would be relieved of this burden. This stands in contrast with, for example, dedicated sales taxes, under which both users and nonusers share the burden. Further, by incorporating vehicle value into the fee structure, the burden on drivers from lower-income groups would be lessened. On the other hand, registration fees would not vary with the amount of travel. As such, they would do a much poorer job of fairly aligning the costs and benefits of using the roads than, say, fuel taxes, tolls, or mileage-based user fees (NSTIFC 2009).

I.3.5 Barriers

The main challenge to increasing registration fees is general opposition to higher taxes in any form, although enabling legislation might also be needed.

Low public support—moderate barrier (uncertain). All states levy registration fees, providing evidence of the political viability of this approach. On the other hand, the level of resistance to taxes in any form has risen considerably in recent decades, and registration fees have not been immune to this sentiment (Cambridge Systematics et al. 2006). In California, for example, the recall of Governor Gray Davis and subsequent election of Governor Arnold Schwarzenegger was largely precipitated by Governor Davis's decision to increase registration fees to help address funding shortfalls after reducing them earlier in his tenure when the state was enjoying a fiscal surplus. In short, it is unclear whether low public support constitutes a moderate or significant barrier; the longer-term record suggests the former, while more recent history suggests the latter.

Enabling legislation—moderate barrier. Although all states already levy registration fees, increasing the rates is likely to require legislative action in most cases.

I.3.6 Required Lead Time

States already levy registration fees. Assuming that public support for increased fees can be secured, it should be possible to institute the increases with little delay. The effects in terms of boosting available revenue would be immediate, while the secondary effects on vehicle ownership and travel choices would likely unfold within a few years.

I.3.7 Qualifications

Increasing registration fees should be a viable approach across all states.

I.4 Beneficiary Fees and Value Capture

Public investment in transportation facilities can increase the value of surrounding property through improved access. Value capture and beneficiary fees—including, for example, special assessment districts or developer impact fees—involve raising revenue from property owners and developers who benefit from improved access to fund needed transportation investments. Such revenue streams are commonly directed to support further transportation improvements within a specified area or to fund broader transportation programs. While they are often used to construct urban transit facilities or local roadway or pedestrian enhancements, these strategies may also be used to fund improvements to the state highway system. For example, revenue raised from a property tax imposed through joint petition of the majority of commercial and industrial property owners in the vicinity of Route 28 in Loudoun County, Virginia, covered 80% of the cost to improve supporting roadway infrastructure (Halligan 2011).

I.4.1 Supportive Policies

The most common forms of beneficiary fees and value capture taxes must be enabled in state authorizing legislation but are administered by regional or local governmental units. Potential strategies include establishing tax increment financing and special assessment districts, imposing impact fees on new developments, and enacting transportation utility fees. Other forms of tax policy less commonly used for transportation purposes are payroll taxes, joint development agreements, and split-value tax rate mechanisms.

Tax increment financing. Tax increment financing (TIF) leverages the additional taxes on property within a defined geographic area, often a downtown area or transportation corridor, accruing from publicly supported improvements. Public investment in these areas, including new transportation infrastructure, is expected to increase assessed property values. TIF levies apply only to a portion of assessed value—the increase that is assumed to be directly associated with a public investment. Additional revenues are often used to bond or finance the initial infrastructure investment or are reinvested in improvements within the TIF area (AASHTO 2011).

Special assessment districts. Special assessment districts involve the creation of a taxation district around a new or improved public facility. Landowners adjacent to the facility typically must agree by referendum to introduce the assessment as a means of funding a planned improvement. Assessment districts are a broader tool than TIF areas since they result in increased tax rates on the full assessed value of property, regardless of valuation changes (AASHTO 2011).

Impact fees. The creation of new housing or commercial development often requires the public sector to provide additional transportation services or infrastructure. If real estate developers do not provide facilities (e.g., improved street frontage), municipalities may require them to pay a fee to fund the additional infrastructure. Most states must first provide enabling legislation to allow for the imposition of impact fees, which are often analyzed and levied by local governments. Impact fees are based on the expected impacts of a development, the cost of new infrastructure required, and the developer's share of that cost (AASHTO 2011).

Transportation utility fees. Property owners typically pay fees for specific public utilities such as sewage and water service. Fees for transportation services can be levied and used to fund transportation system maintenance or infrastructure improvements. Fees can be imposed as flat rates or can be set in proportional to a building's square footage, occupancy, estimated trip generation, or other proxies for usage of the transportation system. For example, several local jurisdictions in Oregon allocate a portion of road maintenance costs to households by charging monthly rates based on estimated travel patterns (Halligan 2011).

Other beneficiary fees and value capture policies. Several other forms of value capture and beneficiary fees are also possible, though their use in raising transportation revenue is less common:

- **Employment-location–based payroll taxes.** Many localities impose local payroll taxes on those who work within an area and thus benefit from transportation improvements. While such taxes are seldom dedicated to transportation, they can be. For example, a special payroll tax applied within the urban transit districts of Portland and Eugene, Oregon, is used to fund transit improvements (AASHTO 2011).
- **Joint development.** Joint development occurs when a transportation agency and a real estate developer partner to develop land around a new transportation facility. The agency may own the land in question or may be paid by the developer in exchange for implementing a new transportation facility or service (AASHTO 2011). While joint development is most frequently practiced by transit agencies that own land surrounding urban transit stations, examples of joint development of highways, such as I-110 in Pensacola, Florida, also exist (Office of Planning, Environment, & Realty, undated).
- **Land value and split-rate taxes.** Land value and split-rate or two-rate taxes make up an alternative mechanism for capturing property value increases associated with better access through improved infrastructure. These taxes are imposed either solely on the estimated value of the land (a single land-value tax) or through separate assessments of the value of the land and the value of any buildings or improvements (a split-rate tax). Land is usually taxed at a higher rate, reflecting in part the value of access, than any subsequent improvements in order to encourage development of vacant or underutilized properties. These tax strategies are relatively uncommon in the United States and are primarily in use only in Pennsylvania (Maryland DOT 2011).

Assumed policies for assessing value capture and beneficiary fees. The following sections for assessing value capture strategies and beneficiary fees assume that states aggressively pursue tax increment financing or special assessment districts to fund improvements to state-owned transportation infrastructure. Impact fees and utility fees would also be employed, as appropriate.

I.4.2 Intended Mitigation Effects

Value capture strategies and beneficiary fees could be somewhat effective in helping to address revenue challenges likely to arise with alternative energy futures.

Increasing transportation revenue—moderately effective (uncertain). DOTs may partner with local governments to use value capture strategies to fund spot improvements to the state highway system. However, these strategies are unlikely to generate substantial revenue for general use by DOTs due to the fact that value capture revenues (e.g., property taxes) are typically collected by local governments and must often be reinvested in local areas (AECOM Consult 2007). Tools such as impact fees or tax increment financing generate revenue streams that are sporadic or unstable, while mechanisms such as utility fees generate stable but very low levels of revenue. (They are generally unsuitable to fund significant operation and maintenance of the highway system and are rather devoted to new capacity improvements.)

I.4.3 Intended Shaping Effects

Value capture and beneficiary fees are mainly intended to raise revenue from those who benefit from the improved access provided by transportation improvements; they would not be expected to have significant influence on evolving energy patterns.

I.4.4 Other Effects

Value capture strategies and beneficiary fees generally have positive effects on the economy, environment, and equity.

Economy—highly positive. Value capture taxes, particularly tax increment financing and special assessment districts, are frequently cited as an economic development tool because they provide a mechanism for investment in improvements expected to generate additional economic activity. Additionally, most value capture strategies are considered economically efficient in that they assign the cost of paying for new infrastructure to those who will benefit most (Johns 2009).

Environment and public health—neutral (uncertain). Value capture taxes and beneficiary fees may be applied to support a range of infrastructure investments in different contexts with differing environmental outcomes. On one hand, they are frequently used to develop new urban transit stations or to improve walking and biking amenities in the surrounding area. Yet they are also applied to new roadways or new developments in rural and suburban areas, leading to decentralized development patterns and potentially greater vehicle use. Given this range of outcomes, the effects on environment and public health are rated as neutral but uncertain.

Equity—moderately positive. Value capture taxes and beneficiary fees are considered efficient and equitable in allocating the costs of new transportation facilities to those who benefit most from them. However, they often rely on property taxes, which can be considered somewhat regressive in nature (Institute on Taxation and Economic Policy 2009).

I.4.5 Barriers

Several barriers create a challenge for using value capture as a significant future option for raising revenues for state DOTs.

Technical risk—moderate barrier. Value capture taxes and beneficiary fees can be technically challenging, requiring complex partnerships, enabling legislation, and assessment criteria. This can be particularly problematic for road projects because they are accessible to many people, and it is difficult to geographically isolate and charge via a property tax all those who benefit (AASHTO 2011). Additionally, the relationship between highway access improvements and property values can be complex; values can sometimes decline immediately adjacent to new facilities due to the effects of noise and additional pollution.

Enabling legislation—moderate barrier. Most value capture arrangements or beneficiary fees require enabling legislation. For example, development impact fees are only authorized in 26 states (Duncan Associates 2008). Although special assessment districts and tax increment financing have been authorized in nearly all states (Council of Development Finance Agencies and International Council of Shopping Centers 2007), not all states permit revenues to be used to fund state-owned or operated transportation infrastructure. Maryland expanded its TIF authority in 2009 to make state-owned transit-related infrastructure eligible for funding, although highway projects remain ineligible (Bauman 2011). Minnesota law precludes Minnesota DOT and Metro Transit from using TIF arrangements (Johns 2009).

Institutional restructuring—moderate barrier. Value capture strategies are usually implemented at local levels of government. For state DOTs to use value capture as a meaningful source of funding to expand and improve the state transportation network, institutional capacity must be developed to enter into financial and legal partnerships with local governments and private development partners. Some state DOTs, such as Maryland's, have aggressively explored building this capacity (Bauman 2011).

I.4.6 Required Lead Time

Because state DOTs would have to enable and enter into complex institutional arrangements to benefit systematically from value capture, approximately 5 to 10 years of lead time would be required before a state could begin making frequent use of value capture arrangements. If required legislation depends on state constitutional amendments, the lead time would be much longer.

I.4.7 Qualifications

Value capture and beneficiary fee strategies are likely to be most successful in states with dense urban or growing suburban populations since they require a critical mass of property owners to generate sufficient funding for new improvements. However, special assessment districts and similar strategies could be applied to improvements in rural areas or corridors with wide but well-defined geographic coverage.

I.5 General Revenues

General funds include government revenues from taxes and fees that have little or no direct dependence on the use of the transportation system. Income, property, sales, and value-added taxes are examples of general fund revenues, as are revenues from the sale of lottery tickets, alcohol, tobacco, and various licenses and permits. While real estate or personal property taxes can be considered a benefit-related tax when levied exclusively in areas served by a new investment or service, property taxes on all commercial or residential property are usually understood to be general revenues.

From the perspective of efficiency or equity, general revenues as a source of funding for transportation are not as desirable as user fees, but they are often viewed as being more politically palatable.

I.5.1 Supportive Policies

The most well-known examples in this category are dedicated shares of sales taxes, income taxes, and property taxes. General obligation bonds are a related instrument by which general revenue may be raised, with debt retired over time using the sources of revenue listed previously.

Sales taxes. There are 45 states that employ general statewide sales taxes and five that do not. Of those that raise revenue through general sales taxes, 36 also by state law empower local units of government to employ dedicated sales taxes. General sales taxes in some states are apportioned annually by the legislature for transportation and other competing uses, while in some states a portion of the general sales tax is earmarked specifically for transportation programs.

Income taxes. There are 41 states that generate revenue through personal and corporate income taxes, which may be apportioned to transportation programs as part of the normal state budgeting process.

Property taxes. A few states directly employ property taxes as an instrument of general revenue, while the vast majority of states empower local jurisdictions, primarily counties, to levy such taxes. These are often a source of support for local roads and public transit.

Other general revenue policies. Often states or local governments issue debt to raise capital for transportation and other investments to be paid back over time from general revenue. Most units of government are subject by statute to debt limits. Higher debt limits, and the willingness of state legislative bodies to raise them, are thus among the most important policies supportive of the use of general revenues for transportation. Additionally, more than a dozen states have in the past two decades enacted enabling legislation to permit the states or their counties and municipalities to hold referenda in which voters may approve borrowing to be backed by general revenue sources (Goldman and Wachs 2003). In California, for example, enabled by state law, nearly 30 counties have placed local-option sales taxes on the ballot for consideration by the voters (Crabbe et al. 2005). Finally, state interest tax deductions are a common device by which general fund debt is encouraged. Citizens purchase debt instruments where public agencies promise to pay them back over time, and a very important policy to encourage the purchase of such debt is the provision of income tax exemptions or credits on the interest earned through such debt instruments.

Assumed policies for assessing general revenues. In the assessments that follow, it is assumed that a state would allow its current fuel taxes to remain stagnant, leading to declining real fuel-tax revenue over time. To make up for this shortfall, the state would instead raise additional revenue dedicated to transportation through some combination of higher sales taxes, higher income taxes, and (less likely) higher property taxes. The specific combination of general revenues employed for transportation in any state would depend on what type of taxes it already levies.

I.5.2 Intended Mitigation Effects

Increased reliance on general revenues would mainly be intended to boost available transportation funding, which could in turn accommodate higher construction costs.

Increasing transportation revenue—highly effective. Although few forms of taxation are popular, general revenue sources enjoy the advantage of being spread across a broad base of individuals or transactions (sales taxes on many goods, transaction taxes on all businesses, or property taxes on all real property); as such, even modest increases in tax rates can produce substantial returns. Further, citizens are often more tolerant of small rates of increase in existing revenue sources than they are of new taxes and fees, especially if they are seen to be fairly administered.

I.5.3 Intended Shaping Effects

Greater reliance on general revenue would not be expected to exert much influence on evolving energy use patterns.

I.5.4 Other Effects

While potentially an effective way to raise funds, general revenue strategies do not fair particularly well with more general policy goals related to the economy, environment, and equity.

Economy—moderately negative (uncertain). While the transportation investments funded by general revenue could promote economic growth, increased taxation is often viewed as a drag on the economy. Additionally, in comparison to fuel taxes or other forms of user fees, relying on general revenue to fund transportation would not promote more economically efficient use of the system (Wachs 2003). Another consideration is that increasing general revenue tax rates could in some cases motivate businesses to relocate to other states. Businesses with the ability to relocate often prefer to invest in new facilities in low tax states. Faced with the prospect of increased tax rates, such businesses often threaten to, and on occasion actually do, leave states with higher taxation rates. In contrast, businesses may be more tolerable of small increases in taxation rates in areas where taxes are already low, such as in the rural South and Southwest. While the net economic effect of greater reliance on general revenue sources is uncertain, it is likely to be negative overall in comparison to user fees.

Environment and public health—moderately negative. User fees such as tolls or fuel taxes create an incentive for individuals to reduce travel or fuel use and rely on non-automotive modes to a greater extent. Increased reliance on general revenue sources, in contrast, offers no benefit to those who use less fuel, purchase vehicles that are more efficient, or take transit, bike, or walk instead of driving. By reducing the marginal cost of travel, a shift from user fees to general revenue would encourage more travel and in turn more energy use and emissions, with negative consequences for both the environment and public health.

Equity—moderately negative. Relying on general revenue to fund transportation has at least two negative equity implications. First, general sales taxes—a common source of general revenue—are regressive in the sense that the burden of paying them falls more heavily as a proportion of income on the poor than on the rich (Sorensen 2006). This regressivity can be mitigated somewhat by granting tax credits or by applying different tax rates to people in different income categories. For example, the use of progressive income tax brackets or the taxation of commercial property at rates that differ from the taxation rates for principal residences is used to mitigate the impacts of general taxes on lower-income people.

Second, the use of general revenues to fund transportation does not fairly align the costs of building and maintaining the system with the benefits of using the system (Wachs 2003). In particular, those who do not drive but still pay income, property, or sales taxes end up subsidizing the road network for those who do drive. The subsidization of users by nonusers was perhaps more problematic in the past, when fewer households owned vehicles; with the vast majority of the population now consisting of travelers and vehicle owners, this distinction has become less significant.

While there are still some nondrivers, their numbers have decreased as a share of the overall population, and it can be argued that almost all citizens benefit by accessibility and by the delivery of goods and services even if they do not own vehicles (Cambridge Systematics et al. 2006). Still, reliance on general revenue to fund transportation will, all else being equal, tend to result in lower-mileage drivers subsidizing higher-mileage drivers.

I.5.5 Barriers

The main barrier to general revenue enhancements is public opposition to new taxes, but it is possible that modest changes can be more acceptable than some of the alternative revenue sources that might be considered.

Low public support—moderate barrier. Recent increases in the cost of petroleum provide the context within which general taxes and fees for transportation must be considered. There is opposition to almost any tax or fee; this is especially notable with respect to transportation because of its steadily increasing share of household expenditures. While increases in user fees are a source of objection, any new revenues devoted to transportation are a source of consternation, and general revenues are not spared. Still, evidence indicates that voters in many local jurisdictions, at least, are willing to accept higher rates of general taxation to pay for much-needed transportation improvements (Goldman and Wachs 2003).

Enabling legislation—moderate barrier. Some states may set tax rates via legislation. In other states, voter referenda have been undertaken, and many have failed at the polls. Increasing these general revenue sources appears most likely to require legislative changes at the state level, though it could involve election campaigns by advocates.

I.5.6 Required Lead Time

This strategy envisions increasing the rate for a form of general taxation (e.g., sales, income, and property taxes) already levied in the state. Once political consensus to take this step has been achieved, implementing the actual increase should be possible within a year's time.

I.5.7 Qualifications

This strategy could be pursued by any state.

I.6 Leveraging Private Capital

Leveraging private capital encompasses a variety of methods to attract funding from the private sector to construct or operate transportation infrastructure. Such means are more common outside the United States (especially in Europe and Australia) but have recently gained ground domestically as a potential strategy for expanding the pool of available transportation funding. In the United States, generally the investments made by private firms are repaid through tolling rather than government transfers (also known as "availability payments"), which are more common overseas. One key distinction from other funding strategies is that private capital is generally tied to specific projects (although in some cases multiple projects may be involved), so it is not necessarily a strategy through which to fund a statewide transportation program. However, it is possible for a state to shift more of its new capacity building to a PPP basis and to make greater use of PPPs as a state policy.

I.6.1 Supportive Policies

States can leverage private funds in a variety of ways. These are better thought of as lying along a spectrum rather than as discrete categories because there are many ways to categorize them based on a variety of factors. For the purposes of this discussion, the possibilities are organized into two broad categories:

Public–private partnerships. PPPs (also known as P3s) are arrangements for building or operating transportation facilities that "allow more private sector participation than is traditional" (U.S. DOT 2004). This broad definition covers the many varieties of PPPs that have been used, some of which do not include private funding. Zhao, Saunoi-Sandgren, and Barnea (2011) provide a useful typology for PPPs that do leverage private funding:

- **Private-financing PPPs:** In this form of PPPs, the private entity may contribute financing through debt or equity finance, up-front payments, or revenue streams. Possibilities are a design–build–finance model, in which the contractor helps with construction financing; asset-monetization leasing, in which the contractor pays an up-front fee in exchange for later revenues; and various other types that combine a long-term concession and contractor finance. In such arrangements, the public sector continues to own the facility.
- **Value capture PPPs:** In this form, a private entity agrees to build a facility in exchange for the ability to profit from new development. For example, air rights development is common in transit projects, in which a station is built or upgraded in exchange for the right to build a private project above the station.

Note that the U.S. DOT currently allows states to experiment with PPP structures that waive the standard requirements in contracting, right-of-way acquisition, project finance, and environmental compliance through a program called Special Experimental Project Number 15, or SEP-15 (FHWA, undated c).

Full privatization. Privatization means that the private entity becomes the owner of a facility, either through building it or by purchasing it from a public entity. Generally the private owner is still subject to some public oversight, much as with a regulated utility. Another distinguishing factor from PPPs is that privately owned facilities are private in perpetuity, while PPPs have a specified concession date, often in the range of 25 to 75 years.

These methods of attracting private capital are often buttressed by other innovative financing tools to help states leverage their own funds. For example, many states operate state infrastructure banks, which are state-level lending institutions that are capitalized with federal or state funds. Funds are lent to specific projects that may or may not include private capital, depending on how a particular deal is structured. Another example is 63-20 public benefit corporations, which are "nonprofit corporations that . . . [are] authorized to issue tax-exempt debt on behalf of private project developers for activities that are public in nature" (U.S. DOT 2004). However, these particular tools are more properly considered financing tools than revenue sources.

Assumed policies for assessing efforts to leverage private capital. For the evaluation, it is assumed that states are willing to use both PPPs and full privatization, depending on the specific project. The 2005 SAFETEA-LU authorization allows all states to use PPPs for any project eligible for federal funding, but as of October 2010, only 29 states had passed legislation allowing the use of PPPs (Rall, Reed, and Farber 2010). Legislation differs from state to state—for example, in some states it narrowly defines specific projects, while in other states it allows use on any project fulfilling certain criteria (FHWA, undated b). For this assessment it is assumed that enabling legislation would be written broadly enough to make these strategies widely available.

I.6.2 Intended Mitigation Effects

Strategies to leverage private capital could play a modest role in mitigating the impacts of declining transportation revenues or higher construction and maintenance costs by bringing in a new source of revenue to the transportation system as a whole that can allow a state to stretch its budget.

Increasing transportation revenue—moderately effective (uncertain). While in many cases PPPs and privatization do not provide additional revenue to the public sector, they often do expand the total amount of funding (public plus private) that is directed to transportation improvements. This can unfold in several ways. First, private capital may allow a state to spend less of its own funds on construction or maintenance. For example, the Port of Miami tunnel received about $420 million of its $1.1 billion cost from senior bank debt and equity contributions (FHWA, undated a). Second, projects with private finance are often, though not exclusively, paid for with new or higher tolls on those facilities, thus expanding the stream of user fees flowing into the system. The Dulles Greenway in northern Virginia was built privately and provides the private owner with toll revenues; rates are subject to public oversight (FHWA, undated a). A third possibility is asset monetization, although this approach has been relatively rare in the United States. Under this arrangement a private entity purchases the right to manage a facility from the public owner and then recoups its investment over time through the collection of tolls or other fees. Both the Chicago Skyway and the Indiana Toll Road produced these one-time revenue infusions (FHWA, undated a).

Despite prior successes, the leveraging of private capital is rated as being only moderately effective in addressing revenue shortfalls, although it is also characterized here as uncertain. This is because private funding to date has mainly been employed for projects involving existing toll roads or for the construction of new capacity that will be subject to tolls. Much of the highway system, however, is not currently tolled, and it is generally difficult from a political perspective to add new tolls to currently free routes. This reduces the prospects for relying on PPPs or privatization to address shortfalls in revenue more broadly throughout a state's entire network.

Reducing DOT costs—moderately effective (uncertain). PPPs and privatization can also be helpful in reducing DOT costs, although this only applies for roads that fall under the public–private management arrangements. Construction cost savings have been documented on a number of specific projects involving PPPs. A Florida study found that while most projects had cost overruns, they tended to be far lower with the innovative contracting techniques employed in PPPs (U.S. DOT 2004). Some observers have noted that these cost reductions may also be tied to the shorter time frames for construction often achieved with PPPs, since delays usually increase costs (Rall, Reed, and Farber 2010). Ideally, for a facility managed by a private entity, tolls would be set based on the needs of any debt repayment for construction costs in addition to ongoing maintenance costs. However, the likely effectiveness of leveraging private capital in this context is rated as uncertain for two reasons. First, almost all PPP projects have long concession periods, and most projects have been in service only a few years, so it is difficult to say how they will fare in the long term. Second, several private entities that managed PPPs have been restructured or have filed for bankruptcy when toll revenues did not cover costs. For example, the South Bay Expressway was built with private funding and a TIFIA (Transportation Infrastructure Finance and Innovation Act) program loan, but the owner filed for bankruptcy less than 3 years after the roadway opened for service. Claims against the private operator and a downturn in revenues led to its financial problems, even though the concession allowed tolls to be set at market rates. The private entity was restructured as a result, and the toll revenues are shared by the TIFIA program and the lending banks (FHWA, undated a).

Reducing traffic congestion—moderately effective (uncertain). Leveraging private capital can make it possible for states to add new capacity that would not otherwise have been possible with state funding alone, which in turn can help relieve existing traffic bottlenecks. However, such benefits will not tend to be system-wide but will be constrained to the corridors in which the investments are made. Additionally, while adding new capacity will accommodate more vehicle travel, it will not necessarily solve congestion over the long term due to the effects of latent and induced demand (Downs 2004). To maintain uncongested travel conditions in tolled lanes, PPP operators may choose to implement congestion pricing (FHWA, undated a); this was the case, for example, with the SR 91 express lanes in Southern California. Whether future PPP projects would commonly employ this technique is unknown, resulting in characterization of this rating as uncertain.

I.6.3 Intended Shaping Effects

Strategies to leverage private capital would not be intended to shape evolving energy use patterns.

I.6.4 Other Effects

In general, the use of private capital to pay for construction and operating costs is not expected to have major impacts on the economy, environment, or equity. Any of these concerns could arise on a particular project, depending on its structure, but they are less related to the question of whether private capital is involved.

Economy—moderately positive (uncertain). It is reasonable to expect that leveraging private capital for transportation investment should have a moderately positive effect on the economy as private firms gravitate to projects that they anticipate will be profitable. One key reason for profitability is the existence or projection of sufficient demand from drivers willing to pay tolls, which will tend to align with prospects for greater economic activity. This rating is characterized as uncertain, though, for several reasons. First, while there may be localized economic benefits to investing in a specific new road or bridge, for example, such local investments are more likely to redistribute economic activity than produce overall gains (Shatz et al. 2011). Second, there may also be negative economic impacts if private firms use lower-wage construction labor; it is possible, though, for states to require private construction firms to pay prevailing wages (Rall, Reed, and Farber 2010). Finally, although private capital should generally be attracted to the most potentially productive projects, it still seems unlikely that any selection process for new roads would be entirely free of political considerations.

Environment and public health—neutral. The presence of private capital in construction or maintenance does not in itself raise any particular environmental or public health issues, either positive or negative. While some critics have alleged that private operators could use less environmentally friendly construction techniques or encourage more traffic to generate higher revenues, carefully written contracts can probably address these concerns (Rall, Reed, and Farber 2010).

Equity—neutral (uncertain). In the literature on PPPs and privatization, concerns about equity are generally related to issues such as toll increases and whether the public, broadly defined, benefits from the arrangement. Toll increases are not necessarily inequitable if they reflect the cost of maintenance and help the operator provide better service, but they create equity concerns if they are allowed to rise enough to price some lower-income drivers off of a facility. This would be most relevant in the case of asset monetization in which a private entity anticipates significant toll increases to recoup its investment.

I.6.5 Barriers

The main barriers to PPPs and privatization are low public support, the possibility of long-term financial cost, and other types of risk unique to these strategies. The relative importance of these barriers will vary from project to project.

Low public support—moderate barrier (uncertain). Some surveys have found general public opposition to privatization versus other forms of PPPs (Baxandall, Wohlschlegel, and Dutzik 2009). For existing projects (as distinct from new construction), public support can be low based on concerns over toll rate increases, which voters may perceive as being motivated exclusively by profit (Rall, Reed, and Farber 2010).

Technical risk—moderate barrier (uncertain). PPPs and privatization, by their nature, carry specific types of risk that are not present with other strategies. First, non-compete clauses—which essentially restrict the state from building or improving other infrastructure in the vicinity of a privately managed road—may lead to a loss in public control over transportation policy (Baxandall, Wohlschlegel, and Dutzik 2009). Some states have specifically restricted the use of these clauses for this reason (Rall, Reed, and Farber 2010). Second, traffic may be diverted to other roads, which could negatively affect rural areas that depend on that traffic (Pew Center on the States 2009), reduce the revenues available to the private entity, or increase congestion on heavily used roads. Third, inadequate oversight of private entities has sometimes been linked to a loss of technical capacity in the public sector (EC 2003). This can lead to declines in maintenance and safety standards if the public sector cannot be sure that the private entity is adhering to established standards (FHWA 2007). Fourth, private entities may have conflicts of interest (Baxandall, Wohlschlegel, and Dutzik 2009). The mark of a successful PPP is that each party bears the risks it can best manage (U.S. DOT 2004). However, if risk is not managed properly through up-front comparison, contracts, and performance measures, it is possible that the private sector will reap the rewards if the project is successful and that the public sector will pay the price if the project fails.

Finally, in the long term—looking at operations cost versus construction cost—the overall cost to the public sector under a PPP structure could be higher than it would have been if a facility was built or operated in the conventional way. Critics have expressed concerns about the disparity between up-front payments and long-term toll collection, as with the Indiana Toll Road (Baxandall, Wohlschlegel, and Dutzik 2009); cost overruns and the resulting need for the public sector to assume control over a facility (Hodge and Greve 2007); and the possible cost to the public sector if a private operator declares bankruptcy (Rall, Reed, and Farber 2010). Collectively these technical risks are rated as moderate but uncertain. PPP projects vary so widely that some concerns can be mitigated with carefully structured and well-monitored contracts. Also, the lack of long-term evidence makes it difficult to assess the probability of these risks over the lifetime of a concession.

Enabling legislation—moderate barrier (uncertain). While for the purposes of this assessment it is assumed that states have such legislation in place, in reality just over half the states are able to pursue such policies under their current legislation. While model legislation exists (FHWA 2010), it would constitute new legislation rather than a modification to existing legislation, and it may engender a number of debates related to how to use revenues, whether to allow any project or specify certain projects, whether to consider unsolicited bids, and so forth. The extent to which enabling legislation constitutes a barrier thus varies widely from state to state.

Institutional restructuring—moderate barrier (uncertain). Some state DOTs may find that institutional restructuring will be required because their current organization does not lend itself to dealing effectively with the private sector for developing PPPs or other agreements. It is also possible that the skills needed to successfully negotiate with private firms—including specialized legal and financial skills—are not available in-house at every state DOT. This is rated as uncertain since it likely varies from state to state depending on previous experience with private capital.

I.6.6 Required Lead Time

Provided legislation is in place, the anticipated time frame for delivering new construction under a PPP model is probably in the range of 5 to 10 years, which includes time for negotiating the financing as well as environmental review and construction. While the length of time for construction depends on a number of factors unrelated to the financing concerns, the time to finance and build these projects is generally shorter than it would be under more conventional means (U.S. DOT 2004). The time needed for conversion of an existing roadway to a PPP is shorter, in the 1- to 5-year range.

I.6.7 Qualifications

These strategies could be used in any state with authorizing legislation, but they may be more practical in areas that are experiencing economic and population growth because these drive the toll revenues that are generally used to repay private investors.

References

AASHTO. 2011. Center for Excellence in Project Transportation Finance. http://www.transportation-finance.org/ (accessed March 21, 2011).

AECOM Consult. 2007. "Briefing Paper 5A-11: Evaluation of Impact Fees and Value Capture Techniques." Prepared for the National Surface Transportation Policy and Revenue Study Commission, Washington, D.C.

Baker, R. and G. Goodin. 2010. *Exploratory Study: Vehicle Mileage Fees in Texas.* U.S. Federal Highway Administration and Texas Department of Transportation.

Bauman, G. 2011. *Final Report of the Maryland Blue Ribbon Commission on Transportation Funding.* Annapolis.

Baxandall, P., K. Wohlschlegel, and T. Dutzik. 2009. *Private Roads, Public Costs: The Facts about Toll Road Privatization and How to Protect the Public.* U.S. PIRG Education Fund, Boston.

Cambridge Systematics, Mercator Advisors, A.E. Pisarksi, and M. Wachs. 2006. *NCHRP Web-Only Document 102: Future Financing Options to Meet Highway and Transit Needs.* Transportation Research Board of the National Academies, Washington, D.C.

CBO. 2002 (November). *Reducing Gasoline Consumption: Three Policy Options.*

Council of Development Finance Agencies and International Council of Shopping Centers, 2007. *Tax Increment Finance Best Practices Reference Guide.*

Crabbe, A., R. Hiatt, S. D. Poliwka, and M. Wachs. 2005. "Local Transportation Sales Taxes: California's Experiment in Transportation Finance." *Public Budgeting & Finance*, 25 (3): 91–121.

Downs, A. 2004. *Still Stuck in Traffic: Coping with Peak-Hour Traffic Congestion.* Brookings Institution Press, Washington, D.C.

Duncan Associates. 2008. Impact fees.com. http://www.impactfee.com (accessed March 21, 2011).

EC. 2003. *Guidelines for Successful Public–Private Partnerships.* Directorate-General Regional Policy, Brussels.

EIA. 2013. *Annual Energy Outlook 2013.*

FHWA. 2007. *Quality Assurance in Materials and Construction.* Office of Professional and Corporate Development Program Improvement Team.

FHWA. 2010. Working Draft, FHWA Model Legislation for States Considering P3 Authorization.

FHWA. Undated a. Innovative Program Delivery: Project Profiles. http://www.fhwa.dot.gov/ipd/project_profiles/ (accessed December 29, 2011).

FHWA. Undated b. State P3 Legislation. http://www.fhwa.dot.gov/ipd/p3/state_legislation/state_legislation_overview.htm (accessed December 29, 2011).

FHWA. Undated c. Tools & Programs: SEP-15, FAQs. http://www.fhwa.dot.gov/ipd/p3/tools_programs/sep15_faqs.htm (accessed February 12, 2012).

Giuliano, J. and J. Dargay. 2006. "Car Ownership, Travel, and Land Use: A Comparison of the U.S. and Great Britain." *Transportation Research Part A: Policy and Practice*, 40 (2): 106–124.

Goldman, T. and M. Wachs. 2003. "A Quiet Revolution in Transportation Finance." *Transportation Quarterly*, 57 (1): 19–32.

Greene, D. 2011. "What Is Greener than a VMT Tax? The Case for an Indexed Energy User Fee to Finance U.S. Surface Transportation." *Transportation Research Part D: Transport and Environment*, 16 (6): 451–458.

Halligan, D. 2011. "Value Capture: A Transportation Revenue Option for Maryland." Presented at the eighth meeting of the Maryland Blue Ribbon Commission on Transportation Funding, Annapolis.

Hanley, P. and J. Kuhl. 2011. "National Evaluation of Mileage-Based Charges for Drivers." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2221:* 10–18. Transportation Research Board of the National Academies, Washington, D.C.

Hodge, G. A. and C. Greve. 2007. "Public–Private Partnerships: An International Performance Review." *Public Administration Review*, 67 (3): 545–558.

Institute on Taxation and Economic Policy. 2009. *Who Pays? A Distributional Analysis of the Tax Systems in All 50 States.* Washington, D.C.

Johns, R. 2009. "Harnessing Value for Transportation Investment: A Summary of the Study: Value Capture for Transportation Finance." University of Minnesota Center for Transportation Studies.

Maryland DOT. 2011. "Value Capture: A Transportation Revenue Option for Maryland." Prepared for the Maryland Blue Ribbon Commission on Transportation Funding.

NSTIFC. 2009. *Paying Our Way: A New Framework for Transportation Finance.*

Office of Planning, Environment, & Realty. Undated. Joint Development Study. http://www.fhwa.dot.gov/realestate/jntdev.htm (accessed May 9, 2013).

OHPI. 2012 (January). Table SF-1: Revenues Used by State for Highways. *Highway Statistics 2010.* http://www.fhwa.dot.gov/policyinformation/statistics/2010/sf1.cfm (accessed March 12, 2013).

Parry, I. W. H. 2006. "How Should Heavy-Duty Trucks Be Taxed?" Resources for the Future, Washington, D.C.

Pew Center on the States. 2009. *Driven by Dollars: What States Should Know When Considering Public–Private Partnerships to Fund Transportation.* Washington, D.C.

Rall, J., J. B. Reed, and N. J. Farber. 2010. *Public–Private Partnerships for Transportation: A Toolkit for Legislators.* Partners Project on Public–Private Partnerships for Transportation, National Conference of State Legislatures, Denver.

Roth, D. 2011. "Mileage-Based User Fees: Getting the Trucking Industry to Yes." Presented at the *2011 Symposium on Mileage-Based User Fees*, Breckenridge, CO.

Rufalo, A. 2011. "Cost Estimates for Collecting Fees for Vehicle Miles Traveled." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2221:* 39–45. Transportation Research Board of the National Academies, Washington, D.C.

Santos, A., N. McGuckin, H. Y. Nakamoto, D. Gray, and S. Liss. 2011. Summary of Travel Trends: 2009 National Household Travel Survey. Federal Highway Administration.

Shatz, H. J., K. Kitchens, S. Rosenbloom, and M. Wachs. 2011. *Highway Infrastructure and the Economy: Implications for Federal Policy.* RAND Corporation, Santa Monica.

Small, K. A., C. Winston, and C. A. Evans. 1989. *Road Work: A New Highway Pricing and Investment Policy.* Brookings Institution Press, Washington, D.C.

Sorensen, P. 2006. "Cheaper Gas and More Expensive Shoes: California's Transportation Finance Reform Proposal." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 1960:* 1–7. Transportation Research Board of the National Academies, Washington, D.C.

Sorensen, P., L. Ecola, and M. Wachs. 2012. *Mileage-Based User Fees: A Primer for State and Local Decisionmakers.* RAND Corporation, Santa Monica.

Sorensen, P., L. Ecola, M. Wachs, M. Donath, L. Munnich, and B. Serian. 2009. *NCHRP Web-Only Document 143: Implementable Strategies for Shifting to Direct Usage-Based Charges for Transportation Funding.* Transportation Research Board of The National Academies, Washington, D.C.

Sorensen, P. and B. D. Taylor. 2006. "Innovations in Road Finance: Examining the Growth in Electronic Tolling." *Public Works Management & Policy*, 11 (2): 110–125.

Sorensen, P., M. Wachs, and L. Ecola. 2010. *NCHRP Web-Only Document 161: System Trials to Demonstrate Mileage-Based Road Use Charges.* Transportation Research Board of The National Academies, Washington, D.C.

TRB. 1996. *Special Report 246: Paying Our Way: Estimating Marginal Social Costs of Freight Transportation.* Transportation Research Board of the National Academies, Washington, D.C.

TRB. 2006. *Special Report 285: The Fuel Tax and Alternatives for Transportation.* Transportation Research Board of the National Academies, Washington, D.C.

U.S. DOT. 2004. *Report to Congress on Public–Private Partnerships.*

Wachs, M. 2003. *Improving Efficiency and Equity in Transportation Finance.* The Brookings Institution, Washington, D.C.

Weatherford, B. A. 2011. "Distributional Implications of Replacing the Federal Fuel Tax with Per Mile User Charges." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2221:* 19–26. Transportation Research Board of the National Academies, Washington, D.C.

Whitty, J. 2011 (June 13-14). "Oregon Electric Vehicle Implementation." Presented at the *2011 Symposium on Mileage-Based User Fees*, Breckenridge, CO.

Zhao, Z. J., E. Saunoi-Sandgren, and A. Barnea. 2011. *Advancing Public Interest in Public–Private Partnership of State Highway Development.* Minnesota Department of Transportation Research Services, Office of Policy Analysis, Research, & Innovation.

APPENDIX J

Strategies to Reduce Costs

As an alternative to raising additional revenue in response to declining fuel-tax receipts, or perhaps as a complement, states could focus on strategies for reducing costs. This could involve striving for greater efficiency or paring the scope of DOT responsibilities to focus on core missions and either eliminating or devolving other activities. This appendix provides assessments for these two strategies.

J.1 Increasing Efficiency

DOTs have in recent decades focused significant attention on increasing efficiency. This broad concept encompasses efforts to select investments that maximize social benefits—including improved economic, environmental, and equity outcomes—and to reduce the life-cycle costs associated with ongoing construction, maintenance, and administrative tasks. This strategy involves a range of new materials, technologies, and management approaches—incorporating strategic asset management, improved risk management, and greater reliance on performance measures—that some states have already employed to achieve dramatic increases in efficiency.

J.1.1 Supportive Policies

States have pursued at least three broad approaches for improving cost-efficiency: adopting advanced materials and technologies, inclusive of information technologies aimed at more effective asset and risk management; contracting out for certain services; and structuring incentives tied to measured performance measures (described in the following as performance-based accountability).

Adopting materials and technologies that lower DOT operating costs. Maintaining and operating existing highway facilities consumes large shares of the budgets of most state DOTs. Innovations that lower these costs can increase efficiency and stretch increasingly limited funds. Adopting synthetic building materials (e.g., lightweight composite structures having long service lives) and recycled materials has already helped some states reduce operations and maintenance costs, and advances in these fields suggest that increasing efficiencies are possible in the future (Kissinger and Testa 1997). Similarly, adopting lower-cost approaches to the delivery of traditional services—for example by substituting light-emitting diodes for traditional traffic signal lights—has saved agencies money and reduced their use of energy and production of greenhouse gases. A third example of innovative technology likely to yield significant efficiency gains is the replacement of traditional bridge and pavement inspection procedures by embedded sensors that report on the condition of assets continuously, more accurately, and at lower cost than traditional visual inspections. Optimizing the use of sensors in the context of more strategic asset management systems has been shown to reduce maintenance costs by up to half in some instances, while improving the safety of the system (Ralls 2007).

Public–private partnerships. States have lowered costs for the delivery of many transportation services by contracting with private entities that in some instances are able to offer those services at a lower cost to the public than when they are offered directly by the state. Examples are contracting with private corporations and Amtrak to operate state-supported rail operations in California and privately operated bus transit operations in many states (Richmond 2001). The capitalization of such state-owned assets as the Indiana Toll Road through long-term leases to private operators has produced cash flow in the short run to replace revenues lost due to reductions in fuel taxes, while the contractual agreements have also provided for ongoing maintenance and management of the state's assets. In increasingly common arrangements, design–build–operate–transfer agreements have resulted in considerable cost savings when new projects have been managed by the private sector through carefully specified contractual obligations (International Technology Scanning Program 2009).

Performance-based accountability. By putting in place systems that periodically rate the performance of transportation facilities and services and then allocate funding on the basis of established improvements in measured performance over time, some states have improved the efficiency of service delivery in the realm of public transit and in highway maintenance and traffic safety. Some states have applied performance-based accountability to operations that are privately managed; other states have applied it to the funding and oversight of local programs, such as transit programs operated by cities or counties, and others still have applied it to ongoing statewide programs (Poister 1997, Cambridge Systematics 2000, Bipartisan Policy Center 2011).

Assumed policies for assessing efforts to increase efficiency. States are already pursuing most of the policies listed previously. In the assessments that follow, it is assumed that a state would continue to invest in such policies even more broadly.

J.1.2 Intended Mitigation Effects

The main intent of this strategy is to mitigate adverse effects associated with the likely decline in fuel-tax revenue and the potential for higher future oil costs to increase the cost of construction and maintenance. Striving for greater efficiency is a worthy goal even in states that also take steps to boost transportation funding, but it may be crucial in states that allow revenue to continue to decline.

Reducing DOT costs—moderately effective. Reducing the unit cost of construction and maintenance is the primary objective of most of the strategies considered here, and these strategies, in most cases, have already been proven by experience to be effective (Ralls 2007). The reason that this is only ranked as moderately effective is that many states have already been striving for greater cost-efficiency, thus leaving less room for further improvement at the margin.

J.1.3 Intended Shaping Effects

This strategy is not expected to have any appreciable effect on shaping broad energy use patterns and outcomes. As noted earlier though, DOTs may in some cases achieve cost savings through energy efficiency measures.

J.1.4 Other Effects

This strategy could have a modestly positive effect on the economy but also poses some risk for negative equity implications. The environmental effects are unclear.

Economy—moderately positive (uncertain). All else being equal, this strategy should lead to more efficient use of resources with corresponding positive economic effects. If, on the other hand, a state facing declining fuel-tax revenue were to solely focus on greater efficiency and not seek to bolster revenue, this decline could preclude investment in new facilities that might otherwise spur growth. The moderately positive rating is therefore characterized as uncertain.

Environment and public health—neutral (uncertain). Focusing on efficiency rather than raising new revenue is likely to limit new capacity investment, in turn limiting growth in travel and corresponding emissions. On the other hand, limiting new capacity may also lead to greater traffic congestion, producing more emissions per mile of travel. This leads to some uncertainty as to whether the net environmental effects would be positive or negative. It is likewise unclear whether this would have any significant effect on public health.

Equity—moderately negative. Privatizing certain functions could result in cost savings resulting in part from the reduction of employee salaries and benefits. Unionized state employees have brought legal action in opposition to privatization on the grounds that it is deliberately designed to deprive them of work and benefits. Another issue related to equity is that the distribution of funds based on performance-based accountability would likely result in some geographical areas losing out, resulting in assertions of unfair treatment.

J.1.5 Barriers

This strategy could face modest barriers with respect to financial cost, legislation, and institutional restructuring.

Financial cost—moderate barrier. More efficient asset management is likely to require up-front investment in software systems, sensors, and training of state employees in the use of the technology. While a state could be expected to recoup this cost over time (given the underlying goal of greater efficiency), the start-up costs could act as a barrier in some states given prevailing budgetary shortfalls.

Enabling legislation—moderate barrier (uncertain). Relying to a greater extent on public–private partnerships could require enabling legislation, for example where tolls are prohibited by law on state facilities, as could a shift to performance-based accountability as a principle for allocating funding. This is likely to vary, though, from one state to the next.

Institutional restructuring—moderate barrier (uncertain). There are presently regulations in many states that require unionized state employees to perform many of the duties that could possibly be contracted out under public–private partnerships. These would have to be modified or suspended in order to implement some of the strategies in this section. Likewise, greater use of public–private partnerships and performance-based accountability could require modest restructuring of offices within the DOT.

J.1.6 Required Lead Time

This is difficult to predict with precision. Some of the strategies in this section could be undertaken within 5 years, but others might take longer because of legal and political challenges. The lead time is therefore estimated at 5 to 10 years.

J.1.7 Qualifications

This strategic direction should be equally applicable in any state.

J.2 Reduced Scope of DOT Responsibility

Should a state face declining fuel-tax revenue and not choose to develop an alternative revenue source, its DOT may eventually be required to re-prioritize its efforts, reducing the range or scope of activities for which it is responsible. There are two ways in which this could occur. With reductions in funding levels and absent state legislation, a DOT might reduce the efforts devoted to existing functions, for example by performing maintenance activities less frequently or reducing miles of roadway on the state system through devolution. Re-prioritization could also be the result of state legislation that explicitly reduces the scope of state DOT responsibilities, for example by removing any responsibilities associated with public transit or livability initiatives.

J.2.1 Supportive Policies

The main options in this vein include devolving ownership and maintenance responsibilities for certain facilities to local jurisdictions and reducing or eliminating certain programs. By extension, any such retrenchment would also suggest significant reduction in the construction of new facilities.

Devolving responsibility for facilities. This would probably be most often applied to lightly used roads that are especially expensive to maintain and on which the majority of traffic is local in nature and does not generate fuel-tax revenues that justify continuing state expenditures. For example, Caltrans has proposed devolving to local governments its responsibility for Highway 39, a lightly traveled, 27-mile winding road through rough mountainous terrain that is costly to maintain and serves largely recreational users (Scauzillo 2011).

Narrowing areas of program responsibility. Given the historical origins of state departments of transportation, the reduction of program scope would probably involve focusing mainly on highway maintenance and preservation and shedding programs more recently acquired that are related to transit, aviation, and what have been called “enhancements,” which might include the maintenance of historic sites and aesthetically pleasing vistas and rest areas.

Other efficiency strategies. Reduction of the scale and scope of state transportation programs is distinct from but complementary to programs that might instead achieve programmatic goals through greater efficiency, as described in the prior section in this appendix. As an example, where more maintenance can be performed per dollar spent as a result of technological innovation, it would become less necessary to reduce the miles of highway maintained each year.

Assumed policies for assessing re-prioritization. In the assessments that follow, it is assumed that a state resorting to this strategy both would pare back its programs to focus mainly on highway maintenance and operations and would also seek to devolve to local jurisdictions the responsibility for lightly traveled state routes that do not serve a significant economic role. It is further assumed that a state would be systematic and consistent when assessing options for devolution. A state could employ economic evaluations of alternatives, for example by applying benefit–cost or cost-effectiveness methodologies to alternative proposals for devolution. Because each facility or service proposed to be eliminated from the state system has a constituency that benefits from it, it would be necessary to base decision making on a process that is recognized to be fair, neutral, and unbiased.

Note that there is little precedent for systematic downsizing of state DOTs in the manner described in this strategy. As such, many of the ratings are inevitably speculative.

J.2.2 Intended Mitigation Effects

The main intent of this strategy is to mitigate the effects of reductions in fuel-tax revenue—not by raising additional revenue, but rather by reducing state DOT responsibilities in light of the revenue reductions.

Reducing DOT costs—highly effective. Depending on the number of facilities or services that a DOT devolves, this strategy could be highly effective in reducing costs for which a DOT is responsible. It is worth noting, however, that while devolution may relieve the state of responsibility for ongoing maintenance and operations of certain facilities, there is no guarantee that local jurisdictions—many of which face similar budgetary constraints—will have the financial wherewithal to take over these duties. Thus, strategic devolution of certain facilities could ultimately equate to abandonment.

J.2.3 Intended Shaping Effects

This strategy is not expected to have a significant effect in terms of shaping future energy use patterns and outcomes.

J.2.4 Other Effects

This strategy could have negative effects on the economy as well as on equity; net impacts on the environment are unclear.

Economy—moderately negative (uncertain). This strategy implies a reduced tax burden, which, all else being equal, could promote economic growth. On the other hand, it also constrains the state's ability to invest in improved infrastructure that might otherwise have stimulated economic growth. It is also possible that reduction of maintenance would increase vehicle operating costs for at least some system users. Further, removing some roads from the state system, assuming that they are ultimately abandoned, could increase the circuitry of some travel, thus increasing economic costs. States would logically choose to first shed routes and functions that have the smallest negative impacts on the economy. Because the economy depends so heavily on effective transportation, however, the net effect over time seems likely to be negative, but the exact trade-offs are uncertain and likely to vary by location.

Environment and public health—neutral (uncertain). Lack of investment in new capacity is likely to constrain growth in travel and accompanying emissions. It is also likely to lead to more congested travel conditions and slower speeds on lower-quality roads and, hence, more emissions per mile. Trade-offs between these two factors are uncertain in the abstract but amenable to analysis at the level of individual cases. From a public health perspective, any reduction in vehicle travel could translate to more transit use, walking, and biking. On the other hand, any narrowing of programmatic scope might well lead to the elimination or severe reduction of investments in transit, walking, and biking to preserve more funding for highways, still the dominant mode of travel and the historic focus of state DOTs.

Equity—moderately negative. Each road or service has a natural geographic constituency on the basis of where it is located and a user constituency that differs from the population as a whole. That is, the reduction of transit service affects one group of travelers and the elimination of bicycle programs affects another, and rural projects affect different populations than do urban ones. Political action will reflect the perceptions of each constituency. While analysis may demonstrate that proposals are efficient or even fair in terms of cost saved per user, the removal of existing services and programs is nearly always controversial because some groups are affected more directly than others. Given the assumption that a state DOT pursuing this strategy would likely eliminate programs related to transit, biking, and the like, and that transit users in particular are disproportionately more likely to come from lower-income and minority groups, a rating of moderately negative has been assigned with respect to equity. Given the considerations outlined, however, this strategy may be perceived as being significantly inequitable.

J.2.5 Barriers

This strategy could face moderate barriers with respect to public support, enabling legislation, and institutional restructuring.

Low public support—significant barrier (uncertain). Members of the public along with local officials, especially in affected areas and among affected groups of system users, could object strenuously to plans that call for devolving certain facilities or eliminating certain programs. It is unclear, however, whether voters would view a reduced scope for the DOT as preferable to increasing fuel taxes or other sources of transportation revenue. Thus the rating of significant barrier is described as uncertain.

Enabling legislation—moderate barrier (uncertain). Enabling legislation could be required for states to eliminate certain programs, especially where transportation services have been expanded by state legislation over the past several decades.

Institutional restructuring—moderate barrier. Eliminating certain programs would require corresponding elimination or restructuring of some existing offices within state DOTs. In some cases, employees to be affected are unionized, and negotiations would be required under the terms of many existing union agreements.

J.2.6 Required Lead Time

There would be great variation and uncertainty in the time that would be required to reduce the scope of some state programs or to devolve the management of facilities to local governments. The variation would depend greatly on public responses and the frequency of lawsuits and other challenges. In some cases, lead times as short as 1 to 5 years seem realistic, but controversy could extend this period considerably. Therefore, a more conservative time frame of 5 to 10 years is assumed.

J.2.7 Qualifications

Any state could pursue this strategy, although it would appear to be a more likely outcome in states with the strongest anti-tax sentiment.

References

Bipartisan Policy Center. 2011. *Performance Driven: Achieving Wiser Investment in Transportation***.** Report of the National Transportation Policy Project of the Bipartisan Policy Center, Washington, D.C.

Cambridge Systematics. 2000. *NCHRP Report 446: A Guidebook for Performance-Based Transportation Planning.* TRB, National Research Council, Washington, D.C.

International Technology Scanning Program. 2009. *Public–Private Partnerships for Highway Infrastructure: Capitalizing on International Experience*. Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program, Washington, D.C.

Kissinger, P. and N. Testa. 1997. "Three Years Later and Exceeding Expectations: Highway Innovative Technology Evaluation Center." *Public Roads*, 61 (3).

Poister, T. 1997. *NCHRP Synthesis 238: Performance Measurement in State Departments of Transportation.* TRB, National Research Council, Washington, D.C.

Ralls, M. L. 2007 (November/December). "Transportation Structures Over, Under, and Across to 2020 and Beyond: Targeting a Service Life of 100 Years." *TR News*, 25 (3): 15–19.

Richmond, J. 2001. *The Private Provision of Public Transportation.* Taubman Center, John F. Kennedy School of Government, Harvard University.

Scauzillo, S. 2011 (December 29). "Caltrans to Shed Responsibility for Highway 39." *San Gabriel Valley Tribune.*

APPENDIX K

Strategies to Improve Auto and Truck Travel

In certain plausible energy futures, driving could become much cheaper on a per-mile basis. This would support higher growth in vehicle miles of travel for both cars and trucks, in turn leading to greater traffic congestion and possibly more vehicle crashes and fatalities. This appendix discusses several potential strategic directions aimed at mitigating traffic congestion, either by investing in new road capacity or managing existing capacity more efficiently, or by improving traffic safety, with additional benefits for cyclists and pedestrians. Note that strategies with the primary aim of improving alternative modes of travel, such as transit, biking, and walking, could also play some role in mitigating traffic congestion; such strategies are discussed in Appendix L.

The strategic directions reviewed in this appendix include expansion of road capacity, goods movement investments, congestion pricing, ITSs, TSM&O, and traffic safety measures.

K.1 Road Expansion

Under this strategy, states would focus on expanding highway capacity as a principal response to mounting traffic congestion in urban and suburban areas, as well as to provide enhanced mobility in rapidly developing areas. This would require significant financial resources; as such, pursuit of this strategy would likely require that a state also take steps to increase available transportation funding through one or more of the strategies discussed in Appendix I on revenue strategies.

K.1.1 Supportive Policies

The addition of new capacity could take the form of adding additional lanes to existing routes or building entirely new routes.

Adding capacity to existing routes. In urban areas and in many suburban areas, the road network is already dense, and much of the surrounding land is well-developed. In such instances, the provision of additional road capacity usually translates to adding more lanes to existing routes. Other types of improvements, such as the construction of over- or underpasses for grade-separated interchanges, can also increase the effective throughput capacity of a route.

Building new routes. In developing areas where the road network is less dense and much of the surrounding land is undisturbed, the construction of entirely new routes may offer greater transportation benefits than the expansion of existing routes.

Assumed policies for assessing road building. In assessing the potential effects of this strategy, it is first assumed that a state would take steps to boost transportation revenue—for example, through increased fuel taxes, higher vehicle registration fees, or mileage-based road-use fees. With the necessary funding in place, the state would then seek to add lanes to existing routes that are chronically congested and build new routes in areas of rapid growth, as appropriate. The ratings for this strategy assume that a state would not implement congestion tolling for the purpose of using existing or newly added capacity as efficiently as possible; that option is considered as a separate strategy later in this appendix. On the other hand, the assessment does assume that states would only invest in new capacity in cases where benefit–cost analysis indicates a strong return on investment.

K.1.2 Intended Mitigation Effects

Taking stock of the potential impacts under various energy futures, the main intent of building more roads would be to help ease traffic congestion.

Reducing traffic congestion—moderately effective. Traffic congestion occurs when the number of vehicles trying to use a route exceeds the capacity of that route. This is most common during morning and afternoon peak periods, although so-called nonrecurrent traffic congestion can also arise due to traffic incidents, construction activities, severe weather, special events, and the like. Building new capacity has the effect of increasing the ratio of the available road space to the number of vehicles traveling in a corridor, in turn reducing traffic congestion. Over the short term, congestion reduction can be dramatic. Over the longer term, however, as more vehicles begin to use the route due to latent and induced demand, congestion often returns to previous levels. Downs (2004) describes this common phenomenon as "triple convergence." In essence, traffic is already so severe in many metropolitan areas that numerous travelers routinely go out of their way to avoid peak-hour travel in the most congested corridors. Instead, they travel at less convenient times, select less convenient routes, or choose less convenient modes of travel—all to avoid sitting in traffic congestion. When adding road capacity leads to a reduction in peak-hour congestion, however, travelers will soon learn of the improvement. As they observe traffic flowing more freely, they will return to peak-hour use—converging from other times of travel, routes of travel, and modes of travel—slowly undermining the initial congestion-reduction benefits. Given this effect, road building is rated as being only moderately effective in reducing congestion over the long term.

K.1.3 Intended Shaping Effects

The strategy of building more roads would not be expected to exert significant influence on the types of fuels and vehicle technologies used in the transportation sector.

K.1.4 Other Effects

Beyond its potential effects in reducing congestion, road building can also play a role in enhancing economic productivity and growth. At the same time, it may have negative implications for the environment and equity.

Economy—moderately positive. Throughout the history of the United States, investments in transportation infrastructure—the Erie Canal, the Transcontinental Railway, and the Interstate system, to name a few prominent examples—have created the basis for continuing growth and prosperity. Even today, with a road network that is already extensive, investment in new routes or additional lane capacity can create jobs in the short term and support a stronger economy over the longer term. This is because well-selected road investments allow goods and services to be transported quickly and at lower cost, resulting in both lower prices for consumers and increased profits for firms (U.S. Department of the Treasury and U.S. Council of Economic Advisors 2012). While in some cases road investment has the effect of attracting economic activity that otherwise would have occurred elsewhere, a recent analysis of the literature indicated that investing in highway capacity remains generally positive for net economic growth (Shatz et al. 2011). With that in mind, the main reason that this strategy is rated as being only moderately positive with respect to the economy is that it does not ensure that road capacity, new or existing, will be used as efficiently as possible. To maximize the economic productivity of the road network, congestion pricing, as discussed later in this appendix, would be even more effective.

Environment and public health—moderately negative. By easing traffic congestion, investments in new road capacity can reduce emissions per vehicle mile of travel. On the other hand, new capacity also accommodates a greater amount of total travel. And, as described previously, the effects of triple convergence tend to erode the congestion-reduction benefits of new capacity over the long term. Finally, any new roads built in previously undeveloped areas could lead to loss of habitat and open space. Turning to public health, more highway investment could lead to more driving and less transit use, walking, or biking. On balance then, the environmental and public health effects can be generally characterized as negative overall.

Equity—moderately negative. Because of both noise and pollution, home values in areas immediately adjacent to freeways tend to be lower than in other areas. As a result, such areas are more likely to be populated by residents with lower incomes and other disadvantaged groups. Any of the negative local effects of expanding freeways are therefore likely to be concentrated among these groups as well, with negative implications for equity and environmental justice (Deka 2004).

K.1.5 Barriers

Financial constraints represent the main barrier to significant road expansion, although some degree of public opposition is likely as well. Incidentally, these two factors are cited by Brown, Morris, and Taylor (2009) as the main reasons for the decline in freeway building in this country since the 1960s.

Low public support—moderate barrier. Due to the potential concentration of negative effects on lower-income and minority groups living near freeways as well as the more general adverse effects of emissions and loss of undeveloped land, efforts to add lanes to existing freeways or build new routes are often opposed by social justice advocates and environmental proponents (Brown, Morris, and Taylor 2009). The process of environmental review affords such groups the opportunity to challenge major infrastructure projects in court, potentially delaying or even preventing their completion.

Financial cost—significant barrier. Building new road capacity is expensive. As a base estimate, the American Road and Transportation Builders Association (ARTBA) suggests a cost of about $1 million to $1.5 million per lane mile in rural areas and about $2 million to $2.5 million in urban areas (ARTBA 2012). However, construction costs have been rising more rapidly than general inflation over the past decade due to greater global demand for resources. Additionally, some projects can be far more expensive than the base costs listed by ARTBA. Factors that can contribute to higher costs include the need to tunnel or elevate structures and the need to acquire additional right-of-way that has already been developed, especially in urban areas with higher property values. As an illustration of how expensive a road expansion project can be, the cost of adding a single HOV lane on a 10-mile stretch of the I-405 freeway over the Sepulveda Pass in Los Angeles was $1.03 billion [LACMTA (Los Angeles County Metropolitan Transportation Authority) and Caltrans, undated], translating to over $100 million per mile. Finally, any new lane mile that is constructed will also need to be maintained over time, adding to the ongoing demands on a state DOT's budget. In short, building new road capacity is an expensive proposition; given that many states are already facing severe budgetary shortfalls, increasing revenue would be a necessary precursor to aggressive pursuit of this strategy.

K.1.6 Required Lead Time

Building or expanding roads entails a long process that includes planning, financing, detailed engineering, environmental review, and construction. While smaller projects could be completed in the 5- to 10-year time frame, larger projects are likely to take 10 to 20 years, or in some cases (e.g., where there is significant opposition and litigation) even longer.

K.1.7 Qualifications

This strategy could be most helpful in states or regions that are experiencing rapid growth. It is also likely to be easier and less costly in suburban and exurban areas than in dense urban locales.

K.2 Goods Movement Improvements

State DOTs are increasingly broadening the scope of project activities and expanding institutional roles to better support goods movement. In the past, freight has often been overlooked and underfunded in state planning processes. More recently, there has been renewed interest in the economic development potential of major international trade gateways and regional freight hubs, greater awareness of the environmental benefits of facilitating intermodal system efficiencies, and direct interest in strategies to shift truck travel off of major corridors and out of urban areas. As a result, states are pursuing broad, coordinated strategies to facilitate goods movement by engaging in projects and activities, often in cooperation with the private sector, to increase system efficiency and expand capacity. Intended outcomes can include enhancing economic development, reducing traffic congestion and delay, improving air quality and in turn public health, and enhancing travel safety and domestic facility security.

K.2.1 Supportive Policies

The approaches included in this strategy focus on supporting truck and rail freight movements, although sea and air modes are closely connected and also planned for by states in some cases. The overall objective is to enable more efficient goods movement, thus reducing impacts on shared infrastructure such as state highways.

Truck efficiency and capacity expansion. In recognition of the economic importance of goods movement and the parallel need to mitigate the negative impacts of heavy truck traffic on urban areas, regional corridors, and the Interstate system, many states are now focusing more on freight planning issues in general, and especially on truck travel. One option is to focus on roadway improvements designed to increase the connectivity to multimodal terminals, to major industrial areas, or between corridors. Often such road access is older and more constrained, traversing areas never designed for the larger equipment and heavier volumes of today. As a result, minor improvements in turning lanes, road width, interchange design, pedestrian overpasses, and other design features can offer significant improvements for truck movements. The *Connect*Oregon program, for example, is a lottery-bond–based initiative that generates revenues for investments in air, marine, rail, and transit infrastructure; freight-related investments are intended to improve connections between the highway system and other modes of transportation to facilitate the flow of commerce and reduce delay.

States are pursuing other activities such as truck-only toll lanes and new corridor development to add capacity specifically for goods movement. A related option is to modify vehicle size and weight restrictions to facilitate more efficient truck operations (Cambridge Systematics 2009). Finally, some states are also supporting the development of statewide freight planning, investing in better commercial freight data collection and analysis, or developing freight corridor plans and programs. In Washington State, the Freight Mobility Strategic Investment Board offers freight-specific project prioritization at the state level, while the Freight Action Strategy for the Everett–Seattle–Tacoma Corridor partnership improves public and private freight stakeholder coordination in the Puget Sound region (Washington State DOT 2008).

Rail efficiency and capacity expansion. Some states have also begun to commit public funding, in partnership with private rail operators, to support rail projects intended to relieve congested choke points and bottlenecks along major rail corridors or to improve access to major inland hubs and seaports. These actions reflect recognition of the need for states to play a greater role facilitating freight mode shifts from truck to rail in order to reduce interstate congestion and better use capacity on existing systems. Additional motivations are renewed interest in seaports and rail terminals as drivers of economic development and in the energy and environmental efficiency of rail options. System efficiency and expansion projects include capacity investments that improve connections of rail lines to terminals and seaports or roadway overpass and grade crossing separation redesigns to allow for double-stack containers or more direct rail service; grade separation projects can also play an important role in reducing traffic congestion on roads in the surrounding area. Many states are also expanding state loan programs or dedicating transportation funds typically reserved for highways to rail programs. For example, the State of Delaware recently funded rail bridge improvements to the Port of Wilmington. The Norfolk Southern Railroad will repay the state over 20 years through a toll on each railcar passing over the bridge. Missouri DOT has funded two railroad overpasses to eliminate bottlenecks in one of the most heavily used rail hubs in the country. Washington State DOT has committed $400 million to improve rail access and egress to the ports of Seattle and Tacoma (Horsley 2006).

Freight management and commercial vehicle operations. Advanced technologies are also being applied to better manage freight movements and reduce delays across modes. Automated pre-pass and weigh-in-motion screening systems, for example, help reduce unnecessary stops for trucks. Transponders on freight containers and automatic vehicle identification systems are also in use at border crossings and ports of entry to speed transit time and address security concerns. The Cross-Town Improvement Project in Kansas City, for example, was introduced to improve the efficiency of regional freight movement. This program included the development of an Intermodal Move Exchange (IMEX) database, designed to increase communication and coordination among truck, rail, and terminal operators with the goal of maximizing loaded moves and minimizing unnecessary return or empty trips. As a result, regional intermodal trips fell 22% in the Kansas City region, and significant reductions in cross-town and local delivery trips were achieved (Delcan Corporation 2007). Systems such as IMEX can be described as open-architecture information systems that use communications technologies and real-time information to improve freight logistics and travel patterns.

Multimodal freight policies to improve environment performance. DOTs may also pursue freight-related activities with the intent of mitigating environmental impacts associated with goods movement. States support projects and activities such as idle-free zones, truck-stop electrification, clean fuel and vehicle standards, vehicle equipment design, and active system management technologies to reduce the air quality impacts of goods movements. The Oregon and Connecticut DOTs, for example, are piloting truck-stop and rail corridor electrification projects to reduce emissions and create idle-free zones. The Port of Long Beach's (POLB) Clean Truck program restricts vehicles not meeting 2007 federal emissions standards from accessing the port (POLB, undated). Urban freight consolidation and pickup centers, intermodal hubs, and information systems are increasingly attracting attention as ways to reduce local delivery truck congestion in urban areas. Given the energy and emissions advantages of rail freight, more states are considering strategies to facilitate mode shifts from truck to rail as well.

Assumed policies for assessing DOT involvement in goods movement. The strategy assessments that follow assume that a state DOT would pursue a coordinated set of freight optimization strategies designed to reduce delays, improve system efficiency, and produce environmental benefits. To support these activities, the state DOT would expand its role in freight planning, prioritize freight project funding, and engage in new partnerships and institutional arrangements. The assessments also assume that a state would take steps to boost transportation revenue, through one or more of the options discussed in Appendix I, to allow for greater investment in freight-related projects.

K.2.2 Intended Mitigation Effects

Increasing DOT support for goods movement is likely to produce modest reductions in traffic congestion, improvements in safety outcomes, and some environmental benefits.

Reducing traffic congestion—moderately effective. Many bottleneck relief and capacity-expansion projects are aimed at reducing traffic congestion. In areas with high volumes of freight flow by rail or truck, targeted infrastructure improvements can result in significant congestion relief. For example, Southern California's Alameda Corridor project illustrates how improved freight flows through a local bottleneck affect destinations well beyond the immediate project area. The Alameda Corridor project is estimated to have significantly reduced congestion on rail connections between the ports of Los Angeles and Long Beach and the rest of the nation and to have eased local traffic congestion in the Los Angeles area on streets that formerly crossed the railroad at grade (Alameda Corridor Transportation Authority 2012). The strategy is only rated as being moderately effective at reducing traffic congestion, however, for two reasons. First, its effects will tend to be limited to areas or corridors with high levels of trucking activity rather than helping to reduce traffic congestion more broadly throughout entire metropolitan areas. Second, to the extent that traffic congestion is reduced, the improvement in traffic conditions may attract additional peak-hour trips resulting from latent or induced demand, eroding some of the benefits over the longer term (Downs 2004).

Improving safety outcomes—moderately effective. To the extent that freight management and roadway system improvements reduce congestion, there will be safety improvements associated with minimizing commercial and passenger vehicle incidents. In addition, roadway design improvements, such as pedestrian overpasses, eliminating at-grade crossings, interchange designs, and truck-only lanes, will produce immediate safety benefits, particularly in areas surrounding ports and terminals. Management systems and operational improvements are also stressed because of the safety and security improvements offered, particularly to address domestic security concerns for ports of entry and high-value infrastructure and facilities.

Improving air quality—moderately effective. Shifting significant freight volume from truck to rail, reducing bottlenecks and congestion on major corridors, minimizing stops and delays, and routing goods through consolidation centers and inland ports should all result in more efficient freight movements and, in turn, improved air quality. Other projects, such as rail corridor or truck-stop electrification, are specifically aimed at improving local air quality, especially in nonattainment areas. The effects of goods movement projects on air quality can be quite significant; in the case of the Port of Long Beach's Clean Trucks program, for example, qualifying trucks (those that meet or surpass the 2007 federal emissions standards) are estimated to produce 80% less pollution than older models (POLB, undated).

K.2.3 Intended Shaping Effects

These strategies are mainly intended to mitigate the adverse impacts associated with the potential for continued growth in truck travel and goods movement rather than to shape specific fuel and vehicle technologies.

K.2.4 Other Effects

In terms of broader effects, this strategy is likely to be quite positive for economic growth, moderately positive with respect to the environment, and neutral from an equity perspective.

Economy—highly positive. Freight movement plays a critical role in the national economy, and any improvements in the efficiency of the transportation system should translate to productivity gains for the trade, logistics, warehousing, and wholesale industries, ultimately translating to lower costs for other businesses and consumers. Congestion delays are a major source of economic loss for freight shippers and wholesalers, and they affect inventory costs and consumer prices. Improvements in the fuel economy of vehicles and trains based on reductions in congestion delays are also likely to produce returns for freight shippers. Larger-scale, catalytic investments, such as a major rail grade separation or investment in a port connector facility, could provide significant economic development and trade benefits to regional economies.

Environment and public health—moderately positive (uncertain). Some of the policies included here, such as the electrification of rail lines and idle-free zones for truck stops, are intended principally for their air quality benefits, with positive environmental and public health outcomes. Policies under this strategy should also improve safety, which can be viewed as beneficial from a public health perspective. Still other policies are aimed at greater efficiency in goods movement—for example, by eliminating empty truck trips, by reducing delays, and by encouraging multimodal transfer and mode shift to rail. These improvements are also likely to result in air quality benefits at local and regional scales. Improved efficiency, however, could lead to greater overall vehicle travel over the longer term, either from latent passenger vehicle demand that emerges as congestion is reduced or from increased demand for longer-haul trips as freight logistics costs decrease. Taking all of these factors into consideration, the environmental and public health impacts of this strategy are judged as moderately positive but uncertain.

Equity—neutral (uncertain). While policies for improving goods movement raise some equity concerns, it should be possible to mitigate these to a large degree by prioritizing the inclusion of environmental improvement projects, as has been assumed here, and by choosing appropriate revenue sources to fund improvements. Regarding the first of these, goods movement facilities and rights-of-way are historically located on commercial or industrial land often abutting low-income neighborhoods. Residents in these areas have suffered the brunt of the negative impacts associated with goods movement, including worsening traffic, harmful air pollution, and noise. These impacts can be mitigated through such policies as requiring cleaner trucks in port areas, idle-free truck stops, electrified rail, and reduced empty return truck trips. Regarding the second issue, appropriate funding sources, goods movement improvements can offer both public and private benefits. Careful analysis is therefore warranted in determining who should pay, and how much, for such investments. As a general rule, though, user fees—such as weight-distance truck tolls on the road network and container fees at ports—represent an equitable means of raising funds that also encourages more efficient use of the system (NSTIFC 2009).

K.2.5 Barriers

Financial cost represents the most significant barrier for this strategy, although some institutional restructuring may also be needed for a state DOT to take a more active role in planning and funding goods movement improvements.

Financial cost—significant barrier. The question of how to fund and finance freight transportation projects has been a topic of increasing interest at the local, state, and federal levels. Traditionally, most freight system improvements have been funded by the private sector, with minimal involvement from the public sector. However, many states are now beginning to provide some assistance in the funding of freight-specific improvement projects. The sheer size and cost of many of these projects, as well as the necessary involvement with private-sector freight partners, often mean that states and regions must draw on a wide range of sources to fund and finance freight improvement projects. State infrastructure banks, other loan assistance programs, and matching funds programs are being used to help offset the high up-front capital costs of these projects. Other projects are being funded with direct user fees generated from mechanisms such as truck-only tolls, weight-distance taxes, and per-carload or port entry fees.

Institutional restructuring—moderate barrier. Recognizing that freight trips typically involve greater transport distances across more jurisdictions than passenger trips, states and freight stakeholders must form coalitions and partnerships at increasingly large scales to plan for goods movement. Current examples of multi-state and multi-stakeholder partnerships exist at the regional, mega-regional, and cross-continental or international levels. The resources, institutional arrangements, and additional activities required of states involved in coordinated freight planning could present a moderate barrier.

K.2.6 Required Lead Time

While smaller-scale freight-related projects could be completed more quickly, larger-scale corridor developments or more ambitious programs, such as truck-only toll lanes, are likely to require considerable lead time to finance, plan, design, and construct. As a result, the time frame required for a DOT to assume a greater role in goods movement and fully implement a comprehensive set of freight optimization strategies is estimated to fall in the range of 10 to 20 years.

K.2.7 Qualifications

Given that all states have at least some goods-movement activities, this strategy should be helpful in all states. However, it would offer the greatest benefits in states with major port facilities, intermodal facilities, or goods-movement corridors.

K.3 Congestion Pricing

Congestion pricing is a road pricing strategy in which tolls or charges differ by time of day to provide a financial incentive for drivers to shift some of their trips from peak to off-peak periods. Congestion pricing has proven a potent though often controversial tool for reducing traffic congestion, generally in urban areas or along specific corridors.

K.3.1 Supportive Policies

To date at least four broad forms of congestion pricing have been implemented or considered. These are facility-based congestion tolls, cordon or area pricing, network-wide congestion pricing, and parking pricing.

Facility-based tolls. Facility-based tolls have two distinct configurations: full-facility congestion tolls, in which all users of a facility (e.g., a bridge, a tunnel, or a stretch of highway) pay tolls that are differentiated by time of day; and managed lanes, in which only a subset of the lanes of a facility are priced. The latter gives drivers a choice between paying for a faster trip in the less-congested lanes and continuing to use the more-congested general-purpose lanes for free.

In the United States, full-facility congestion tolls have only been implemented on routes that were already subject to tolls. In switching from a flat toll structure (i.e., the same toll rate at all times of the day) to a variable toll structure, it is possible to decrease the off-peak toll or increase the peak toll (or both). In Fort Myers, Florida, a discounted toll rate was offered just before and just after peak hours; this change encouraged many drivers to switch to driving during off-peak hours (FHWA 2008a). In 2000, the New Jersey Turnpike Authority introduced electronic toll collection (ETC) along with tolls that varied by time of day as well as by method of payment (cash versus ETC). The ETC off-peak toll remained the same as it had been previously, while the toll rates for peak-period use and cash payments increased. Currently there are at least nine examples of full-facility congestion tolls operating in the United States, with several others in the planning stages (FHWA 2012b).

Managed lanes, including HOT lanes and express lanes, have been the most popular approach to congestion pricing in the United States because they offer drivers a choice of paying extra for a faster drive when needed but still maintain the option of traveling in the general-purpose lanes for free. In the HOT lanes approach, the extra capacity in preexisting or newly constructed carpool lanes is made available to solo drivers willing to pay a toll for faster travel; to ensure that the lanes remain free-flowing, the toll rate for solo drivers increases as the lanes become more crowded. To date, HOT lanes have been implemented in California (I-15 in San Diego and I-680 in Alameda County), Colorado (I-25 and US-36 in Denver), Florida (I-95 in Miami), Georgia (I-85 in Atlanta), Minnesota (I-394 in the Twin Cities), Texas (I-10 and US-290 in Houston), Utah (I-15 in Salt Lake City), and Washington (SR-167 in Seattle). Express lanes are similar in concept to HOT lanes, with the toll rate varying to maintain a high level of service even during peak periods. The main difference between HOT lanes and express lanes is that all vehicles, including carpools, must pay for express lane tolls. By this definition, SR-91 in Southern California is the only current example of the express lanes approach. As noted by Poole (2012), many more HOT lane and express lane projects are currently in the planning stages.

Cordon pricing. With a cordon congestion toll, vehicles must pay a fee to travel within a congested area (typically a central business district or urban core) with a clearly defined boundary (the cordon line) during peak hours. Depending on implementation details, the toll may be incurred when the vehicle is observed to be traveling within the zone (often referred to as an area licensing scheme) or when the vehicle crosses the boundary into or out of the zone. In the latter case, a vehicle may be assessed the toll at most once per day or, alternatively, may be assessed the toll each time it crosses the boundary (up to some maximum number of times per day), and the toll rate may be structured to vary by both time and location of entrance or exit. The most well-known examples of cordon tolls are in Singapore, London, and Stockholm. Although Singapore initially began with a paper-based area licensing scheme in the 1970s, it switched to an all-electronic tolling system in the late 1990s and is now the most advanced program in terms of varying the toll rate by time and location around the charging zone to optimize flow rates in different areas throughout the day (Goh 2002, Fabian 2003). No cities in the United States have yet implemented a cordon toll to reduce urban traffic congestion, although both New York City and San Francisco have studied the concept. The plan in New York was nearly implemented but ultimately failed to gain enough support in the state legislature. The concept has been implemented, however, to help control truck traffic at the ports of Los Angeles and Long Beach. Under the PierPASS program, trucks that pick up or drop off loads during a defined set of peak hours must pay a fee of $60 per 20-foot container or $120 for any other size container; the fee does not apply for trucks that visit during off-peak hours (PierPASS undated).

Network-wide congestion pricing. Under network-wide congestion pricing, all vehicles traveling on the network of major routes (e.g., highways and major arterials) within a city or region would pay variable congestion tolls based on time of day, route, and distance traveled. Singapore's electronic road pricing (ERP) system approaches this idea. In addition to the cordon toll charged for entering the central business district, the Singapore system also includes gantries set up on highways and major arterials in the broader metropolitan region to assess tolls for traveling during peak commuting hours. No other such system has been implemented, but the Puget Sound region has conducted field trials of this concept (Puget Sound Regional Council 2008) and subsequently proposed, in its most recent long-range plan, Transportation 2040, to use congestion pricing on most of its major highways and arterials to both manage congestion and raise revenue.

Parking pricing. The concept of congestion pricing can also be applied to rates for on-street parking, as described by Shoup (2005). Many cities routinely underprice their curb parking spaces in relation to demand, resulting in a chronic scarcity of available spaces. Because the prices are so low, drivers have an incentive to circle around the block searching for an available space—described as "cruising for parking"—rather than paying higher rates for private off-street parking. This behavior, which can result in significant additional traffic congestion in busy commercial districts, wastes time, wastes fuel, and produces excess greenhouse gas and local air pollutant emissions.

The solution proposed by Shoup is to vary parking meter rates throughout the day in accordance with prevailing demand conditions with the goal of achieving a parking space occupancy rate of roughly 85%—that is, ensuring that there are usually one or two open curbside spaces on any block (assuming that a typical block has about 10 curbside spaces). Achieving this goal would make the process of parking much more convenient for visitors to an area, reduce congestion, and eliminate the extra time, fuel consumption, and emissions that result from cruising. Simultaneously, it would result in greater parking revenue for municipalities. To date, variable curb parking rates have been implemented in New York City, Washington, D.C., San Francisco, and other cities. Although states cannot directly implement street parking reforms, a state DOT could offer technical support, encouragement, and even incentives for cities wishing to pursue such a policy.

Assumed policies for assessing congestion pricing. HOT lanes have proven both successful and popular wherever implemented, and many more are currently in the planning stages. To date, though, their application has been limited to either existing HOV lanes with excess capacity or to new lane construction. However, because there are many congested freeways that lack HOV lanes and lack sufficient rights-of-way to construct new lanes, the potential for further expansion of the HOT lanes concept is ultimately constrained. For this assessment, a more ambitious approach to congestion pricing is considered where states would establish some form of managed lanes on all congested highway routes. In many cases, this would require the conversion of one or two existing general-purpose lanes to priced lanes, an idea likely to prove controversial. This would most likely occur in concert with a switch from fuel taxes to some form of electronic tolling or MBUF to raise highway revenue since either of these could provide the underlying technology able to support such a broad application of congestion tolls. The assessment does not assume the implementation of cordon tolls, network-wide congestion pricing (i.e., including arterials along with freeways), or variable parking pricing because any of these would likely be initiated by local jurisdictions. A state could, however, provide assistance and technical support for any such efforts on the part of local decision makers.

K.3.2 Intended Mitigation Effects

While the main intent of congestion pricing would be to reduce traffic congestion and offer a choice of faster travel in the priced lanes, the strategy could offer several other important benefits such as increased revenue, reduced DOT costs, improved safety outcomes, and support for alternative modes of transportation.

Increasing transportation revenue—highly effective. While it is difficult to provide a general estimate of how much additional revenue might be raised through congestion pricing on the highway network within a state, there is reason to believe that it would be substantial. The following examples help illustrate the potential revenue effects of congestion pricing. The Singapore ERP system, which includes both congestion tolls on major routes approaching the central business district along with a cordon congestion toll, grossed about $90 million and netted $72 million (both in U.S. dollars) in 2008 (Arnold et al. 2010). On the I-15 HOT lanes and SR-91 express lanes in Southern California, peak-hour congestion toll rates approach a dollar per mile; by contrast, California fuel taxes (at 18 cents per gallon) cost drivers in the state a little less than a penny per mile on average. A recent congressional commission study estimated that the revenue raised by tolling highways across the country (including base tolls and, possibly, congestion tolls) could range between $22 billion and $105 billion, comparing favorably with the roughly $35 billion currently generated by federal fuel taxes and other sources of HTF revenue (NSTIFC 2009).

Reducing DOT costs—highly effective. Roads can accommodate greater vehicle throughput when traffic is flowing smoothly than when traffic is heavily congested. During peak hours on the SR-91 express lanes in Southern California, for example, the congestion-tolled lanes serve almost twice the number of vehicles per lane per hour as the heavily congested general-purpose lanes (Obenberger 2004). Broad application of congestion pricing to maintain free-flowing traffic conditions should therefore enable more efficient use of existing capacity, in turn lessening the need for DOT investments in new capacity. Reflecting this potential, a recent Conditions & Performance report from the FHWA estimated the costs of maintaining or improving the nation's road network both with and without congestion tolls (FHWA 2010). The findings were dramatic. In the absence of congestion tolling, the cost of improving the Interstate system for projects with a benefit–cost ratio of at least 1.5 was estimated at $47 billion. With the addition of congestion tolls, and again using a benefit–cost ratio of 1.5, the cost of improving the Interstate system would decrease to just $24 billion (Poole 2010), nearly a 50% savings.

Reducing traffic congestion—highly effective. This is the main goal of congestion pricing, and evidence shows it can be very effective in this regard. For example, during peak-hour travel on the SR-91 express lanes, per data reported by Obenberger (2004), traffic speed in the priced lanes averaged 60 to 65 miles per hour, while traffic speed in the adjacent heavily congested general-purpose lanes averaged just 15 to 20 miles per hour. When Singapore upgraded to its ERP system for congestion pricing in the 1990s, peak-hour travel speed in the central business district (CBD) nearly doubled to 36 km per hour, while peak-hour travel speed on the radial expressways approaching the CBD increased from 45 to 65 km per hour (Goh 2002). Early results in London were similarly impressive. After launching the central charging zone, congestion delays within the zone were reduced by 30%, travel speeds within the zone increased by 21%, and travel speeds from outer London to the zone increased by 12% (Santos and Shaffer 2004).

Another particularly valuable attribute of congestion pricing as a means of reducing traffic congestion is that it will remain effective indefinitely provided that the charge rates are allowed to vary with changes in demand. This is not the case with most other congestion-reduction strategies pursued in the past. The basic challenge is that traffic is already so severe in most metropolitan areas that many travelers choose to avoid peak-hour vehicle travel in congested corridors whenever possible. They may, for example, travel at different times of day, by different routes, or by different modes. When an investment is made to reduce traffic congestion within a corridor—such as adding a lane to an existing freeway or building a new transit line that is successful in luring some drivers from their cars—the flow of traffic may be significantly improved over the near term. Over the longer term, however, travelers who had taken steps to avoid severe peak-hour traffic will learn of the improved conditions and adjust their trips—shifting back from other modes, routes, or times of day—to take advantage of the faster peak-hour traffic flow. This phenomenon, described by Downs (2004) as "triple convergence," tends to slowly but steadily erode the benefits of most traffic reduction investments within a few years.

A critical benefit of congestion pricing is that it is the only strategy for reducing traffic congestion that resists the effects of triple convergence. This is because the imposition of the congestion charge—again assuming that it is structured to fluctuate with demand—serves as an ongoing deterrent that acts to prevent excessive use of a facility during peak hours. Over a period of several decades now, Singapore's continued application of congestion tolls to reduce traffic in and around the central business district has experienced ongoing success (Olszewski 2007).

A final point is that the application of congestion pricing for a subset of lanes on all crowded freeways, as envisioned in this assessment, could actually help reduce congestion on parallel untolled routes as well. This may seem counterintuitive at first given that congestion tolls are likely to induce some drivers to choose an alternate facility. One of the benefits of congestion pricing, however, is that it keeps traffic moving smoothly; as noted previously, this allows a facility to accommodate much greater vehicle throughput per lane per hour than occurs when the lanes become significantly congested. Broad application of congestion pricing throughout the network of highways within a region could therefore allow more vehicles to use those highways during peak hours, in turn drawing off some of the traffic from parallel free routes.

Incidentally, the benefit of allowing increased vehicle throughput does not necessarily apply to all forms of congestion pricing. Cordon congestion tolls, for example, tend to reduce total vehicle use within the priced zone. In the three major cordon toll areas implemented to date, overall traffic volume in the charge area declined by 30% in London [Transport for London (TfL) 2008], 22% in Stockholm (City of Stockholm 2006) and 45% in Singapore (Willoughby 2000).

Improving safety outcomes—moderately effective (uncertain). By promoting more even traffic flow and eliminating the abrupt stop-and-go conditions associated with traffic congestion, it is possible that congestion tolls could lead to improved safety outcomes, although the research team is not aware of studies to confirm this. While evidence indicates that cordon tolls can be effective in reducing vehicle crashes (TfL 2008), this is likely to be at least partly a result of reduced traffic volume. As noted previously, congestion pricing on the freeways would actually support greater overall volume during peak hours.

Improving air quality—moderately effective (uncertain). Congestion pricing can in principle reduce emissions through two mechanisms: by smoothing traffic flow and by reducing aggregate vehicle travel. Applying congestion pricing on the freeways would accomplish the former, but the effect on total travel within a corridor across priced and unpriced routes during the course of a day is unclear. At an aggregate level, congestion tolls should increase the average financial cost of travel while reducing the average time cost of travel; whether this interaction will lead to more or less total travel is not certain. Turning to empirical evidence, Burt et al. (2010) reviewed data from eight examples of several different types of congestion pricing, including both trials and implementations. Data on air quality effects were available for five of the examined cases. Of these, two projects were credited with air pollutant reductions estimated in the range of 8.5% to 16% (depending on the specific pollutant), one resulted in an unspecified level of reductions, one resulted in no observed effects, and one led to an increase in emissions, although the level of increase was less than that which occurred on a control roadway.

Reducing GHG emissions—moderately effective (uncertain) The real-world effects of congestion pricing on GHG emissions have not been closely studied (Burt et al. 2010), but they should be broadly similar to the effects on local air pollution. In modeling the effects of congestion reduction on greenhouse gas emissions under realistic driving conditions, Barth and Boriboonsomsin (2007) found that per-mile emissions are lowest for travel speeds in the range of 40 to 60 miles per hour and much higher under more congested conditions.

Enhancing non-automotive travel options—highly effective (uncertain). Congestion pricing could improve transit and other non-automotive travel options in two ways. First, any improvement in travel speeds will also help make bus transit faster. With implementation of the ERP system in Singapore, for example, the reduction in traffic congestion allowed for an increase in bus speeds of 16% (Goh 2002). In London, bus delays within the charging zone were reduced by about 30% (Santos and Shaffer 2004). Such gains, combined with desire to avoid the congestion charge, have translated to increased ridership. In Singapore, the mode share for bus transit traveling into the charging area increased from 30% to 46% (Willoughby 2000). In London, peak-period bus ridership increased by 38% (TfL 2008), while overall transit use in Stockholm increased by about 6% (City of Stockholm 2006).

Second, congestion pricing revenues are often, though not always, directed to transit improvements in the region. Providing improved travel options to those unwilling or unable to pay the congestion tolls can help mitigate equity concerns commonly associated with congestion pricing (Ecola and Light 2009). In the case of the I-15 HOT lanes in San Diego, for example, the modest net operating proceeds are used to help subsidize express bus service in the corridor. In London, where the net revenue stream is several orders of magnitude greater, all proceeds have been devoted to significant bus service improvements along with enhanced bicycle and pedestrian infrastructure (TfL 2008). Revenue from the Singapore ERP system, in contrast, is channeled into the general fund. In a more democratic society such as the United States, the political calculus of congestion pricing suggests that a sizeable share of the revenue resulting from broader adoption of congestion pricing revenue would likely be devoted to transit improvements to offset equity concerns.

K.3.3 Intended Shaping Effects

While the main objective of congesting pricing is not to influence energy use patterns, it could play a modest role in reducing oil consumption and the energy cost of travel.

Reducing oil consumption—moderately effective (uncertain). Vehicle fuel economy degrades significantly in highly congested traffic conditions (Barth and Boriboonsomsin 2007). By promoting more smoothly flowing traffic, congestion pricing could improve the average fuel economy of vehicles in use, thus decreasing overall fuel consumption. An important caveat is that by allowing for more efficient use of existing capacity, congestion pricing may also allow for more total peak-hour trips. If at least some of these are new trips as opposed to trips that otherwise would have been taken using other routes or at different times of day, the aggregate effect on reduced fuel use could be diminished. This creates some uncertainty for the rating.

Reducing energy cost of travel—moderately effective. From the perspective of an individual driver, as described previously, the smoother traffic flow on congestion-priced facilities would lead to greater realized fuel economy, in turn reducing the energy cost of travel. (Note, however, that the total monetary cost of driving would likely increase as a result of the tolls, but this would be offset by the value of reduced travel time and greater travel time reliability.)

K.3.4 Other Effects

A shift to broader application of congestion pricing would provide strong economic benefits and could offer more modest environmental and equity gains.

Economy—highly positive. Congestion pricing would provide strong support for greater economic efficiency and growth in at least three ways. First, from a theoretical view, congestion pricing helps to better align the cost that a driver pays for each trip with the full social cost (including delays imposed on others) imposed by the trip (Downs 2004). This leads drivers to ration their least-valued trips (i.e., those for which the benefits are exceeded by the costs, with the latter including previously unpriced congestion delays), thus leading to more economically efficient use of the system. In more practical terms, failure to reflect the cost of congestion delays in the price of travel leads to overconsumption of road space, which in turn manifests as traffic congestion. Congestion pricing, in contrast, stimulates changes in travel behavior that result in significantly reduced peak-hour delays. In terms of concrete economic effects, this would lower the delivery time and cost of freight movements; it would lead to better quality of life, which could help attract companies and employees to locate in a region; and it would reduce the costs of excess fuel consumption caused by inefficient stop-and-go traffic patterns, potentially leading to marginal gains in disposable income and consumer demand.

Second, as described earlier, congestion pricing would lead to significantly more productive use, in terms of vehicles per lane per hour, of existing highway capacity, thereby reducing the level of public investment needed to provide a given level of service.

Third, congestion pricing would create a potentially significant revenue source to fund needed transportation investments. And, unlike other revenue mechanisms, congestion tolls would provide unambiguous information about where to direct investments in order to provide the greatest economic benefits (NSTIFC 2009). Specifically, when congestion tolls are structured to vary with demand in order to maintain smoothly flowing travel, the level of the tolls—that is, the amount to which they need to rise in order to maintain optimal flow—offers a helpful measure of the disparity between demand and available capacity. Assuming that travel behavior correlates at least roughly with economic activity, the relative level of congestion tolls on different facilities should help clarify where additional capacity investments would allow for the greatest productivity gains.

Environment and public health—moderately positive (uncertain). As described above, the environmental effects in terms of local air quality and greenhouse gas emissions are likely to be moderately positive, though this is viewed as uncertain. Additionally, the more productive use of existing capacity enabled by congestion pricing may reduce the need for investment in new capacity, which could offer environmental benefits. Congestion pricing could also encourage some mode shift to non-automotive alternatives; in combination with improved air quality, this could offer benefits to public health.

Equity—moderately positive. The equity implications of congestion pricing can range from positive to negative and will generally vary from one project to another. Relevant considerations include how equity is defined, the type of pricing scheme to be employed (e.g., HOT lanes versus cordon tolls), and how the revenue stream is directed. In terms of possible definitions for equity, congestion pricing performs quite well with respect to aligning costs and benefits—specifically, those who benefit the most from faster peak-hour travel must also pay higher costs. On the other hand, congestion pricing may have negative equity effects for drivers, particularly those from lower-income or other disadvantaged groups, who find themselves priced off of the roads during peak hours. This is most problematic, however, for cordon tolls and network-wide congestion pricing, which apply to all roads in an area and offer no untolled options. It is much less of a problem for managed lanes, as envisioned in this assessment, because drivers would still have the option of using the remaining general-purpose lanes for free. To further address any remaining equity concerns, some of the resulting revenue can be directed to investments that tend to benefit disadvantaged groups, such as improved transit options. Additionally, it is possible to offer discounts or exemptions to lower-income drivers to lessen any negative effects (Ecola and Light 2009). Finally, it is worth noting that congestion pricing can be less regressive than other forms of taxation often used to fund transportation, such as sales taxes (Schweitzer and Taylor 2008). In short, the form of congestion pricing assumed here is likely to perform well for some measures of equity and be relatively neutral for others.

K.3.5 Barriers

While congestion pricing has been widely touted as an effective strategy to reduce congestion, few cities have yet turned to congestion pricing as a solution. This stems from the considerable barriers that confront congestion tolls.

Low public support—significant barrier. Similar to direct user fees, the adoption of congestion pricing is hampered by lack of public support and in some cases active opposition. This low support can be attributed to a lack of understanding regarding fuel taxes (many drivers have little idea about how much they currently pay in fuel taxes) and a corresponding view that congestion tolls would represent double taxation, opposition to increased taxes and fees in any form, concern that the supporting technologies will lead to further erosion of privacy, concern that lower-income drivers will be further disadvantaged, and skepticism that congestion pricing will achieve its goals. Political leaders are generally sympathetic to such concerns. Also, the current lack of public experience with pricing appears to make a difference. With regard to cordon pricing in Stockholm and London, opinion polls found that public support increased once the systems were put in place and proved to be effective. In Stockholm, support increased from about 30% to just over 50% (Algers, undated), while in London, support rose from 40% to 57% (Glaister 2007). Different forms of congestion pricing have ranged widely in their level of public support in the United States, with general approval of HOT lanes in most locations and active opposition to cordon pricing in New York City. Given that the approach considered here would involve the conversion of general-purpose lanes to priced lanes, it seems safe to assume that low public support would likely prove a significant barrier.

Technical risk—moderate barrier (uncertain). While well-developed technologies for collection of congestion tolls exist, there still may be some risk. For example, a state might choose to implement congestion pricing on all congested freeways as part of a larger shift to mileage-based user fees. This would likely entail the deployment of a more complex system architecture, introducing some technical uncertainty.

Enabling legislation—significant barrier. Broader application of tolling on congested freeways would almost certainly require enabling state legislation. While the most comprehensive appraisal of legal issues at the state level was done with regard to mileage-based user fees, the findings from that review suggest that legislation would be helpful and in some cases necessary in dealing with such issues as whether the charges are legally viewed as taxes, fees, or tolls; whether there are limits on how revenues can be used; how rates would be set; how revenues would be collected and distributed; whether operations could be outsourced; how violations would be enforced; and how to ensure driver privacy (I-95 Corridor Coalition 2010). Enabling federal legislation would also likely be needed before states could pursue this strategy for general-purpose lanes on Interstate highways.

Institutional restructuring—moderate barrier (uncertain). In contrast to other common state transportation revenue sources such as fuel taxes and registration fees, many toll roads are operated by private industry. If a state were to pursue broad application of congestion tolls, it might choose to engage one or more private firms to assist in setting up and operating the system. Developing the capacity to work with industry in this manner could, for some states, require moderate institutional restructuring. Additionally, if local jurisdictions within a state decided to set up cordon tolls or network-wide congestion pricing on the arterials to be integrated with state-levied congestion tolls on the freeway system, it would be necessary to set up a collaborative institutional partnership between the state and local jurisdictions to allow for proper collection and distribution of revenue.

K.3.6 Required Lead Time

Although electronic tolling technology is already proven, setting up a congestion tolling network covering all congested freeways would still be somewhat complex and time consuming. If expedited, however, it could plausibly be accomplished within a 5-year time frame once the decision to do so had been made.

K.3.7 Qualifications

Congestion pricing is appropriate for congested areas, which for the most part means metropolitan areas. Thus this strategy will be most applicable for states that have large urban areas and less applicable for predominantly rural states.

K.4 Intelligent Transportation Systems

The term “intelligent transportation system” describes the use of advanced applications involving vehicle-to-vehicle (V-V) and vehicle-to-infrastructure (V-I) communications to improve safety, mobility, and operating efficiency in the transportation network. The U.S. Department of Transportation’s ITS Joint Program Office describes its mission as focusing on “intelligent vehicles, intelligent infrastructure and the creation of an intelligent transportation system through integration with and between these two components.” The Connected Vehicle initiative, formerly called IntelliDrive or vehicle-infrastructure integration (VII), includes the development of safety, mobility, and environmental applications that use real-time and archived data to improve vehicle operation and reduce crashes, improve transportation system management and operations capabilities, and reduce the environmental impacts of travel-related choices (RITA 2012b).

There is considerable overlap, in terms of applicable technologies and objectives, between ITSs, as defined previously, and rapidly emerging autonomous vehicle technology.

The latter, however, requires much less in the way of public investment—though it would still require federal or state action to establish relevant legal and regulatory frameworks—and in particular does not depend on V-I communications to support much of the intended functionality. Thus, autonomous vehicles could prove successful even if the government does not choose to invest in instrumenting the road network with sensors and electronic communications technologies. This creates some degree of risk that major public investments in ITSs could be overtaken and rendered superfluous by private-sector development of autonomous vehicles.

There is also some overlap between ITSs and the strategy of focusing on improved TSM&O, discussed later in this appendix, as both rely on technology to improve the transportation system. The key distinction being made in differentiating between these two strategies is that ITSs, despite their considerable promise, are still emerging and for the most part remain unproven in terms of broadscale application; thus, both the cost and technical risk factors are significant. In contrast, TSM&O involves proven technologies—such as freeway ramp metering or traffic signal synchronization—that are already widely used but in some cases could be upgraded or deployed to additional areas.

K.4.1 Supportive Policies

ITSs and connected vehicles strategies are commonly discussed in two areas: V-V applications and V-I applications.

V-V applications. By providing drivers and automated vehicle control systems with information on external conditions—such as the relative location of other vehicles—such connected-vehicle applications can identify hazards and take steps to avoid crashes or loss of vehicle control. V-V applications such as proximity warnings and advance notification of rapid deceleration by downstream vehicles allow drivers to assess threats and react more quickly. Increasingly, V-V applications are interacting with automated on-vehicle safety systems like adaptive cruise control that maintain a safe distance between two vehicles with no need for driver input. Transit V-V applications include the ability for drivers to determine when bus headways are reaching unacceptable levels due to bunching or spreading, or when a bus or train should wait at a stop to facilitate passenger transfers. Currently, these applications are limited to newer vehicles and are not fully integrated systems. In the future, these technologies could allow for roadways to accommodate significantly more vehicles traveling in very close proximity and at extremely high speeds with virtually no driver instructions (RITA 2012b).

V-I applications. Wireless communications technologies have greatly simplified and reduced the costs associated with V-I applications. Emerging technologies include the ability to control vehicle speeds and maintain safe operations during weather events, to smooth vehicle flows during periods of roadway congestion and prevent shockwaves that reduce vehicle throughput or cause rear-end collisions, and to optimize aggregate fuel consumption and emissions based on environmental factors (RITA 2012b). V-I applications are already being used to more efficiently weigh and screen commercial vehicles and cargo and help commercial vehicle drivers find safe places to park and rest. Positive train control, a form of V-I integration for trains, is being used today to keep trains at safe operating speeds and at safe distances. Bus rapid transit signal prioritization, in which an electronic message transmitted from an oncoming bus instructs a traffic signal to turn green a little earlier or remain green a little longer, is another current example of V-I communication applications.

Other ITS and connected-vehicle policies. Aggregations of vehicle travel data compiled from V-V and V-I applications can be used by transportation system operators to improve system operating efficiency, or they can serve as the basis for real-time traffic information across the road network that allows travelers to adjust their trip decisions accordingly. Both of these are described in the subsequent TSM&O strategy assessment. As noted, there is a close relationship between ITSs and TSM&O.

Assumed policies for assessing ITSs and connected vehicles. ITSs and connected-vehicle systems are still being developed, deployed, and improved on. The following assessment of this strategic direction assumes that a state would take an active role—for example, upgrading infrastructure with appropriate sensing technology—in support of the eventual implementation of ITSs in which many real-time vehicle operating decisions are automated or heavily assisted by onboard computers.

K.4.2 Intended Mitigation Effects

Core policy aims of ITSs include reducing traffic congestion and improving safety outcomes. Additionally, adoption of an ITS could offer air quality and GHG emission reduction benefits.

Reducing traffic congestion—moderately effective. At full implementation, an ITS could help optimize flows and reduce system-wide traffic congestion by rerouting vehicles, passengers, and freight around bottlenecks and incidents. Also, by maintaining appropriate headways between vehicles, ITSs could reduce the need for sudden braking that can trigger stop-and-go traffic conditions. Likewise, ITSs could prevent a significant percentage of vehicle crashes, one of the major sources of nonrecurrent traffic congestion. However, while an ITS can make more efficient use of existing capacity, it would do little to halt any growth in travel demand that might result from other factors (e.g., economic and population growth). To fully mitigate traffic, therefore, it would likely be necessary to pair an ITS with complementary supply and demand policies such as congestion pricing, transportation demand management, and strategic capacity expansion, where appropriate.

Improving safety outcomes—highly effective. Safety is one of the primary benefits expected from ITS applications. Connected-vehicle safety applications offer the promise of eliminating up to 82% of crash scenarios with unimpaired drivers, preventing tens of thousands of automobile crashes every year (RITA 2012b).

Improving air quality—moderately effective (uncertain). With the reductions in stop-and-start traffic conditions possible with ITS applications, local and regional air quality may be positively affected. However, air quality improvements will depend on the current fuel and fleet mix in use and may be offset by additional induced or latent travel demand increases as a result of system optimization.

Improving GHG emission reductions—moderately effective (uncertain). Similar to air quality improvements, smoother traffic flow conditions should translate to improved fuel economy, thereby reducing GHG emissions per vehicle mile. Increased vehicle travel spurred in part by improved system efficiency could, however, offset such benefits.

Enhancing non-automotive travel options—moderately effective. Any benefits in reducing traffic congestion would accrue to bus transit as well, and the ability of transit vehicles to communicate with traffic signals for bus signal prioritization would also speed bus journeys.

K.4.3 Intended Shaping Effects

Although ITSs are not primarily aimed at energy technologies, successful deployment could help reduce fuel consumption and, in turn, the cost of travel.

Reducing oil consumption—moderately effective (uncertain). For most vehicles, fuel economy is greatest at between 40 and 60 miles per hour (Barth and Boriboonsomsin 2007). I-V applications can control vehicle speeds to optimize fuel efficiency depending on roadway conditions. Vehicle control technologies that reduce speeding, rapid acceleration, and hard braking can improve individual vehicle gas mileage by 33% at highway speeds. The use of cruise control can improve vehicle fuel economy by up to 7% (I-95 Corridor Coalition 2011). Yet while individual vehicle fuel economy may be improved, full-scale ITS implementation would also increase the effective capacity of the road network, potentially inducing more total travel. Thus the rating is qualified as uncertain.

Reducing energy cost of travel—moderately effective. From the perspective of the individual driver, as described previously, ITSs would enable greater fuel economy, in turn lowering the energy cost of travel.

K.4.4 Other Effects

From a broader perspective, the effects of ITSs should be positive for both the economy and the environment, and neutral with respect to equity concerns.

Economy—highly positive. ITS technologies should increase effective system capacity, safety, and the cost of travel in comparison to current conditions. By moving more passengers and freight per lane mile or track mile, an ITS would help the system operate more efficiently, in turn providing net positive economic benefits at both the micro and macro scales. Additionally, an ITS would dramatically reduce the number of crashes and their attendant economic costs.

Environment and public health—moderately positive. As discussed earlier, the effects of ITSs on air quality and greenhouse gas emissions, although uncertain, are expected to be positive. Additionally, ITSs would reduce the need for system capacity expansion and its associated environmental costs. The potential effects of ITS investments in improving air quality, improving safety, and enhancing non-automotive travel modes should all be beneficial for public health.

Equity—neutral (uncertain). ITS applications that improve transit service should have positive equity effects, given that transit is most frequently used by lower-income households and other disadvantaged groups. The same technology, though, can make vehicle travel even more attractive. Due to the high costs of incorporating ITS technology into private vehicles, there could be an initial period during which many of the ITS benefits would accrue mainly to wealthier drivers with newer vehicles, as well as to commercial vehicles. Over time, though, as the technology diffused through the passenger fleet, the benefits would be more widely shared. Taking these various factors into consideration, the equity effects appear to be neutral, if somewhat uncertain.

K.4.5 Barriers

There are a number of barriers to implementing full-scale ITSs, and most of these are likely to be significant.

Low public support—moderate barrier. The public is often resistant to major shifts in technology, and this could prove to be the case with ITSs. One possible concern relates to driver privacy. Additionally, there could be resistance to the notion that ITSs would give greater control to either the government or to computer systems over vehicle operations, route selection, and the like.

Financial cost—significant barrier. Developing advanced ITSs would be an expensive proposition, involving the inclusion of enabling technology within each vehicle, the retrofitting of existing infrastructure with sensors and communication capabilities, and the development of computing and telecommunications platforms to integrate the overall system. While the investment would likely be repaid over time through greater operational efficiencies, it could still prove challenging to assemble the necessary up-front investment.

Technical risk—significant barrier. ITS technologies face significant technical risks and will require extensive testing before they can be approved for use by federal or state governments and accepted by regulatory agencies, insurers, vehicle owners, and fleet operators. Of particular concern, for example, is the possibility that bugs in a system involving semi-automated vehicle control could lead to fatal crashes. Such systems would need to be proven as highly reliable prior to deployment, and the prospects for success in this regard are not certain. From the perspective of a state interested in an ITS, then, there is a real risk that early investment in an ITS—for example, equipping roads with sensors and transponders in anticipation of ITS-equipped vehicles—would not ultimately lead to successful implementation and thus would represent wasted resources. Also, as discussed earlier, it is quite possible that rapidly emerging autonomous vehicle technology could provide many of the promised benefits of an ITS with little in the way of public investment. This compounds the risk that significant state investments in an ITS would yield little additional benefits.

Enabling legislation—significant barrier (uncertain). Broad application of ITSs would likely require legislation to clarify privacy, liability, and data ownership issues, possibly at the federal level. For example, it might be necessary to specify which parties could be held liable in a crash involving one or more vehicles equipped with semi-automated collision-avoidance systems. ITSs might also provide access to much more detailed information about individual travel behavior, motivating legislation to clarify privacy rights in the context of telematics.

Institutional restructuring—significant barrier. ITSs could affect who is responsible for operating and maintaining which components of the transportation system—including, potentially, a larger role for private-sector systems integrators. In order for the system to be fully optimized, either a central authority or strong institutional and cross-jurisdictional coordination mechanisms will need to be in place. Given the complexity of implementing ITS technologies to date in many metropolitan areas, institutional barriers could represent the most significant obstacle to overcome in implementing these strategies.

K.4.6 Required Lead Time

Given the span of challenges, full implementation of ITSs and connected-vehicle systems would likely require greater than 20 years of lead time.

K.4.7 Qualifications

ITSs should be applicable in all states, although the specific applications most helpful could differ between rural travel conditions and urban travel conditions.

K.5 Transportation Systems Management and Operations

TSM&O encompasses systems, services, and projects—potentially multimodal and cross-jurisdictional—involving the collection, analysis, and application of real-time and archived system performance data to actively manage transportation infrastructure and services. TSM&O applications seek to make more efficient use of existing capacity and to improve the security, safety, and reliability of transportation systems (FHWA 2008b). In its focus on the application of data integration and sophisticated analytics to improve transportation systems, TSM&O can be viewed as similar to ITSs, described earlier in this appendix. The term “ITS,” however, is often used to describe advanced applications, such as high-speed vehicle platooning, that may not be deployed for many years. In contrast, TSM&O focuses on well-defined applications of existing technologies that are already deployed in the active management and operations of transportation systems.

K.5.1 Supportive Policies

Many TSM&O applications are already commonly used by DOTs. This assessment focuses on core approaches to system management and operations, including multimodal applications, as well as on real-time system information and incident management practices.

Proactive traffic management. Historically, many states first initiated TSM&O programs with a focus on better management of freeway and arterial traffic. Early applications were signal synchronization, ramp metering, and variable speed limits. The underlying technology has advanced considerably in recent years such that further benefits can often be achieved by upgrading older systems. Adaptive signal control systems, for example, are now able to respond to real-time traffic conditions by adjusting phase and cycle lengths to accommodate uneven flows of traffic through intersections in a corridor or network. Some signal control system algorithms can combine real-time and archived data to proactively adjust signal times to prevent or significantly reduce intersection-related bottlenecks, particularly during recurring special events or holiday weekends. Ramp metering evenly distributes traffic merging onto a congested freeway. Variable speed limits, or speed harmonization, help prevent disruptive shockwaves from forming in a stream of traffic that is nearing the limits of the roadway’s capacity. Hard shoulder running, or the allowable use of roadway shoulders, during peak travel times, may be communicated by variable message signs.

Multimodal system management. Transit agencies use automatic vehicle location (AVL) and global positioning systems (GPSs) to track locations of buses to better manage on-time performance, bus headways, and the synchronization of arrivals and departures at intersecting transit routes. The net effect is to improve efficiency and reduce average passenger wait times. Positive train control (PTC) technology allows train dispatchers to monitor train locations and control speeds to prevent collisions between trains, reduce the likelihood of incidents involving construction workers and equipment, and reduce derailments due to excess speeds. Increasingly, integrated corridor management (ICM) approaches are allowing for more sophisticated management of multiple parallel roadways and transit facilities in a single corridor. Freeway system management, arterial signal systems, bus operations, and rail operations can be managed jointly by implementing a complementary set of strategies across modes. ICM requires sharing of information across jurisdictional boundaries and institutional silos and allows more comprehensive information to be disseminated to system users (RITA 2012a).

Real-time system information. Providing up-to-date information about travel times, incidents, delays, weather-related closures, and congestion on multiple modes and routes helps transportation system users decide whether to make a trip, when to start a trip, what mode to use, and what route to take. Real-time system information can be delivered via on-road variable message signs (such as those that display travel times to downstream destinations, sometimes via two alternative routes), via audio and video systems in transit stations and on transit vehicles (including screens or public address announcements with next-vehicle arrival times and information about delays and service disruptions), to wireless communication devices (including navigation devices, smartphones, and tablets), via public and private websites, via toll-free phone numbers such as 511 systems, via dedicated short-range highway advisory radio, and via broadcast media (traffic and transit updates on the radio and television news). Real-time system information is also sometimes monitored by a central dispatcher employed by a truck or bus fleet operator and then relayed to drivers by radio (Deeter 2009). As discussed in the earlier assessment of the ITS strategy, one of the potential benefits of the U.S. Department of Transportation's Connected Vehicle research initiative is to expand real-time data availability to include information on situational safety risks, environmental and weather conditions, congestion data, real-time cost information (for example, variable toll rates on managed lanes), and parking availability (both at truck rest areas and in urban parking garages). Future real-time data and computational algorithms could also allow for comparisons of costs and travel times via multiple modes (RITA 2010).

Incident and delay management. Incident management is another area in which TSM&O approaches can offer significant benefits. Weather, natural disasters, crashes, special events, and construction work zones can all lead to additional, and in some cases unpredictable, traffic delays and safety risks, and the application of certain TSM&O technologies—for example, warning of downstream incidents or roadwork on variable message signs or altering signal timing to clear special event traffic more quickly—can help mitigate these challenges. Emergency medical services, fire, police, and tow operators are all key partners with transportation agencies in implementing incident management strategies. Many traffic management centers invite emergency responders to station personnel at the center to facilitate communication of information about the location and severity of incidents (for example, via a live video feed or closed-circuit transmission of audio from first responders). Roving road-service patrols and pre-positioning of emergency responders and equipment can cut incident response and clearance times, helping to relieve incident-related bottlenecks and safety hazards.

Assumed policies for assessing TSM&O. In assessing the potential effects of TSM&O, it is assumed that a state DOT would invest aggressively in the applications described previously as appropriate, particularly in larger metropolitan areas most prone to traffic congestion. In some cases this could involve upgrading to latest-generation technology, such as with ramp metering, while in other cases it might involve deploying technology for the first time. It is further assumed that the state DOT would work with local agencies and transit operators to implement multimodal, cross-jurisdictional applications such as integrated corridor management.

K.5.2 Intended Mitigation Effects

Core motivations for TSM&O applications include reducing traffic congestion, improving safety, and, in some cases, improving the quality and efficiency of transit services. Additionally, deployment of TSM&O strategies can help improve air quality and reduce greenhouse gas emissions.

Reducing traffic congestion—moderately effective. One of the primary motivations of TSM&O policies is to relieve traffic congestion and associated impacts, and available evidence indicates considerable success in this regard. According to FHWA (2004), full deployment of TSM&O policies can reduce delay in congested urban areas by as much as 15%. Research on the impacts of ramp metering, signal coordination, arterial access management, and incident management strategies in metropolitan areas shows reductions in traffic delays of up to 40% (Schrank and Lomax 2010). The main limitation of TSM&O policies with respect to reducing traffic is that over the longer term, the effects of latent and induced demand may lead to more total peak-hour travel, offsetting some of the initial improvements.

Improving safety outcomes—moderately effective. Incident management approaches, a core component of TSM&O, help remove obstacles and bottlenecks, reduce rear-end collisions that occur in stop-and-go traffic, and lower the rate of secondary crashes at incident scenes. Variable speed limits, peak-period shoulder use, and ramp metering have been shown to reduce both the likelihood and severity of conflicts and have an overall positive effect on safety (Waller et al. 2011).

Improving air quality—moderately effective (uncertain). By reducing stop-and-go travel conditions, TSM&O applications can yield reductions in the emissions of harmful air pollutants. For example, in a study that examined the retiming of 640 traffic signals in Michigan, the results indicated that carbon monoxide emissions were reduced by 2.5%, nitrogen oxide emissions were reduced by 3.5%, and hydrocarbon emissions were reduced by 4.2% (RITA 2011). Over the longer-term, however, such benefits may be at least partially undermined if improved traffic flow leads, as a result of latent demand, to additional vehicle travel. Thus the rating is qualified as being uncertain.

Reducing GHG emissions—moderately effective (uncertain). Through reducing traffic congestion and promoting smoother traffic flow, TSM&O strategies may reduce the average amount of fuel consumed and, in turn, GHG emissions, per passenger mile. The main uncertainty is whether the reduction in congestion will lead to greater total travel, potentially offsetting these benefits.

Enhancing non-automotive travel options—moderately effective. A core benefit of TSM&O is to reduce congestion delays, and this would assist in improving bus transit times as well. Some TSM&O applications, such as traffic signal prioritization for bus rapid transit, focus specifically on improving transit options. Traveler information systems can also provide more and better information about multimodal options, assisting in the initial trip planning process as well as providing up-to-date information on vehicle arrivals and departures during the course of travel. Evidence indicates that such improvements often translate into gains in ridership. In the United Kingdom, the introduction of real-time transit information in combination with increased marketing led to gains in transit use that translated into a reduction in automotive travel of between 2% and 6% (Jones 2003). According to Tang and Thakuriah (2012), popular smart-phone applications to access information on transit routes and timing have been shown to have modest positive impacts on bus ridership in urban areas. Results from *TCRP Report 118: Bus Rapid Transit Practitioner's Guide* indicate that comprehensive bus rapid transit programs, which rest in part on TSM&O applications, can increase ridership from 35 to 75% (Kittelson and Associates, Herbert S. Levinson Transportation Associates, and DMJM+Harris 2007).

K.5.3 Intended Shaping Effects

While TSM&O strategies are not principally intended to influence energy use patterns, they could have a modest effect on improving fuel economy through improved traffic flow, thus reducing oil consumption and decreasing the energy cost of travel.

Reducing oil consumption—moderately effective (uncertain). One of the main benefits of TSM&O, as described previously, is to reduce traffic delays. Given that vehicle fuel economy is much lower in heavily congested stop-and-go traffic conditions (Barth and Boriboonsomsin 2007), reducing traffic congestion has the effect of increasing average fuel economy during actual driving conditions, in turn driving down total oil consumption. Yet, as a result of latent demand, improving travel conditions can often serve to encourage more drivers to use the roads during peak hours, undercutting some of the traffic reduction benefits and adding more fuel consumption. Although there still may be some overall reduction in fuel use, the degree to which these factors offset one another is unclear.

Reducing the energy cost of travel—moderately effective. From the perspective of an individual driver, greater fuel economy resulting from reduced traffic delays translates directly to a lower average energy cost per mile of travel.

K.5.4 Other Effects

Pursuing TSM&O strategies could lead to modest, if secondary, benefits with respect to the economy and environment, and should be neutral with respect to equity.

Economy—moderately positive. TSM&O approaches can be expected to offer a range of benefits for transportation system users, including reduced delays, improved travel time reliability, reduced vehicle fuel costs, and improved safety conditions. These benefits can be quantified in economic terms and should be positive for individual travelers, businesses, and the economic productivity of a region as a whole.

Environment and public health—moderately positive (uncertain). By reducing congestion delays, TSM&O strategies can help improve vehicle fuel economy and reduce emissions. They should help reduce crashes, with positive implications for public health. By providing better information about alternative modes of travel, they can also lead to increased transit ridership. Over the longer term, TSM&O applications may support additional vehicle travel stemming from latent and induced demand, and this could undermine some of the environmental and public health benefits. On balance, though, the net effects are likely to be positive, if uncertain.

Equity—neutral. TSM&O approaches can improve travel conditions for both drivers and transit users, resulting in an overall rating of neutral. It is also worth noting that TSM&O applications can defer the need for other congestion-reduction strategies—such as building new capacity—that may pose greater equity concerns.

K.5.5 Barriers

While full implementation of TSM&O poses some barriers, most are moderate in nature. This stems from the fact that TSM&O technologies are already proven and widely deployed.

Financial cost—moderate barrier. TSM&O applications offer a less-expensive systematic approach to mitigating traffic congestion and other concerns. Still, deploying the necessary technology is not inexpensive and requires considerable up-front costs. To deploy the types of applications included in TSM&O on a broad scale, many states might find it necessary to first increase available funding streams.

Technical risk—moderate barrier. Most TSM&O applications rely heavily on technology that may require custom integration within a particular context, thus posing some technical risk. Technologies that are poorly implemented or improperly applied could actually worsen congestion and create safety issues that did not previously exist.

Enabling legislation—moderate barrier. Provision of real-time system information may rely on data gathered from system users with or without their explicit permission. Due to privacy concerns, some states have made it difficult to collect and distribute such information to private-sector participants, who often have a role in processing and disseminating real-time system information.

Institutional restructuring—moderate barrier. Effective design and implementation of TSM&O programs, such as for signal timing, may require the collaboration of state and regional transportation agencies, local inter-governmental cooperation, and coordination among public- and private-sector partners. There are examples of effective institutional coordination arrangements for the implementation of TSM&O strategies.

K.5.6 Required Lead Time

The majority of TSM&O strategies, depending on complexity, can be implemented in a 1- to 5-year time frame.

K.5.7 Qualifications

TSM&O strategies may be implemented in any context, but benefits are greatest in metropolitan regions that experience high congestion as a routine matter. In rural areas, TSM&O strategies often are targeted to congestion during recurring special events and nonrecurring emergency events, or to managing peak intercity traffic levels during holiday weekends.

K.6 Improving Traffic Safety

Federal guidelines, state priorities, and auto manufacturer emphasis on improving roadway, driver, and vehicle safety have helped reduce the national rates of crash-related injuries and fatalities to their lowest recorded level. Still, more than 30,000 persons die in motor vehicle crashes each year, and many more are injured (NHTSA, National Center for Statistics and Analysis 2010). Highway safety improvements over the past 50 years of have focused largely on crash survival, while the current focus has shifted to the prevention of crashes. Over the next several decades, changes in the marginal cost of driving associated with alternate fuels and vehicle technologies could have the effect of increasing aggregate traffic volumes and congestion levels. Additionally, it is possible that consumers could opt for smaller passenger cars, whereas the goods movement industry could shift to larger truck configurations for greater efficiency, heightening the risks associated with vehicle–truck collisions. Absent additional safety interventions, such shifts could boost the overall number of crashes, fatalities, and injuries that occur on the nation's roadways each year (Pisarski and Council 2010).

K.6.1 Supportive Policies

This assessment focuses on three groupings of related policies and actions—measures to reduce roadway departures, intersection improvements, and pedestrian and cycling improvements—that could enable states, through increased levels of investment, to further reduce crashes, fatalities, and injuries. Several other approaches to safety are briefly mentioned but not fully discussed in this assessment.

Roadway departure reduction measures. More than half of all vehicle crash fatalities result from roadway departures, which are frequently severe in nature. Strategies to reduce road departures generally involve roadway design improvements, including rumble strips, skid-resistant pavements, median barriers, and modifications to highway alignments, curves, and shoulders. Many of these measures have been shown to be cost-effective, yielding substantial risk reductions. Centerline rumble strips have been documented to result in a 44% reduction in head-on fatal crashes on rural two-lane roads and a 64% reduction on urban two-lane roads (Torbic et al. 2009). Flattening side slopes, removing guardrails, and flattening crests on vertical curves can reduce crashes by 50% to 80%, depending on roadway type (Hovey and Chowdhury 2005).

Intersection improvements. Vehicle crashes at dangerous intersections are the second leading cause of highway fatalities. Key strategies to improve intersection safety include design and operational changes that increase visibility, decrease turning movements, minimize access conflicts, maximize traffic intervals, or add traffic control signals and warning devices. Traffic engineers may consider a wide variety of intersection improvements, ranging from subtle changes in signal timing or all-red light clearance times to major improvements such as roundabout installations or access management changes. Increasingly, states are applying systematic methods of identifying dangerous intersections and determining the most cost-effective improvement projects. Changes in crash frequency and severity vary considerably with the type of improvement and characteristics of the roadway, but expected safety improvements can be considerable. For example, replacing intersections with roundabouts on high-speed rural roadways can reduce crash frequency by 84% (Isebrands 2009.) Adding left-turn lanes to major road approaches at urban intersections can reduce crashes by 47% (Harwood et al. 2003).

Pedestrian and cyclist protections. The majority of pedestrian and cyclist conflicts with motor vehicles occur in urban areas and most often in non-intersection areas of the roadway (NHTSA 2012). Many cities with high rates of cycling and walking are redesigning urban areas to more safely accommodate nonmotorized traffic, including by embracing complete-street or pedestrian-oriented design principles. Dangerous areas with high vehicle–pedestrian crash rates are often localized—an outdoor mall, a central business district, or school zone, for example—and the dangers here may be addressed with targeted safety improvements such as illuminated crosswalks, pedestrian overpasses, and pedestrian-only zones. Raised median refuge areas have been shown to reduce vehicle crashes with pedestrians by 46% at marked crosswalks and by 39% at unmarked crosswalks (FHWA 2012a). Other protections, which may be larger in scale, include enhancing trail networks, adding bike lanes on major commute corridors, and implementing speed limit changes. Because the installation of bike lanes tends to increase the number of cyclists and thus the number of crashes, bicycle boulevards on less-congested parallel routes are being considered as safer alternatives for urban commuters (Minikel 2011).

Other traffic safety policies. Several other approaches to improving traffic safety—including improved vehicle technologies, ITSs, and programs to reduce distracted driving or driving under the influence—are also worthy, but are not part of this assessment. Many auto manufacturers already devote significant effort to vehicle designs, materials, and technologies aimed at helping to avoid crashes in the first place or reducing adverse consequences when crashes do occur. Examples are blind spot and hazard warnings, automated braking and traction control systems, improvements in airbag technologies, and the use of advanced materials. Such advances, though, are generally regulated at the federal level rather than by states, and thus are not further discussed here. ITSs, which involve vehicle-to-vehicle or vehicle-to-infrastructure communications to help improve the safety and efficiency of vehicle travel, are discussed as a separate strategy earlier in this appendix. Finally, programs to reduce distracted or impaired driving are also very important for safety, but most states are already fully engaged in such efforts.

Assumed policies for assessing DOT involvement in highway safety. Safety is already a top priority in federal and state planning efforts. In assessing this strategic direction, it is assumed that a state would accelerate its progress toward greater traffic safety by increasing the level and pace of investments in projects aimed at reducing crashes from roadway departures, collisions at intersections, and collisions involving pedestrians and cyclists. Depending on the state, and recognizing the need to allocate scarce resources to address a broader spectrum of DOT activities, increased investment in safety projects could require a state to augment transportation revenue. A state pursuing this strategy would logically address the most dangerous facilities, intersections, and grade crossings first, leading to substantial initial improvements in safety. Over time, additional safety investments could yield lower benefits at the margin, but it is assumed that a state would continue to invest in safety projects for which the benefits appear to exceed the costs.

K.6.2 Intended Mitigation Effects

The main intent of this strategy would be to reduce crashes, including crashes involving bicyclists or pedestrians, and crash-related fatalities and injuries. As positive by-products, this strategy could also help reduce traffic congestion and improve non-automotive modes of travel.

Reducing traffic congestion—moderately effective. Traffic incidents can be responsible for a significant share of nonrecurrent traffic congestion in urban areas (Downs 2004). By helping to reduce the number of crashes, this strategy should also help reduce nonrecurrent traffic delays.

Improving safety outcomes—highly effective. Highway safety improvements are well researched and documented. Advances in design, operations, and technologies continue to contribute to the improved effectiveness of safety interventions and countermeasures. The FHWA's Office of Safety and NHTSA, in cooperation with other federal and state agencies, industry associations, and private contractors, have produced a wealth of information to help states incorporate the most effective and proven safety improvements into new projects and to redesign and retrofit existing problem areas. The Crash Modification Factors Clearinghouse provides a database of researched crash-reduction probabilities and factors for use by traffic engineers (FHWA, undated). The documented effectiveness of safety improvements ranges from negative (in the case of bike lanes, which tend to increase the number of cyclists and in turn the number of cyclist-involved crashes) to marginally effective (in the case of small changes to signals at intersections or road signs) to very effective (in the case of roadway redesign or pedestrian projects). A coordinated and fully implemented safety improvement program across a state could be considered highly effective at continuing to reduce the incidence and severity of vehicle crashes.

Enhancing non-automotive travel options—moderately effective. Making walking and cycling safer through pedestrian crossings or overpasses, for example, will enhance the general quality and attractiveness of these non-automotive modes.

K.6.3 Intended Shaping Effects

The policies considered here would not be intended or expected to exert a major shaping influence on oil consumption, the use of alternative fuels, or the energy cost of travel.

K.6.4 Other Effects

Improvements in traffic safety could offer strong benefits for the economy along with the environment and public health. The effects on equity are less clear, though likely to be positive.

Economy—highly positive. Vehicle crash fatalities and injuries account for a significant economic loss to society, including the cost of death or injury to persons; the cost of property damage; the direct costs of emergency response, medical, legal, and insurance services; and significant productivity, traffic delay, and travel time reliability losses. A study sponsored by the American Automobile Association (AAA) estimated the overall social cost of vehicle crash fatalities and injuries in 99 urbanized areas across the nation to be at $299.5 billion in 2009 (Cambridge Systematics 2011). The Centers for Disease Control and Prevention estimated that the direct cost of medical care associated with motor-vehicle injuries exceeds $17 billion annually (Naumann et al. 2010). Reducing the frequency and severity of crashes will reduce social welfare losses, result in productivity gains for workers and the economy, and save the lives of tens of thousands of individuals each year.

Environment and public health—highly positive. First and foremost, safety measures will reduce crash-related fatalities and injuries, which will be a strong public health benefit. Policies that support walking and biking in urban and rural areas also provide environmental and public health benefits resulting from reductions in motor vehicle use and increased physical activity. Safety improvements in roadway design or intersection operations can sometimes result in lower vehicle speeds with more frequent stops (e.g., school speed zones with mandatory-stop crosswalks), which may worsen local air quality. In other cases, improvements may result in more efficient traffic flow (e.g., dedicated left-turn lanes), which can improve local air quality. Overall, the environmental effects may be positive but modest, while the safety-related public health benefits should be significant. Given the latter consideration, performance on this criterion is rated as highly positive.

Equity—moderately positive (uncertain). In terms of environmental justice, an increased emphasis on safety is likely to improve outcomes for all user groups and populations, regardless of income, residence, age, gender, race, or ethnicity. If safety improvements are pursued in a strategic manner that focuses on problem areas rather than on projects or in communities that can afford to install enhancements, overall equity may improve moderately.

K.6.5 Barriers

The main barrier to more aggressive pursuit of the safety measures discussed as part of this strategy relates to financial cost.

Financial cost—moderate barrier. While the safety improvements included in this strategy are generally recognized as being cost-effective, they can also be costly to implement. Assuming that states continue to face mounting cost constraints in the coming years, the inclusion of desired safety enhancements and improvements in highway projects could become more challenging. As noted earlier, augmenting current revenue sources may therefore prove necessary.

K.6.6 Required Lead Time

Many roadway design and operational safety improvements require relatively little lead time and can be incorporated into new projects immediately, taking advantage of available technologies and methods. Most of the safety improvements discussed here could be achieved within a time frame of 1 to 5 years, or within the current project planning, engineering, and construction time frame.

K.6.7 Qualifications

This strategy direction is applicable to both populous states and less-populated, urban, and rural areas, and to most roadway and facility types.

References

Alameda Corridor Transportation Authority. 2012. Alameda Corridor Fact Sheet. http://www.acta.org/projects/projects_completed_alameda_factsheet.asp (accessed January 20, 2012).

Algers, S. Undated. "The Stockholm Congestion Charging Trial." Presented at WSP Analysis & Strategy, Royal Institute of Technology, Stockholm.

Arnold, R., V. C. Smith, J. Q. Doan, R. N. Barry, J. L. Blakesley, P. T. DeCorla-Souza, M. F. Muriello, G. N. Murthy, P. K. Rubstello, and N. A. Thompson. 2010 (December). *Reducing Congestion and Funding Transportation Using Road Pricing In Europe and Singapore.* International Technology Scanning Program, Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program.

ARTBA. 2012. FAQs: How Much Does It Cost to Build a Mile of Road. http://www.artba.org/about/faqs-transportation-general-public/faqs/#20 (accessed April 3, 2012).

Barth, M. and K. Boriboonsomsin. 2007. "Traffic Congestion and Greenhouse Gases." *Access*, 35: 2–9.

Brown, J. R., E. Morris, and B. D. Taylor. 2009. "Planning for Cars in Cities: Planners, Engineers, and Freeways in the 20th Century." *Journal of the American Planning Association*, Special Centennial Edition, 75 (2): 161–177.

Burt, M., G. Sowell, J. Crawford, and T. Carlson. 2010. *Synthesis of Congestion Pricing-Related Environmental Impact Analyses – Final Report*, FHWA-HOP-11-008. Federal Highway Administration.

Cambridge Systematics. 2009. *Federal, State and Local Freight Regulations.* Oregon Department of Transportation.

Cambridge Systematics. 2011. *Crashes vs. Congestion – What's the Cost to Society?* AAA.

City of Stockholm. 2006. Facts and Results from the Stockholm Trials.

Deeter, D. 2009. *NCHRP Synthesis 399: Real-Time Traveler Information Systems: A Synthesis of Highway Practice*,. Transportation Research Board of the National Academies, Washington, D.C.

Deka, D. 2004. "Social and Environmental Justice Issues in Urban Transportation." In S. Hanson and G. Giuliano, eds., *The Geography of Urban Transportation*, 3rd edition. Guilford Press, New York, pp. 332–355.

Delcan Corporation. 2007. Cross-Town Improvement Project: Freight Travel Demand Management (TDM)–Case Study. Intermodal Freight Technology Working Group.

Downs, A. 2004. *Still Stuck in Traffic: Coping with Peak-Hour Traffic Congestion.* Brookings Institution Press, Washington, D.C.

Ecola, L. and T. Light. 2009. *Equity and Congestion Pricing: A Review of the Evidence.* RAND Corporation, Santa Monica.

Fabian, L. J. 2003. "Making Cars Pay: Singapore's State-of-the-Art Congestion Management." *Transportation Planning*, 18 (1): 1–2, 10.

FHWA. Undated. Crash Reduction Factors: Resources. http://safety.fhwa.dot.gov/tools/crf/resources/ (accessed February 24, 2014).

FHWA. 2004. *Traffic Congestion and Reliability: Linking Solutions to Problems.*

FHWA. 2008a. *Congestion Pricing: A Primer.* FHWA-HOP-08-039.

FHWA. 2008b. *Statewide Opportunities for Linking Planning and Operations.*

FHWA. 2010. *2008 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance Report to Congress.*

FHWA. 2012a. *Proven Safety Countermeasures: Medians and Pedestrian Crossings in Urban and Suburban Areas.* FHWA-SA-12-011.

FHWA. 2012b. Value Pricing Pilot Program Projects Involving Tolls: Priced Roadways. http://www.ops.fhwa.dot.gov/tolling_pricing/value_pricing/projects/involving_tolls/priced_roadways/index.htm as of March 27, 2012).

Glaister, S. 2007. National Road Pricing: Policy Design and Public Acceptance. Presented at the *ITC-CURACAO.*

Goh, M. 2002. "Congestion Management and Electronic Pricing in Singapore." *Journal of Transport Geography*, 10 (1): 29–38.

Harwood, D. W., K. M. Bauer, I. B. Potts, D. J. Torbic, K. R. Richard, E. R. Rabbani, E. Hauer, L. Elefteriadou, and M. S. Griffith. 2003. "Safety Effectiveness of Intersection Left- and Right-Turn Lanes." *82nd Annual Meeting Compendium of Papers.* Transportation Research Board of the National Academies, Washington, D.C.

Horsley, J. 2006. "The Role of State DOTs in Managing Urban Goods Movement." Presented at the Metrans National Urban Freight Conference, Long Beach, California.

Hovey, P. W. and M. Chowdhury. 2005. *Development of Crash Reduction Factors.* Ohio Department of Transportation.

I-95 Corridor Coalition. 2010. *Final Research Report: Administrative and Legal Issues Associated with a Multi-State VMT-Based Charge System.*

I-95 Corridor Coalition. 2011. Drive Clean, Save Green. http://www.i95coalition.org/i95/CoalitionEcoDrivingCampaign/tabid/216/Default.aspx accessed December 30, 2011).

Isebrands, H. 2009. "Crash Analysis of Roundabouts at High-speed Rural Intersections." *88th Annual Meeting Compendium of Papers.* Transportation Research Board of the National Academies, Washington, D.C.

Jones, P. 2003. "Encouraging Behavioural Change Through Marketing and Management: What Can Be Achieved?" Presented at the 10th International Conference on Travel Behavior Research, Lucerne, Switzerland.

Kittelson and Associates, Herbert S. Levinson Transportation Associates, and DMJM+Harris. 2007. *TCRP Report 118: Bus Rapid Transit Practitioner's Guide.* Transportation Research Board of the National Academies, Washington, D.C.

LACMTA and Caltrans. Undated. I-405 Sepulveda Pass Improvements Project: Project Benefits Fact Sheet.

Minikel, E. 2011. "Cyclist Safety on Bicycle Boulevards and Parallel Arterial Routes in Berkeley, California." *90th Annual Meeting Compendium of Papers.* Transportation Research Board of the National Academies, Washington, D.C.

Naumann, R. B., A. M. Dellinger, E. Zaloshnja, B. A. Lawrence, and T. R. Miller. 2010. "Incidence and Total Lifetime Costs of Motor Vehicle–Related Fatal and Nonfatal Injury by Road User Type, United States, 2005." *Traffic Injury Prevention*, 11 (4): 353–360.

NHTSA, National Center for Statistics and Analysis. 2010. *Traffic Safety Facts: Highlights of 2009 Motor Vehicle Crashes.* DOT HS 811 363.

NHTSA. 2012. *Traffic Safety Facts: Bicyclists and Other Cyclists.* DOT HS 811 624.

NSTIFC. 2009. *Paying Our Way: A New Framework for Transportation Finance.* Washington, D.C.

Obenberger, J. 2004. "Managed Lanes," *Public Roads*, 68 (3): 48–55.

Olszewski, P. 2007. "Singapore Motorisation Restraint and its Implications on Travel Behaviour and Urban Sustainability." *Transportation*, 34 (3): 319–335.

PierPASS. Undated. PierPASS: Rules, Regulations and Rates. http://pierpass.org/offpeak-information/rules-regulations-and-rates/ (accessed March 22, 2012).

Pisarski, A. and F. Council. 2010. "Future View of Transportation: Implications for Safety," White Paper No. 1 for *Toward Zero Deaths: A National Strategy on Highway Safety.* U.S. Department of Transportation.

POLB. Undated. Clean Trucks Program. http://www.polb.com/environment/cleantrucks/default.asp (accessed January 20, 2012).

Poole, R. W. 2010. "Conditions & Performance Report Breaks New Ground." *Surface Transportation Innovations.* 78.

Poole, R. W. 2012. "Express Toll Lanes in High Gear." *Surface Transportation Innovations*, 101.

Puget Sound Regional Council. 2008. *Traffic Choices Study – Summary Report.*

RITA. 2010. *Achieving the Vision: From VII to IntelliDrive.*

RITA. 2011. *Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference: 2011 Update.*

RITA. 2012a. Integrated Corridor Management. http://www.its.dot.gov/icms/ (accessed April 9, 2012).

RITA. 2012b. Connected Vehicle Research. http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm (accessed April 13, 2012).

Santos, G. and B. Shaffer. 2004. "Preliminary Results of the London Congestion Charging Scheme." *Public Works Management & Policy*, 9 (2): 164–181.

Schrank, D. and T. Lomax. 2010. *2009 Urban Mobility Report: Six Congestion Reduction Strategies and Their Effects on Mobility.* Texas Transportation Institute, the Texas A&M University System.

Schweitzer, L. A. and B. D. Taylor. 2008. "Just Pricing: The Distributional Effects of Congestion Pricing and Sales Taxes." *Transportation*, 35 (6): 797–812.

Shatz, H. J., K. E. Kitchens, S. Rosenbloom, and M. Wachs. 2011. *Highway Infrastructure and the Economy: Implications for Federal Policy.* RAND Corporation, Santa Monica.

Shoup, D. 2005. *The High Cost of Free Parking.* Planners Press, Chicago.

Tang, L. and P. V. Thakuriah. 2012. "Ridership Effects of Real-Time Bus Information System: A Case Study in the City of Chicago." *Transportation Research Part C: Emerging Technologies*, 22: 146–161.

Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. J. Ronchetto, E. T. Donnell, H. J. Sommer, P. Garvey, B. Persaud, and C. Lyon. 2009. *NCHRP Report 641: Guidance for Design and Application of Shoulder and Centerline Rumble Strips.* Transportation Research Board of the National Academies, Washington, D.C.

TfL. 2008. *Central London Congestion Charging Impacts Monitoring: Sixth Annual Report.*

U.S. Department of the Treasury and U.S. Council of Economic Advisors. 2012. *A New Economic Analysis of Infrastructure Investment.*

Waller, S. T., N. Jiang, N. Nezamuddin, T. Zhang, and D. Sun. 2011. *Safety Implications of Using Active Traffic Strategies on TxDOT Freeways.* Texas Department of Transportation.

Willoughby, C. 2000. *Singapore's Experience in Managing Motorization and Its Relevance to Other Countries.* The World Bank.

Washington State DOT. 2008. *Freight Mobility: Joint Report on Washington State Freight Highway and Rail Projects.*

APPENDIX L

Strategies to Improve Alternative Travel Modes

This appendix considers strategies to improve alternative modes of travel, such as transit, ridesharing, bicycling, and walking. Depending on how transportation energy use patterns evolve in the future, such strategies could be helpful in different ways. If, for example, there are significant technological breakthroughs in alternative fuel and vehicle technologies that lead to much cheaper driving, traffic congestion could grow much worse. In this case, the improvement of alternative modes might help lure some drivers from their vehicles, and could also provide other options for those who wish to avoid sitting in traffic. On the other hand, if cost-competitive alternatives fail to emerge, and the price of oil continues to climb, driving could become much less affordable. In such a scenario, improving alternative modes would help ensure mobility options for lower-income travelers. The strategic directions reviewed in this appendix are transportation demand management measures, transit improvements, and integrated land-use policies.

L.1 Transportation Demand Management

Transportation demand management encompasses a wide variety of strategies intended to reduce single-occupant vehicle travel, especially in peak travel hours. TDM strategies can be grouped into several broad categories, including strategies intended to consolidate vehicle trips or shift trips to other modes, such as ridesharing, vanpools, and bicycling or walking improvements; strategies to shift vehicle trips to off-peak periods or less-congested routes, such as flexible or staggered work hours and traveler information services (discussed as part of TSM&O section in the previous appendix); and strategies to eliminate trips entirely, such as telecommuting and compressed workweeks. Various types of TDM strategies can be implemented at the national, state, regional, or local levels. Individually, TDM strategies are unlikely to significantly change travel patterns, but layering multiple strategies at different scales may affect a considerable portion of travel, with corresponding benefits for reduced traffic, fuel consumption, and emissions.

L.1.1 Supportive Policies

Core TDM policies, implemented either separately or in combination and at various scales and levels of government, may include commute trip reduction programs, non-commute trip reduction programs, ridesharing, shuttle services, non-motorized travel improvements, and regulatory enabling of pay-as-you-drive insurance.

Commute trip reduction programs. Commute trip reduction encompasses a wide variety of interventions intended to consolidate employee trips (through carpooling, vanpooling, and parking management), shift trips to times with greater slack capacity (such as off-peak hours), shift trips to other modes (through subsidized or pretax transit passes, bicycle facilities, parking cash-out options, and the like), or eliminate trips altogether through telecommuting or compressed workweeks (working 40 hours in 4 days, for example). Many of these strategies are best implemented by working directly with employers, although some can be initiated by employees or transportation management associations (TMAs). Public agencies can encourage commute trip reduction through outreach and incentives (such as employer recognition or commuter rewards programs), can establish mandatory or voluntary trip reduction goals, can offer tax credits for some measures (such as teleworking), and can directly implement such measures for their own employees. Public transportation agencies can assist employers in providing subsidized transit benefits such as discounted passes for bulk purchase.

Non-commute trip reduction programs. While the focus of trip reduction programs has traditionally been on the daily commute, TDM programs are increasingly aiming at other types of trips as well. For example, innovative marketing campaigns use social media to target and provide customized information to specific groups or individuals that may be responsive to travel options. Often these programs are implemented at a neighborhood level. "School pool" programs foster opportunities for students to carpool, walk, or bicycle to school, and may include "safe routes to school" strategies such as sidewalk improvements or "walking school buses."

Ridesharing (including HOV lanes). Ridesharing, which includes traditional carpools, vanpools, and dynamic carpools, reduces aggregate travel by consolidating multiple trips in a single vehicle. Ridesharing is most commonly oriented toward commuters, although emerging dynamic ridesharing websites and mobile apps now support other types of trips in certain urban areas. Public-sector actions to promote ridesharing may include operation or promotion of rideshare matching and vanpooling services among employers or the general public, the creation of incentive programs offering financial rewards for carpooling, and the formation of TMAs to coordinate ridesharing and other TDM programs with local employers. Employer-sponsored programs are often supported by a guaranteed or emergency ride home program, which provides free rides for employees who must leave in an emergency or stay late. Ridesharing can be further encouraged by the provision of HOV lanes, which permit vehicles with multiple occupants to travel in dedicated lanes, and park-and-ride lots.

Shuttle services. The provision of new or expanded transit services for general public use is considered in the next section of this appendix as a separate strategic direction. However, the operation of dedicated shuttle services to serve a specific employer, office park, or business district is often considered as part of a package of TDM strategies. Shuttle services may offer last-mile connections between residential or employment centers and high-capacity transit or provide local circulation for residents, workers, and shoppers in multi-use districts. This can make it more feasible for workers to commute by transit as well as to run errands in the middle of the day without a car.

Nonmotorized improvements. Nonmotorized transportation investments focus on bicycling and walking as alternatives to driving. Improvements may emphasize door-to-door nonmotorized trips or combined transit-bicycle trips. Nonmotorized projects can include improvements in infrastructure or facilities (such as dedicated bike lanes, bicycle lockers at transit stations, or workplace locker rooms), programs to foster knowledge and awareness of nonmotorized options, and land use policies that enable walking or bicycling trips or trip segments (such as transit-oriented development). Land use strategies are also discussed as a separate strategic direction later in this appendix.

Pay-as-you-drive insurance. The purchase of automobile insurance has traditionally been structured around fixed annual or semi-annual premiums that account for such risk factors as the value of the vehicle, the location where the vehicle is registered, and the age of the driver. With PAYD insurance, a relatively recent innovation, the premium is no longer fixed; rather, the amount owed depends in part on the number of miles that a vehicle is driven each year. From the perspective of insurers, PAYD insurance creates the opportunity to offer lower rates, commensurate with the reduced risk of crashes, to attract lower-mileage drivers. From the perspective of aggregate social travel behavior, PAYD insurance creates an incentive—similar to that provided by other variable costs of driving such as fuel, fuel taxes, and tolls—for drivers to reduce total vehicle travel. Thus, PAYD insurance is often grouped in the broader category of possible TDM strategies. While PAYD insurance is a private-sector product, states can facilitate this innovation through enabling legislation that allows insurers to offer this form of rate structure within their jurisdictions.

Assumed policies for assessing transportation demand management. In assessing the strengths and limitations of increased focus on TDM as a strategic direction for state DOTs to consider, it is assumed that states would either implement or promote, through technical and financial assistance to local governments, the following policies: public-sector TDM outreach programs aimed at employers and employees, such as employer recognition programs, rideshare and vanpool program support (e.g., ride-matching systems, limited start-up subsidies), a guaranteed ride home program, support for transit agency programs to provide discounted transit passes, and partial subsidization of transit shuttle services (with matching funding from the private sector) between transit stations and major employment centers to provide last-mile connections; targeted social marketing programs in neighborhoods with good travel alternatives; policies to improve nonmotorized infrastructure, such as complete streets policies; requirements for developers to create and implement TDM plans (such as TDM-based traffic mitigation) for new large developments in congested areas; and PAYD insurance (states allow insurers to offer a PAYD option, but do not require them to do so).

L.1.2 Intended Mitigation Effects

Transportation demand management could play a role in mitigating several negative impacts that could arise under certain plausible future transportation energy use futures, most notably by improving non-automotive transportation alternatives.

Reducing traffic congestion—moderately effective. Most TDM strategies are directed at reducing peak-period vehicle trips and will therefore have some effect on reducing traffic congestion. The effect, however, is likely to be relatively modest (ICF 2011). For example, the U.S. DOT estimated that worksite trip reduction programs would be likely to reduce VMT in the range of 0.2% to 1.1% (U.S. DOT 2010). Further, such benefits could be reduced by the effect of induced demand—as road space is freed up, other drivers will take advantage of it. One study, however, estimated that induced demand would only reduce the congestion-reduction benefits of TDM-type strategies by a little less than 20% (Cambridge Systematics 2009). Policies that create a direct financial incentive, such as transit subsidies, commuter rewards, or PAYD insurance, are likely to have the most significant impact (U.S. DOT 2010). Estimates suggest, for example, that broad adoption of PAYD would help reduce VMT and vehicle crashes by 5% to 10% (Ferreira and Minikel 2010). It is also worth noting that TDM effects will vary by region and may be most effective where there are good travel alternatives combined with mixed-use, dense, and transit-accessible land uses (Guo et al. 2011.

Improving safety outcomes—moderately effective (uncertain). Fewer vehicle miles of travel should lead to fewer traffic injuries and fatalities, although the overall safety of the traveling public would also depend on the accident rates for the modes adopted by travelers to replace driving. If bicycle fatality rates were higher than driver fatality rates, for instance, a bicycle-oriented TDM strategy would not improve safety for the target population. Strategies that remove trips entirely, like telecommuting, would provide definitive safety benefits.

Improving air quality—moderately effective. More aggressive deployment of TDM strategies could be expected to help improve air quality by reducing VMT as well as idling related to congestion. For example, the U.S. DOT found that current levels of teleworking in the United States remove approximately 10 to 13 million metric tons of CO_2-equivalent greenhouse gas emissions along with a corresponding reduction in criteria pollutants (U.S. DOT 2010). Strategies that require service increases by other modes (e.g., vanpools, transit shuttles, and transit incentives that cause ridership to exceed capacity) may lead to increases in some pollutants, depending on the vehicle load factors and the fuel and emissions characteristics of the vehicles used.

Reducing GHG emissions—moderately effective. TDM can be expected to help reduce GHG emissions by reducing VMT and excess fuel consumption related to congestion. Strategies that require service increases by other modes (e.g., vanpools and transit shuttles) could offset GHG emission reductions if vehicle load factors are not high enough to make up for the additional fuel consumed by the van or transit vehicle.

Enhancing non-automotive travel options—highly effective. One of the primary purposes of TDM is to improve non-automotive travel options, like transit, bicycling, and walking, as well as telecommuting.

L.1.3 Intended Shaping Effects

Though TDM policies have traditionally been pursued in the context of reducing traffic congestion and improving air quality, they could also help in reducing oil consumption.

Reducing oil consumption—moderately effective. Many TDM strategies, such as vanpools, ridesharing, and transit incentives, aim to shift solo driving trips to other modes that are (assuming reasonable load factors) less energy intensive on a passenger-mile basis. PAYD insurance provides a reasonably strong financial incentive to ration driving, while telecommuting can eliminate some vehicle trips altogether. To the extent that TDM strategies are successful, they offer at least moderate promise in helping to reduce vehicle travel and, in turn, oil consumption. A U.S. DOT study found, for example, that current levels of teleworking in the United States remove approximately 29 billion VMT each year (U.S. DOT 2010). Ferreira and Minikel (2010) estimate that broad adoption of PAYD insurance would, through corresponding reductions in VMT, decrease fuel consumption by 5% to 10%.

L.1.4 Other Effects

Individual transportation demand management policies may have differing effects on the economy, environment, and equity. The broad effects of the assumed strategies to be implemented range from neutral to moderately positive.

Economy—neutral. TDM strategies are likely to have very modest, if any, impacts on the economy. Economic benefits may accrue through better access for workers as a result of improved travel options. However, most TDM strategies also incur modest levels of public- and private-sector costs (e.g., the costs of subsidizing transit passes or providing vanpool start-up incentives). Many of these costs are simply transfers from one party to another (e.g., business to employee) and will not have a measurable net economic impact. To the extent that TDM is effective at reducing peak-period congestion, the local economy may benefit.

Environment and public health—highly positive. As previously discussed, most TDM strategies help reduce criteria pollutant and GHG emissions, although TDM generally has no significant impact on other environmental aspects. Through support for much-improved non-automotive travel modes, in addition to air quality and safety benefits, TDM can have a strong positive influence on public health, leading to an overall rating of highly positive.

Equity—moderately positive. Most of the TDM strategies evaluated here, such as improved transit shuttle options or new nonmotorized options, increase travel choices and access to jobs and amenities for lower-income populations, thereby increasing transportation equity. PAYD insurance would also reduce inequities by eliminating the subsidies that low-mileage drivers inevitably pay for high-mileage drivers under more traditional insurance plans with fixed annual premiums (Ferreira and Minikel 2010).

L.1.5 Barriers

For the scope and scale of strategies assumed to be implemented in this assessment, states may encounter some moderate barriers.

Financial cost—moderate barrier. In this assessment it is assumed that a state would provide some level of investment to support TDM—for example, helping to subsidize shuttle services or guaranteed ride home programs. To date, identifying adequate funding sources has been a barrier to expansion of TDM in many places. Yet expenditures on TDM programs are typically modest compared to the costs of building and maintaining roads. For example, a 2002 review of the Congestion Mitigation and Air Quality Improvement Program, a common federal source of funding for trip reduction programs, identified annual costs ranging from $170,000 to $3.5 million for eight regional TDM outreach and promotion programs (TRB 2002).

Enabling state legislation—modest barrier (uncertain). Generally TDM strategies fit within current legislative frameworks. PAYD insurance, which is closely related to currently available usage-based insurance products, may require enabling legislation in a handful of states where usage-based insurance is not yet offered.

Institutional restructuring—moderate barrier (uncertain). DOTs may not consider TDM strategies to be consistent with their traditional missions. Seeking to provide more active and effective support for TDM could therefore require some modest institutional restructuring (such as the creation of an office dedicated to that end).

L.1.6 Required Lead Time

The set of TDM investments assumed for this strategy are not generally capital-intensive and can therefore be implemented in a relatively short time frame. A period of 1 to 5 years may be required to develop the programs and set up the institutional capacity for full implementation.

L.1.7 Qualifications

Each state, region, and locality will have different TDM needs and requirements. TDM is primarily focused on metropolitan areas where travel alternatives exist and there are congestion issues that provide a motivation for TDM. However, smaller metro areas will have different needs than larger, more densely populated areas—for example, a greater focus on ridesharing and telecommuting compared to transit.

L.2 Improving Public Transportation

This strategy encompasses investments, programs, partnerships, and institutional responses to expand or enhance the provision of transit service. Motivating objectives could include reducing vehicle use by inducing more travelers to use transit, reducing emissions of greenhouse gases and harmful local air pollutants, and providing improved options for those who need or prefer alternatives to automotive travel.

L.2.1 Supportive Policies

Policy options for improving public transportation are grouped into several different categories: revised fare structures and integrated payment systems, urban bus transit service, urban transit with exclusive right-of-way (including rail and bus rapid transit with dedicated lanes), and intercity public transportation (passenger rail or bus). Additionally, the possibility of states taking a more active role in planning and funding public transportation is considered.

Fare structures and system integration. Transit operators can implement measures such as variable pricing (e.g., peak versus off-peak fares, distance-based fares, low-income discounts) to better match demand and supply and offer a wider range of payment options (e.g., monthly and weekly passes, and payment via smartphones) to meet the needs of different customer bases. They can also integrate fare payment systems across multiple transit systems serving a region, improving the convenience of travel and fare payment.

Conventional bus transit improvements. Transit operators can improve conventional bus service in a variety of ways. For example, they can provide more frequent service or expanded hours of operation on existing routes; add new routes; restructure fixed-route systems for greater operating efficiencies; add limited-stop service on high-demand routes; implement measures to improve reliability, such as headway control using GPS; and work with local traffic authorities to implement bus signal preemption and queue bypasses where feasible in high-passenger volume, congested corridors. Many of these are often included as elements of bus rapid transit (BRT), although this term is used in the following to include dedicated right-of-way as well. Real-time information on the locations and expected arrival times of buses, discussed at greater length in the previous appendix under the strategy of improved transportation system management and operations, can increase ridership by reducing passenger wait times, supporting better decision making, or helping travelers feel more comfortable using the system.

Fixed-guideway transit improvements. Fixed-guideway services include light rail, heavy rail, commuter rail, streetcar, and BRT with dedicated lanes or guideways. These types of services use higher-capacity vehicles, operate in their own right-of-way, and are often grade-separated to allow for higher operating speeds that do not depend on traffic conditions. Because of their permanence and capacity, they can also serve as a focal point for new high-density development, multiplying the benefits over the long term.

Intercity transit improvements. Agencies such as state DOTs or designated rail authorities can improve intercity rail services through capital upgrades or service improvements to increase operating speeds, provide more frequent service, or provide services to new areas. This may include investments in high-speed rail (HSR), often defined as services operating at 110 to 125 miles per hour or higher, and improvements in conventional services. While public agencies usually limit their role in intercity bus services to safety regulation, they can also help expand mobility options by subsidizing routes or supporting the construction of intermodal facilities serving both intercity and local transit.

Greater DOT involvement in public transportation. While most of these strategies would ultimately be implemented by transit operators, state DOTs could play an expanded role in supporting public transportation improvements. Possibilities include providing supplemental state funding (beyond that provided by the FTA and local sources) for planning, capital projects, and operations; assisting transit operators with joint purchases; providing technical assistance and training to transit providers; and helping to coordinate interjurisdictional services. A few state DOTs already operate or contract out for operation of state or regional transit services; in such states, DOTs would be more directly involved in implementing the improvements.

Assumed policies for public transportation improvements. In assessing the potential effects of greater investment in public transportation, it is assumed that a state would provide technical and financial support for the following improvements: integrated fare payment systems and service coordination in areas with multiple transit operators; convenient noncash payment options; real-time information systems; operational improvements such as GPS-based headway control and limited-stop service, signal preemption, and queue jump lanes in high-priority corridors; additional peak-period capacity and expanded hours of operation on routes where demand warrants; funding for planning, design, construction, and operation of fixed-guideway services (including urban rail and BRT) where demand warrants; and funding for intercity rail improvements (including HSR) and intermodal facilities where demand warrants. Here the phrase "where demand warrants" is used to indicate that minimum cost-recovery ratios and load factors (the ratio of passenger miles to transit vehicle miles) consistent with industry standards would need to be met before investing in new or expanded services.

L.2.2 Intended Mitigation Effects

The primary purpose of this strategy would be to enhance non-automotive travel options. The strategy could also provide moderate benefits in the areas of traffic congestion, safety, air quality, and greenhouse gas emissions.

Reducing congestion—moderately effective. Transit improvements that focus on faster, more reliable, and more convenient peak-period service, in particular, should help reduce traffic congestion. The strength of this effect will depend on growth in transit use and the percentage of new riders who previously drove (often referred to as "choice riders"). A study of Florida transit systems concluded that between 43% and 50% of transit riders also have access to an automobile that they could use (Tindale-Oliver & Associates 2009). Broadly speaking, investments in transit will be most effective in areas with high levels of traffic congestion, high parking costs, and relatively high densities. If traffic congestion and parking costs are less of a concern, or if destinations are dispersed and not easily served by transit, the effects of transit investments in reducing vehicle travel tend to be less pronounced. However, even where transit improvements are successful in stimulating significant mode shift, their effectiveness in reducing traffic congestion is likely to be limited by the effects of latent demand. As some drivers shift to transit and congestion lessens, other travelers will observe the improved driving conditions and return to peak-hour driving in response, thus eroding the initial congestion-reduction benefits (Downs 2004).

Improving safety outcomes—moderately effective. Crash, fatality, and injury rates are generally lower per passenger mile of transit than for automobile travel (National Safety Council 2011), so shifting travel to transit should offer some safety benefits.

Improving air quality—moderately effective. While transit vehicles can carry many more passengers than private automobiles, they also emit, on average, more local air pollutants than the average vehicle. As such, the ability of improved transit service to help improve air quality depends not only on the number of automobile trips replaced with transit trips but also on the average load factor of transit vehicles—that is, the number of passengers carried on each transit vehicle. One study found, for example, that the average bus service in 2006, by displacing 8.72 passenger car trips for each transit vehicle trip, would actually increase NO_x and PM emissions. If the bus fleet were to meet new (2007 and later) federal emission standards, the same load factor would instead result in a reduction of all relevant air pollutants (Ayres 2007, as cited in U.S. DOT 2010). For this assessment, it is assumed that states would only help support transit investments with sufficient demand to achieve specified minimum load factors; accordingly, the investments are rated as being likely to yield modest air quality improvements. It should also be noted that electrically powered transit vehicles offer an even greater potential to improve urban air quality since they do not generate direct emissions, and air pollution from electricity generation is often emitted farther from populated areas.

Reducing GHG emissions—moderately effective. As with air quality, the potential benefits of transit improvements with respect to GHG emissions depend on the number of vehicle trips replaced by transit trips as well as the transit vehicle load factors. In this case, however, evidence suggests that transit, on average, already does help mitigate GHG emissions. Across all existing U.S. transit systems, bus service produces about two-thirds the GHG emissions per passenger mile of a single-occupant vehicle, while rail produces about one-quarter to two-fifths, depending on the mode (FTA 2009). However, the nationwide GHG benefits of existing transit services are dominated by a few large systems (such as New York), and benefits are small or even slightly negative in many states that are heavily rural or generally low in density (Baxandall, Dutzkik, and Hoen 2008). Here again, though, it is assumed that a state would only invest in transit improvements where there is sufficient demand to achieve reasonable load factors.

Enhancing non-automotive travel options—highly effective. The improvements envisioned here would contribute to faster, more reliable, and more convenient service and could include greater temporal and geographic coverage. All of these would serve to enhance non-automotive options and have been shown to increase ridership as well. The elasticity of ridership with respect to frequency averages roughly 0.5 (that is, a 10% increase in service frequency leads to a 5% increase in ridership), but can range from near zero to over 1.0 depending on the context. Based on relatively limited data, it also appears that the number of hours of service each day can be as important as frequency in increasing ridership (Evans 2004). Data on the impacts of other service improvements, including reliability and traveler information, are also very limited. In general, reliability can have an even greater effect on ridership than wait time (Evans 2004).

L.2.3 Intended Shaping Effects

Along with the benefits described previously, transit investments are often promoted for their potential in helping to reduce aggregate oil consumption.

Reducing oil consumption—moderately effective. With the assumption that a state would only invest in improved transit service where there is enough demand to result in reasonably high load factors, travel by bus should consume much less fuel on a per-passenger basis than would travel by private automobile. Also, transit that runs on electricity, such as most light rail and subway lines, does not consume petroleum. Thus, improving transit service, to the extent that it is successful in inducing drivers to switch to transit, should contribute to the goal of reducing oil consumption. It has been noted that if some peak-hour drivers switch to transit and this helps reduce congestion, other travelers may notice the improvement and begin to drive in the corridor to take advantage of the improved traffic flow (Downs 2004). Yet many of these new drivers will simply be rearranging their trips from other routes or other times—as opposed to taking new trips that they otherwise would not have taken—in response to the greater convenience of peak-hour travel in the corridor. While this shifting of trip times and routes may undermine congestion-reduction benefits to some extent, it should not adversely affect savings in fuel consumption to a significant degree.

L.2.4 Other Effects

While transit improvements would not necessarily lead to greater economic productivity, they would be expected to offer modest environmental and public health benefits and significant equity benefits.

Economy—neutral (uncertain). In most cases, the effects of transit on improving mobility and reducing congestion, although helpful, would be modest. Weighed against the opportunity cost of improving transit service, overall effects on the economy are likely to be negligible. For highly congested areas or corridors where significant travel improvements are needed, however, provision of high-quality, high-capacity transit services may provide local and regional economic benefits by increasing business access to labor markets and reducing transportation costs for both individuals and businesses.

Environment and public health—moderately positive. As already discussed, improving transit service in ways that increase ridership is likely to provide moderate benefits in reducing local air pollutants and greenhouse gas emissions. These represent environmental gains, and improved air quality, along with safety benefits, should be positive for public health. The improvement of non-automotive modes should correlate with increased physical activity, although this strategy focuses more on transit than on biking and walking. Therefore, the overall rating is judged as moderately positive rather than highly positive.

Equity—highly positive. By expanding or improving the quality of transit service, lower-income travelers are likely to benefit through improved mobility and access to jobs, services, and other essential destinations.

L.2.5 Barriers

Financial cost is the major barrier to expanding transit service, although in some cases legislation and institutional restructuring might also be required.

Financial cost—significant barrier. Expanding existing service or developing new service can have a significant effect in improving transit options. The capital costs for new rail investment and operating costs for rail and bus services, however, are both expensive. Therefore, in most cases it would likely prove necessary to develop new or augment existing funding streams to pursue such options at a meaningful scale. More modest benefits may be realized at lower levels of effort and investment directed toward revising fare structures, improving existing operations, coordinating services among transit operators, and the like.

Enabling legislation—moderate barrier (uncertain). Some states limit the use of fuel-tax revenue—typically one of the most significant sources of transportation funds—to highways only. A decision to invest considerably more in transit at the state level could require relaxation of any such funding restrictions.

Institutional restructuring—moderate barrier (uncertain). For any state that does not already have significant involvement in the planning and provision of transit service—and this would include most states—a decision to pursue the strategic direction outlined here could require some institutional restructuring to engage more collaboratively with local governments to improve public transportation.

L.2.6 Required Lead Time

Some strategies, such as improved headway control and expanded service on existing routes, can be implemented quickly, in 1 or 2 years. Strategies such as fare integration, route restructuring, and traffic operations improvements may take 3 to 5 years to plan and implement. Major expansion projects may take 5 to 10 years, or perhaps even more, to plan, design, and construct. Taking all of these into account, this strategy is rated as requiring at least a 5- to 10-year lead time to yield significant effects.

L.2.7 Qualifications

This strategy is potentially applicable to large states as well as small states, and to highly urbanized as well as largely rural states. However, the most significant benefits in terms of transit demand, vehicle travel and congestion reduction, and the environment will be realized in densely populated urbanized areas.

L.3 Integrating Land Use

Many of the potential strategies that states might consider could be made more effective with closer coordination between transportation and land use planning. For example, policies to improve transit, walking, and biking can be more successful in dense, mixed-use environments. Land use planning is not typically a state function, but rather resides at the level of local governments. Still, there are some actions that states can take to promote better coordination between land use and transportation. This assessment reviews such actions and their potential effects.

L.3.1 Supportive Policies

States can adopt a number of policies to enable better coordination of transportation and land use decision making without assuming direct control over land use. These may involve changes in how states determine investment priorities, design roads in urban areas, and interact with other levels of government.

Prioritize transportation funding to existing communities. States can deliberately choose to direct funding to areas that are already fairly densely developed instead of building new roads in undeveloped areas. This can help encourage redevelopment in existing communities, leading to higher land-use densities more amenable to transit and nonmotorized modes. Three different frameworks could be considered:

- **Invest in existing communities rather than new ones.** In 1997, for example, Maryland adopted a policy of directing transportation funds to "priority funding areas," which include all of the state's incorporated cities and towns (Maryland Department of Planning, undated).
- **Prioritize existing infrastructure over new projects.** Another variation on this idea is known as "fix it first," which is a policy of directing transportation funding to renovation or rehabilitation of existing infrastructure rather than building new capacity. Massachusetts, for example, adopted such a strategy in its 2006 Long-Range Transportation Plan.
- **Allow for some congestion with additional growth.** Some states have concurrency requirements, which require new transportation investments whenever the level of service is projected to drop below a specified level. While the goal of such policies is laudable, they can have the unintended effect of preventing land use densification—which might trigger required investments—and instead channel additional growth to undeveloped areas where traffic congestion is not yet such a problem (Chapin, Thompson, and Brown 2007). Recognizing this unintended effect, Florida repealed its mandatory concurrency requirements for transportation investments in 2011 (Turner 2011).

Create more flexible guidelines for state roads. Standards for state roads are often created for rural roads, which account for a significant share of the roadways that many states manage. Such standards may require limited access, high design speeds, or other features that make them incompatible with urbanized areas. Relaxing guidelines for urbanized areas can allow more walkable communities and attract development. For example, the Louisiana Department of Transportation and Development worked with local stakeholders in the city of Natchitoches to repave the downtown's brick main street in a historically accurate way rather than using current repaving methods (FHWA 2009).

Build appropriate nonmotorized transportation infrastructure to support bicycling and walking. In an approach often described as "complete streets" (Smart Growth America 2010), states can incorporate nonmotorized access on projects where bicycling and walking are appropriate, thus providing additional travel options where otherwise only motorized vehicles would be allowed or encouraged. For example, Pennsylvania DOT built a parkway with bicycle and pedestrian paths in place of a conventional expressway, which both saved money and provided additional access for nondrivers (AASHTO 2010).

Partner with local governments. States can become partners with regional and local agencies on a number of policies. At the planning level, the state can fund or participate in efforts to develop regional plans. California does this through its California Regional Blueprints Program, which provides funds to MPOs and rural regional transportation planning authorities to develop collaborative regional plans (Applied Development Economics et al. 2010). New Jersey coordinates its Transit Village Initiative via a partnership between the DOT and NJ Transit (New Jersey DOT 2009).

Assumed policies for assessing land use strategies. In the discussion that follows, it is assumed that a state would prioritize funding toward existing communities, create more flexible design guidelines for state roads in urban areas, and work collaboratively with local governments in developing integrated regional land-use and transportation plans. It is further assumed that such actions would generally lead to higher-density land uses, which in turn would lead to some changes in travel behavior.

L.3.2 Intended Mitigation Effects

State policies to promote more integrated land use could help mitigate several of the challenges identified in this report, although the effects would be gradual as the built environment slowly changes.

Reducing DOT costs—highly effective. Areas with more compact development tend to cost less in infrastructure provision than those with low-density development. In reviewing a number of studies over several decades, Muro and Puentes (2004) found that aggregate construction and maintenance costs were less when investments were focused on higher-density areas. A study in Rhode Island estimated that the state, through compact development strategies, could save $78 million (43%) in construction costs for new local roads over a 20-year period, and an additional $14 million in operating costs (H.C. Planning Consultants and Planimetrics 1999). These studies also tended to find cost savings in other utilities, such as water and sewers (Muro and Puentes 2004).

Improving safety outcomes—moderately effective (uncertain). Higher-density land uses tend to be associated with pedestrian safety based on narrower streets, slower vehicle speeds, and larger numbers of pedestrians. While it does not establish a causal link, the *Mean Streets 2004* report on pedestrian safety finds that regions marked by lower-density developments have higher rates of pedestrian deaths per mile walked (Enrst 2004).

Improving air quality—moderately effective (uncertain). Regional air quality should improve with higher-density land uses since VMT would be expected to decline. A major survey on the literature pertaining to the relationship between land use densities and VMT found that doubling the residential density within an area generally reduces household VMT on the order of 5% to 12% (TRB 2009). On the other hand, traffic congestion is usually higher in denser areas, leading to more stop-and-go driving that could exacerbate local emissions to some extent.

Reducing GHG emissions—moderately effective (uncertain). Reducing VMT per capita should also reduce GHG emissions. A recent TRB report found that developing 75% of new and replacement housing at more compact densities over a 20-year period would result in reductions of 7% to 8% in GHG emissions over the base trend line (TRB 2009). Here again, though, it is possible that the inefficiencies of higher levels of traffic congestion could partially undercut such gains.

Enhancing non-automotive travel options—highly effective. Higher-density land use should make non-automotive travel modes more viable and attractive for several reasons. To begin with, greater density creates a larger pool of potential riders, making it more feasible to build and operate well-patronized transit lines. This, in turn, leads to more accessible transit service within denser areas. Finally, greater density tends to make walking and bicycle trips more viable since distances between origins and destination are generally shorter, and walking or biking can often be combined with transit for longer journeys. Based on such factors, higher-density land uses are usually characterized by higher per-capita levels of transit ridership and lower per-capita VMT (TRB 2009).

L.3.3 Intended Shaping Effects

More compact land-use patterns are often viewed as a strategy for reducing vehicle travel and, in turn, oil consumption.

Reducing oil consumption—moderately effective (uncertain). Higher-density and mixed land-use patterns should, in theory, help reduce automobile traffic, both by allowing more trips to be made by transit, biking, or walking and by reducing the average distance between trip origins and destinations. Evidence suggests that this relationship does indeed hold. As noted previously, a TRB study that examined this question found that a doubling of density reduces household VMT between 5% and 12% (TRB 2009). On the other hand, higher densities also result in greater traffic congestion, which reduces vehicle fuel economy to a significant degree (Barth and Boriboonsomsin 2007). This introduces some uncertainty in the ultimate degree to which denser land-use would reduce fuel consumption.

L.3.4 Other Effects

Because the state role in land use remains peripheral rather than central regardless of what actions are taken, all of the effects described in the following are to some extent speculative. In both economic and equity terms, such effects may be both positive and negative, leading the researchers to rate the effects as both neutral and uncertain. The effects on environment and public health, in contrast, should be highly positive.

Economy—neutral (uncertain). The potential effects of higher-density land use on the economy are unclear. Home construction is widely thought to have a positive impact on the economy and on employment, although such effects occur with any type of housing construction. Over the long run, higher-density housing, especially in multifamily buildings, tends to be more affordable because average unit sizes are smaller. On the other hand, new construction also tends to be more expensive, so those units may at first be less affordable. Higher-density housing also tends to be associated with lower infrastructure costs since the same utility lines and roads can serve a larger number of people, meaning that the public sector can save money. For example, Muro and Puentes (2004) found that in the aggregate, states and localities would save almost 12% on road-building costs over a 25-year time frame by using more compact development patterns.

Environment and public health—highly positive. As noted earlier, the main effect of higher-density land use with regard to transportation is to reduce VMT and increase non-automotive travel, which in turn should help reduce air pollutant and GHG emissions and enhance physical activity levels. It could also have secondary impacts such as encouraging the use of smaller vehicles and car sharing, longer vehicle life, and more efficient delivery by truck. Another environmental benefit is that smaller housing units tend to require less energy use for heating and cooling. Finally, denser land use would also reduce the need for new construction on previously undeveloped land, an especially important benefit in areas with endangered species. The scale of such impacts would depend on the amount and type of higher-density development, but the overall combined effects on the environment and public health should be highly positive.

Equity—neutral (uncertain). Equity can be defined in different ways, and land use changes are by nature incremental, making it difficult to generalize about the equity impacts. Important issues include whether there is underserved demand for higher-density housing and whether land use patterns have an effect on housing prices. The literature is somewhat mixed on these effects. One study used a model to assess the equity impacts of different land-use patterns in the Sacramento region; it found that "a more compact urban form designed around transit stations can reduce travel costs, wages, and housing costs by increasing accessibility, which can lead to substantial net benefits for industry and for lower income households" (Rodier et al. 2010, pg. 2). Researchers in the United Kingdom have found that, for some low-income residents, more compact land use has some positive equity effects, such as better public transportation and access to services, but on others there are negative impacts such as the potential for overcrowded housing (Burton 2000, Bramley and Power 2009).

L.3.5 Barriers

Barriers for this strategy, including public support, enabling legislation, and institutional restructuring, are not likely to be significant.

Low public support—moderate barrier. Low public support for land use changes is expected to be a moderate barrier, although one that may vary from state to state and from city to city depending on current land-use patterns. Groups likely to support higher density could include those communities, for instance, that have been in decline and would welcome growth. Opposing groups could include existing lower-density communities concerned about increased traffic as well as those generally opposed to government intervention in land use decisions. However, disputes over land use tend to take place at a very local scale, so it is possible that changes in state DOT regulations or practices would not in and of themselves attract much opposition.

Enabling legislation—moderate barrier (uncertain). In some states, there may be existing laws or regulations that make it difficult for the DOT to become more involved in integrated land-use and transportation planning. As noted previously, for example, Florida's state-level concurrency requirements, prior to their repeal, made it difficult for the state to address anticipated congestion through any means other than building or expanding roads (Chapin, Thompson, and Brown 2007).

Institutional restructuring—moderate barrier (uncertain). It is possible that some state DOTs will require internal restructuring to better address land use issues. Some states already have offices that do so, such as Maryland's Office of Planning and Capital Programming, which has a transit-oriented development program (Maryland DOT 2011). These functions could be housed in an existing but expanded department of planning, environment, or local coordination. They might also be housed in entirely new departments or involve new collaborations with other state or local agencies.

L.3.6 Required Lead Time

Depending on the existing circumstances, which vary from state to state, the time frame for making changes to state laws or regulations that affect how a DOT can deal with land use would likely be quite short, on the order of less than a year. However, such changes may take more than 20 years to have an impact since many other factors, including, most importantly, the economic situation of the area, affect the pace of development. Generally speaking, changes to the built environment unfold over multiple decades.

L.3.7 Qualifications

While any state can change the way in which its actions affect land use and development, realistically such actions are more apt to produce measurable changes in states that are growing rapidly and are hence subject to more development pressure.

References

AASHTO. 2010. *The Road to Livability: How State Departments of Transportation are Using Road Investments to Improve Community Livability.* Washington, D.C.

Applied Development Economics, Collaborative Economics, Information Center for the Environment at UC Davis, and CALCOG Member Agencies. 2010. *2010 California Regional Progress Report.* California Strategic Growth Council, Sacramento.

Ayres, G. 2007. *Bus Emissions Versus Passenger Car Emissions.* Volpe National Transportation Systems Center, Memorandum to Roy Chen, Federal Transit Administration.

Barth, M. and K. Boriboonsomsin. 2007. "Traffic Congestion and Greenhouse Gases." *Access*, 35, 2–9.

Baxandall, P., T. Dutzkik, and J. Hoen. 2008. *A Better Way to Go: Meeting America's 21st Century Transportation Challenges with Modern Public Transit.* U.S. PIRG Education Fund.

Bramley, G. and S. Power. 2009. "Urban Form and Social Sustainability: The Role of Density and Housing Type." *Environment and Planning B: Planning and Design*, 36 (1): 30–48.

Burton, E. 2000. "The Compact City: Just or Just Compact? A Preliminary Analysis." *Urban Studies*, 37 (11): 1969–2006.

Cambridge Systematics. 2009. *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions.* Urban Land Institute, Washington, D.C.

Chapin, T. S., G. L. Thompson, and J. R. Brown. 2007. *Rethinking the Florida Transportation Concurrency Mandate.* Florida Department of Community Affairs.

Downs, A. 2004. *Still Stuck in Traffic: Coping with Peak-Hour Traffic Congestion.* Brookings Institution Press, Washington, D.C.

Ernst, M. 2004. *Mean Streets 2004: How Far Have We Come?* Surface Transportation Policy Project, Washington, D.C.

Evans, J. 2004. Chapter 9: Transit Scheduling and Frequency. In *TCRP Report 95: Traveler Response to Transportation System Changes.* Transportation Research Board of the National Academies, Washington, D.C.

Ferreira, J. and E. Minikel. 2010. *Pay-As-You-Drive Auto Insurance in Massachusetts.* Conservation Law Foundation and Environmental Insurance Agency.

FHWA. 2009. "Balancing Infrastructure Improvements with Historic Preservation: The Front Street Rehabilitation Project." *Successes in Stewardship.*

FTA. 2009. *Public Transit's Role in Responding to Climate Change.*

Guo, Z., A. Weinstein Agrawal, J. Dill, M. Quirk, and M. Reese. 2011. *The Intersection of Urban Form and Mileage Fees: Findings from the Oregon Road User Fee Pilot Program.* Mineta Transportation Institute, San Jose.

H.C. Planning Consultants and Planimetrics. 1999. The Costs of Suburban Sprawl and Urban Decay in Rhode Island, Executive Summary. Grow Smart Rhode Island, Providence.

ICF. 2011. *Potential Changes in Emissions Due to Improvements in Travel Efficiency – Final Report.* U.S. Environmental Protection Agency.

Maryland Department of Planning. Undated. Mapping: Priority Funding Areas. http://www.mdp.state.md.us/OurProducts/pfamap.shtml (accessed November 22, 2011).

Maryland DOT. 2011. Office of Planning and Capital Programming. http://www.mdot.maryland.gov/Planning/Index.html (accessed December 30, 2011).

Muro, M. and R. Puentes. 2004. *Investing in a Better Future: A Review of the Fiscal and Competitive Advantages of Smarter Growth Development Patterns.* The Brookings Institution Center on Urban and Metropolitan Policy, Washington, D.C.

National Safety Council. 2011. *Injury Facts.* 2011 Edition. Itasca, Ill.

New Jersey DOT. 2009. Transit Village Initiative Overview. http://www.state.nj.us/transportation/community/village/ (accessed December 30, 2011).

Rodier, C., J. E. Abraham, B. N. Dix, and J. D. Hunt. 2010. *Equity Analysis of Land Use and Transport Plans Using an Integrated Spatial Model.* Mineta Transportation Institute, San Jose.

Smart Growth America. 2010. National Complete Streets Coalition. http://www.smartgrowthamerica.org/complete-streets (accessed May 30, 2013).

Tindale-Oliver & Associates. 2009. *Conserve by Transit: Analysis of the Energy Consumption, Climate Change, and Health Benefits of Transit.* Prepared for Florida Department of Transportation Central Office.

TRB. 2002. *Special Report 264: The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience.* Transportation Research Board of the National Academies, Washington, D.C.

TRB. 2009. *Special Report 298: Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and* CO_2 *Emissions*. Transportation Research Board of the National Academies, Washington, D.C.

Turner, K. 2011 (June 9). "Growth Management in Florida Back Under Local Control." *The Florida Times-Union*, Jacksonville.

U.S. DOT. 2010. *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions.* Report to Congress.

APPENDIX M

Strategies to Promote Energy Efficiency and Alternative Fuels

This appendix focuses on strategies that states could pursue to promote greater energy efficiency and the development and adoption of alternative fuels. Unlike many of the strategies discussed in earlier appendices, the primary motivation underlying the strategies in this appendix is to shape future energy outcomes—in particular, to positively influence the prospects for transitioning to a more sustainable energy future. Even if only partially successful in this more sweeping objective, such strategies could also help mitigate the emissions of local air pollutants and greenhouse gases within a state. The five strategic directions considered in this appendix are pricing vehicles, pricing fuel or emissions, setting up state mandates and programs for alternative fuels, state production and distribution of alternative fuels, and altering energy use within state agencies.

M.1 Pricing Vehicles

Pricing policies can be applied with the sale of new vehicles to promote the adoption of conventional vehicles with greater fuel economy or alternative-fuel vehicles. Vehicle-based pricing may be applied in ways that increase revenue (e.g., gas-guzzler taxes), require funding (e.g., subsidies for alternative-fuel vehicles), or are revenue neutral (e.g., subsidies for alternative-fuel vehicles or conventional vehicles with high fuel economy combined with taxes on conventional vehicles with low fuel economy). Such policies have the advantage of sending price signals to consumers and vehicle manufacturers that encourage, without requiring, desired production or consumption choices. However, the interaction of pricing policies with other policies, such as fuel economy or renewable fuel standards, must be evaluated carefully because impacts may be masked or the policies may even work at cross-purposes. Pricing is not necessarily superior to such mandates from a standpoint of either effectiveness or net social costs and benefits.

M.1.1 Supportive Policies

Pricing in general is widely acknowledged as being an effective means of influencing energy use (Greene and Plotkin 2011); however, the effect of any given vehicle pricing strategy will depend on the magnitude of the price signal, the alternatives available to consumers, and other related policies in place.

Subsidies or credits on fuel-efficient or alternative-fuel vehicles. One option for promoting certain types of vehicles, such as alternative-fuel vehicles or other designated low-emission or high-efficiency vehicles, is to offer financial incentives in the form of subsidies or tax credits. For example, BEVs and PHEVs are eligible for up to a $7,500 federal tax credit, and additional purchase incentives are offered in some states. The primary aim of such incentives is to help consumers overcome up-front cost differentials associated with efficient-technology vehicles, particularly for technologies that are still in the development stage. Tax credits are most effective when cost and performance differentials between vehicle types are relatively small. Another possibility in this vein is a vehicle scrappage incentive, usually structured as a tax deduction or cash payment for scrapping an existing vehicle with poor fuel economy. The Obama administration's cash for clunkers program was an example of this strategy. While such incentives can be effective and are generally popular, they also require funding and are thus more difficult to sustain over the longer term.

Financial penalties of fuel-inefficient vehicles. An alternate approach for achieving the same objective is to apply additional taxes on vehicles with low fuel economy, such as with the federal gas-guzzler tax. This should have a broadly similar effect on consumer and manufacturer behavior without the need for public investment—indeed, it actually creates a revenue stream. On the other hand, a tax-only approach is sure to face a much higher degree of public resistance.

Vehicle feebate programs. Feebates merge the two prior options, combining graduated fees on high-emission (or low fuel economy) vehicles with graduated rebates for low-emission (or high fuel economy, or alternative-fuel) vehicles (Greene and Plotkin 2011). Through careful design, feebate programs can be structured as revenue neutral, making them more economically feasible over the long term than tax credits alone. At the same time, they still provide consumers with a direct financial incentive to purchase a more efficient new vehicle. In fact, one study (Energy and Environmental Analysis 2008) noted that a feebate program should be more effective than either taxes on low fuel economy vehicles or subsidies for high fuel economy vehicles in isolation; the feebate incentives, ranging from negative to positive, apply to all new vehicles sold, whereas the tax-only or subsidy-only approach would only affect a portion of the new vehicle fleet (either low fuel economy or high fuel economy vehicles, respectively) each year. The success of a feebate program, however, ultimately depends on the magnitude of the fees and rebates.

Other vehicle-based pricing incentives. Other financial incentives and rewards can also be provided to encourage consumers to adopt higher-efficiency or alternative-fuel vehicles. Examples are providing free access to HOV or HOT lanes, exemptions or discounts at other toll facilities, and discounted registration fees. These incentives are most useful for a given category of vehicles during the early stages of market penetration; as adoption grows, the negative effects—such as toll revenue losses or overuse of HOV lanes—can outweigh the benefits.

Assumed policies for vehicle-based pricing. In assessing the strategy of pricing vehicles, it is assumed that states would implement a revenue-neutral feebate system based on fuel economy or CO_2 emissions. Under such a system, conventional vehicles with higher levels of fuel economy along with emerging alternative-fuel vehicle technologies—plug-in hybrids, battery electric, fuel-cell vehicles, and the like—would qualify for rebates, whereas conventional vehicles with lower fuel economy would be assessed fees. The assessment does not consider the possibility of instituting rebates for high fuel economy and alternative-fuel vehicles absent corresponding fees on lower fuel economy vehicles given that such a program would be difficult to sustain financially over a long period of time. Because other vehicle-based incentives such as differential toll rates or HOV access are likely to have only modest impacts, they are likewise not assumed as part of the assessment. As noted earlier, anticipated effects would depend on the magnitude of the price incentive; it is assumed that the maximum penalties, credits, and subsidies would be consistent with past or proposed levels (e.g., maximum rebates or fees on the order of a few thousand dollars per vehicle).

M.1.2 Intended Mitigation Effects

If not employed in the near term to shape future energy outcomes, feebate programs could be employed at a later date to mitigate some of the challenges associated with certain plausible futures—notably challenges related to air quality and greater pressure to mitigate GHG emissions.

Improving air quality—moderately effective (uncertain). If a feebate program results in a significant shift to EVs, PHEVs, or hydrogen vehicles with little or no tailpipe emissions, one of the likely results would be improved urban air quality. However, electric power plant emissions could increase, potentially undercutting the air quality benefits depending on the power source, emission controls, and proximity of the plant to population centers. Switching to more fuel-efficient conventional vehicles, another likely outcome of a feebate program, would not be expected to have that much of an effect on air quality given that all conventional vehicles would likely be held to similar emission standards for local air pollutants regardless of fuel economy.

Reducing GHG emissions—highly effective. A feebate program should be effective in stimulating a shift to conventional vehicles with greater fuel economy and potentially alternative-fuel vehicles with lower carbon profiles as well. Either of these would have the effect of driving down GHG emissions.

M.1.3 Intended Shaping Effects

With respect to the shaping objectives considered in this study, and assuming potential fees and subsidies or tax credits on the order of a few thousand dollars, feebates should be highly effective for reducing aggregate oil consumption along with the energy cost of travel. Feebates could also be effective in stimulating a shift to alternative fuels if other conditions—such as reduced technology premiums and available fueling infrastructure—are met.

Reducing oil consumption—highly effective. A feebate system would create a highly visible incentive for the purchase of vehicles with greater fuel economy, likely leading to significant reductions in aggregate fuel consumption. For example, a French feebate program implemented in 2008 led to an immediate and sustained reduction of 5% in average CO_2 emissions for new passenger vehicles sold, corresponding roughly to a 5% improvement in fuel economy; other countries with graduated CO_2 taxes have seen similar impacts. In the United States, it has been estimated that a national feebate system would further reduce oil consumption and GHG emissions rates by about 10% beyond reductions achieved by existing fuel economy and GHG emission standards (Greene and Plotkin 2011).

Promoting adoption of lower-carbon alternative fuels—highly effective (uncertain). A feebate system should in theory be equally effective at promoting the adoption of alternative-fuel vehicles as they become available. And if the feebate structure is based on greenhouse gas emissions (as opposed to conventional vehicle fuel economy), the program would inherently favor vehicles capable of running on lower-carbon fuels. For this to occur, however, the vehicle technology must first reach the market, and the premium for the alternative-fuel models should not be too much larger than the rebate; experience suggests that purchase incentives are most effective at shifting decisions where the new technology faces only a moderate cost disadvantage and does not have significant performance limitations. Additionally, broad adoption of a particular technology may depend on sufficient availability of fueling infrastructure. This is most relevant for natural gas and hydrogen, and is potentially an issue for electric vehicles as well. As an example, long-standing subsidies for natural gas vehicles have thus far failed to stimulate significant adoption, owing in part to the paucity of fueling stations.

Reducing energy cost of travel—highly effective. Feebate programs create a strong incentive for the purchase of more fuel-efficient vehicles, in turn reducing the amount of fuel that must be purchased to travel a given distance. Further, by reducing demand for oil in aggregate, such programs may exert downward pressure on the price of oil (although the effects of a single state's action in the context of a world market for oil are likely to be quite modest). Finally, depending on their structure, feebates could promote more rapid adoption of alternative-fuel technologies—electric vehicles or natural gas, for example—that already offer much lower energy costs for driving than gasoline- or diesel-propelled vehicles.

M.1.4 Other Effects

The anticipated effects of a feebate program on the economy, environment and public health, and equity are moderately positive, though in some cases uncertain.

Economy—moderately positive (uncertain). A feebate program as envisioned in this assessment would be revenue neutral and would therefore not have a net cost impact on consumers in terms of vehicle purchase price. As noted, though, it would tend to reduce the energy cost of travel, which should have a positive effect on the economy. Additionally, to the extent that the shift in vehicle technology results in reduced reliance on foreign oil, the U.S. economy could benefit in the long run through an improved balance of trade and by reducing volatility associated with factors influencing international energy markets (such as political disruptions in oil-producing countries). On the other hand, if the program is not well designed, it could result in distortions of the vehicle market.

Environment and public health—moderately positive (uncertain). GHG benefits should be achieved from feebates and possibly air quality benefits if the adoption of certain alternative fuels is encouraged. To the extent that feebates encourage the use of biofuels, on the other hand, negative environmental impacts could result from the conversion of land into agricultural uses for feedstocks. These negative impacts could take the form of loss of natural habitat as well as degraded water quality due to agricultural production. However, some offsetting positive environmental benefits may be achieved as a result of reduced oil production (e.g., fewer oil spills and reduced emissions from oil refineries). On balance, the environmental and public health effects should be positive, although the interplay of these various factors remains uncertain.

Equity—moderately positive. A CARB study found that higher-income households purchase the large majority of new vehicles (CARB 2008). As such, this group would be most affected by the penalties and subsidies or tax credits associated with the program. Lower-income households, however, would still benefit slightly from improved access to new fuel-efficient vehicles via tax credits or subsidies, and should also benefit from the increasing share of more efficient vehicles in the used vehicle market.

M.1.5 Barriers

Vehicle purchase incentive programs consisting solely of subsidies or tax credits are generally popular but not financially sustainable over the longer term. Shifting to a feebate structure as discussed here allows for revenue neutrality but at the likely cost of increasing opposition due to the fee component. Feebate programs are also likely to require enabling state legislation.

Low public support—moderate barrier. Feebate systems may be opposed by automobile manufacturers and dealers, who make larger profits off of larger and more expensive vehicles (which are less likely to be fuel-efficient) and by consumers who wish to buy larger vehicles and would therefore face additional fees. One way of minimizing these factors would be to establish a system of graduated fees and rebates within vehicle size classes (to reward the most efficient vehicles in a class), although this would somewhat reduce the overall effectiveness of the program in promoting a shift to vehicles with greater fuel economy.

Enabling legislation—moderate barrier. A straightforward way to apply a feebate system is through the vehicle sales tax (e.g., differentiated tax rates). Changes in the sales tax structure would likely require enabling state legislation.

M.1.6 Required Lead Time

Vehicle feebate programs could be implemented within 1 to 5 years, allowing time to design the specific feebate mechanism, evaluate its impact, and establish an implementation strategy for collecting differential fees.

M.1.7 Qualifications

Feebates can reasonably be implemented at a state level, but the specific fee structure would likely need to vary by state to account for different vehicle fleet characteristics (e.g., rural states with a larger proportion of trucks versus urban states with a larger proportion of small vehicles).

M.2 Pricing Fuel or Emissions

Another strategy for encouraging a transition to more fuel-efficient conventional vehicles or alternative-fuel vehicles is to tax fuels based on their carbon content or, alternatively, to provide more favorable tax rates or subsidies for lower-carbon fuels. Policies that increase prices, as opposed to providing subsidies, will also generate revenue, of which some or all may be directed toward transportation programs. Depending on how it is applied, pricing can have the advantage of sending direct price signals to consumers and vehicle manufacturers related to the impact that is being priced (energy, emissions, etc.), allowing them to choose their own preferred path to mitigating these impacts rather than directing a specific solution. In designing such a strategy, however, it is important to consider interactions with other related strategies such as fuel economy standards, renewable fuel standards, and vehicle taxation policies to ensure that their effects are complementary rather than working at cross-purposes.

M.2.1 Supportive Policies

Pricing in general is widely acknowledged as being an effective means of influencing energy use (Greene and Plotkin 2011). The intent could be to encourage a shift to fuels with lower carbon content, to fuels that are domestically or locally produced, or to fuels that are renewable. The effect of pricing fuels or emissions would depend on the magnitude of the price signal, the range of alternatives available to consumers, and other related policies in use. Options that might be considered include reduced tax rates or subsidies to support alternative-fuel use or a carbon tax on fuels based on their greenhouse gas emissions profile.

Reduced tax rates or subsidies for alternative fuels. A state could promote increased use of alternative fuels through reduced rates or even by subsidizing their production or purchase. For example, ethanol has been eligible for a $0.45-per-gallon excise tax credit in recent years, although Congress allowed this subsidy to expire at the end of 2011. A $1.00-per-gallon tax credit for agricultural biodiesel was enacted in 2004, allowed to expire at the end of 2009, and then retroactively reinstated and extended through December 2011. Cellulosic ethanol is eligible for a credit of $1.01 per gallon. For such tax credits or subsidies to be effective, the tax difference must be large enough to make the fuel attractive to consumers by overcoming any inherent price difference in the cost of producing the fuel and, potentially, the cost of the vehicle. For fuels that require alternate vehicle technology, the tax incentive must also be sustained for long enough to provide consumers with the confidence that any investment in up-front vehicle costs will ultimately be paid back through fuel-cost savings.

Fuel feebates. The concept of feebates, described for vehicle purchases in the preceding section, could be applied to fuels as well. The basic idea would be to offer rebates on the purchase of less-polluting fuels and levy additional fees on the purchase of more-polluting fuels. Although intriguing, implementation could be complicated. To begin with, many fuels are already taxed. Assuming that the existing tax revenue stream is to be maintained, the feebate structure might simply take the form of lower taxes for less-polluting fuels and higher taxes for more-polluting fuels. Examples in this vein are differential taxes for leaded versus unleaded fuel in Sweden (University College Dublin 2008a) and differential taxes based on a range of air pollutants in Denmark (University College Dublin 2008b). If applied to greenhouse gas emissions, such a structure would be quite similar to carbon pricing, which is discussed next. Additionally, with the possibility that some alternative fuels—notably electricity, natural gas, and perhaps even hydrogen—could allow for home refueling, administering the feebate system could be challenging since it would require distinguishing between fuel or power used for vehicle travel and fuel or power used for other applications at home.

Carbon pricing. Carbon pricing involves taxing fuels in proportion to CO_2-equivalent emissions. This can be implemented through a fixed, economy-wide price per unit of carbon or through a cap-and-trade system that allows the market to set prices for a fixed, tradable amount of carbon emissions. Carbon pricing will increase the cost of transportation fuels that result in carbon emissions, which will both increase the cost per unit of travel (creating a greater incentive to reduce travel and to purchase more-efficient vehicles) and change the relative cost competitiveness of different fuels based on their carbon intensity (creating incentives for manufacturers and consumers to adopt vehicles that use less carbon-intensive types of fuel).

Assumed policies for fuel and emissions pricing. It would be difficult, financially, to sustain tax credits or subsidies for alternative-fuel use over the long term—particularly at the state level where budgets must typically be balanced each year. And, as described previously, setting up some type of feebate structure for fuels could prove rather complex. It is therefore assumed that a state interested in this strategy would implement carbon pricing, either by specifying a set carbon tax or setting up a cap-and-trade system. To help gauge the potential magnitude of the effects, it is further assumed that the carbon price would be generally consistent with expectations under recently proposed legislation and that carbon pricing would be applied across multiple sectors (e.g., including power generation and industrial uses). An allowance price of $30 per ton of carbon is in the range of levels proposed for U.S. cap-and-trade systems in the 2030 time frame; this would translate to an increase in gasoline prices of $0.26 per gallon (EIA 2009). Finally, although carbon pricing could result in a significant revenue stream, it is not assumed that the majority of such funds would be devoted to transportation. Instead, for example, some of the revenue might be invested in research to reduce the cost of lower-carbon fuels and vehicle technologies, some might be used to help lower-income households purchase more fuel-efficient vehicles and energy-efficient home appliances, and some might be channeled to a state's general fund in order to allow for a reduction in the tax rates of other general revenue sources (e.g., reducing a state's sales tax); the logic is that spreading the revenue around to multiple uses might prove necessary, if not sufficient on its own, to reduce opposition to carbon pricing.

M.2.2 Intended Mitigation Effects

Taxing fuels based on carbon content would create a strong incentive for adopting lower-carbon fuels, in turn reducing aggregate GHG emissions. This strategy could also play a supporting role in boosting revenue, improving safety outcomes, reducing traffic congestion, and improving air quality.

Increasing transportation revenue—moderately effective (uncertain). As indicated previously, the assumed carbon price of $30 per ton would translate to 26 cents for each gallon, roughly on par with average state fuel taxes. While a portion of this revenue could be directed to transportation, it also seems likely that the revenue would be spread to multiple claimants—for example, to mitigate potential equity issues or to replace other tax streams. Further, if the policy works as intended, GHG emissions should shrink over time. Assuming that the carbon tax is not raised on an ongoing basis, the revenue stream would decline as well. For these reasons, a carbon tax is rated as having only a moderate and uncertain effect in increasing transportation revenue.

Reducing DOT costs—moderately effective. A carbon price would increase the marginal cost of driving, putting downward pressure on vehicle travel. This should in turn have some effect on reducing overall construction and maintenance needs.

Reducing traffic congestion—moderately effective. By reducing total vehicle travel, carbon pricing should also help ease traffic congestion. An analysis by the EIA suggests that a carbon price of $30 per ton would reduce transportation petroleum consumption, and in turn GHG emissions, by about 2.8% (EIA 2009). Of this, about two-thirds would be due to reductions in vehicle travel and about one-third to the adoption of vehicles with higher fuel economy. In other words, carbon pricing, at the level assumed for this analysis, could reduce VMT by a little less than 2%, enough to have some effect on reducing congestion. On the other hand, while higher-priced fuel would encourage a general reduction in travel, it would not specifically incentivize reductions in peak-hour travel. As such, carbon pricing has been rated as likely to be only moderately effective in reducing traffic congestion.

Improving safety outcomes—moderately effective. Motor vehicle crashes vary in proportion to total travel. By helping to reduce overall VMT by a modest amount, carbon taxes should have a moderate positive effect with respect to traffic safety rates as well.

Improving air quality—highly effective (uncertain). A significant share of harmful local air pollutants stems from the combustion of petroleum in motor vehicles and coal in power plants. Because these are carbon-intensive energy sources as well, the application of carbon pricing should have the effect of reducing the consumption of fossil fuels in both of these sectors—by reducing demand in the near term and by creating an incentive for the adoption of cleaner alternatives over the longer term. Still, there is an element of uncertainty given that there is not a perfect correlation between greenhouse gas emissions and local air pollutants. For example, certain forms of biofuels that would reduce carbon emissions could also increase certain local air pollutants (U.S. DOT 2010). The location at which the emissions occur (i.e., proximity to population) would also affect their relative health impacts, and a switch to alternative fuels could result in changes in emissions at the source of fuel production and extraction as well as from the vehicle itself.

Reducing GHG emissions—highly effective. While carbon pricing might lead to only moderate reductions in GHG emissions within the transportation sector, an economy-wide application of carbon pricing would be expected to yield significant reductions in overall GHG emissions, especially in the power generation sector.

M.2.3 Intended Shaping Effects

Carbon pricing is considered a technology-neutral, performance-based policy and will have somewhat different effects than policies that promote specific technologies, such as tax credits for different alternative fuels. At the envisioned price level of $30 per ton of CO_2-equivalent emissions, carbon pricing should be moderately effective in helping to reduce oil consumption and could promote the adoption of alternative fuels, contingent on several other factors.

Reducing oil consumption—moderately effective. Pricing carbon should help reduce oil consumption by providing a financial incentive for the purchase of more fuel-efficient vehicles or vehicles propelled by lower-carbon alternative fuels. The effect, however, is likely to be modest. As mentioned previously, a recent analysis by EIA suggests that pricing carbon at $30 per ton of CO_2-equivalent—translating to about 26 cents per gallon—would reduce transportation petroleum consumption by about 2.8% (EIA 2009). With respect to truck freight, Cambridge Systematics estimated that an increase in the cost of fuel on the order of $1 to $2 per gallon would lead to a reduction in truck fuel use of 20% to 40% over the long run (Cambridge Systematics 2009a), a combined result of reduced truck travel and efficiency improvements. With an increase in the cost of fuel of about 26 cents due to carbon pricing, the corresponding decline in truck fuel use would be about 5%.

Over time, the incremental effectiveness of carbon pricing in stimulating reduced petroleum consumption could decline given recent increases in federal fuel economy standards (U.S. DOT 2010), which are now set to double by 2025. As vehicles achieve higher fuel economy, they use less fuel—and in turn incur less of a carbon tax penalty—for each mile of travel. Unless the carbon tax is increased over time, the incentive for further efficiency gains beyond those already mandated by CAFE standards is likely to grow progressively weaker.

Promoting adoption of lower-carbon alternative fuels—moderately effective (uncertain). A carbon tax, by increasing the cost of gasoline and diesel, could help promote the adoption of low- or zero-carbon alternative fuels by making them more cost-competitive. For this to occur, however, the cost of the alternative fuels, on an energy-equivalent basis, would need to be relatively close to the cost of petroleum.

There is some available evidence on the effects of price differentials for alternative fuels. The lapse of the $1.00-per-gallon biodiesel tax incentive on December 31, 2009, coincided with a sharp 42% drop in annual biodiesel production, and its reinstatement in 2011 coincided with a 69% increase in production (Urbanchuk 2011). In this case, the effect was large because biodiesel can be easily substituted for conventional diesel since it can be used in existing vehicles without modification at up to a 20% blend. However, the price effects for biofuels may be masked by renewable fuel requirements as well as by air quality regulations that encourage use of ethanol as an oxygenate. One study (Babcock, Barr, and Carriquiry 2010) found that eliminating the ethanol tax credit of 45 cents per gallon along with the current tariff of 54 cents per gallon on imported ethanol would only decrease domestic ethanol output modestly, by about 6%; the main impact would be to shift the cost burden of complying with the ethanol production mandate under the federal RFS2. In the future, the scheduled rise in mandated volumes under RFS2 will require the production of biofuels in amounts that are probably beyond what the market would produce even if the effects of tax credits are included (CBO 2010)—or, by extension, even with any cost differential resulting from a carbon tax. In short, available evidence on cost differentials makes it unclear whether a carbon tax would have much effect in stimulating a shift to alternative fuels beyond that anticipated under RFS2.

Additionally, the effects from stimulating a shift to alternative fuels would also be contingent on cost differentials for the vehicle technology. This is less relevant for biofuels but potentially significant for electric and hydrogen vehicles. Based on such considerations, the effect of a carbon tax on alternative-fuel adoption has been assessed as moderately promising but uncertain.

M.2.4 Other Effects

The effects of carbon pricing on broader goals related to the economy, environment and public health, and equity are uncertain but likely to be mixed.

Economy—moderately positive (uncertain). In the near term, a carbon tax could be expected to have a moderately negative effect on economic growth. The costs to the economy of the cap-and-trade system proposed in the American Clean Energy and Security Act of 2007, for example, were estimated at a little less than 1% of U.S. GDP in 2030. Such a program, however, would internalize (that is, price) the negative environmental costs associated with emitting greenhouse gases that would otherwise be passed along to society at large. To the extent that pricing accurately reflects such external costs, the ultimate result is to improve net social welfare—specifically by discouraging activities for which net costs (including social costs) exceed net benefits. In this instance, continued emissions of GHGs contribute to the risk of uncertain but potentially significant costs resulting from climate change. Reducing that risk has economic value. It is also worth noting that the shift to a more sustainable energy future provides enormous opportunities for future economic growth and development. Through leadership in climate policy in the form of either carbon pricing or cap and trade, states could create a business climate conducive to the formation of firms and industries that could become world leaders in such a transition. Taking all of these factors into consideration, it could be expected that carbon pricing would have a moderately positive but highly uncertain (ranging from moderately negative to highly positive) effect on the economy over the long term.

Environment and public health—highly positive (uncertain). As noted previously, carbon pricing in all sectors of the economy could be expected to spur significant reductions in both local air pollutants (with some degree of uncertainty) and GHG emissions. Further environmental benefits would be achieved based on reduced oil production (e.g., fewer oil spills) and reduced coal extraction (e.g. less strip mining and mountaintop removal). On the other hand, to the extent that carbon pricing encourages the use of biofuels, negative environmental impacts could result from the cultivation of land to produce feedstocks, thus adding uncertainty to the rating. These negative impacts could take the form of habitat loss as well as degraded water quality due to agricultural production. Public health would benefit as well from improved air quality, and the higher cost of fuel with carbon pricing would likely induce some mode shift to non-automotive modes, in turn promoting more active lifestyles.

Equity—moderately negative (uncertain). A fixed increase in the unit price of travel would burden lower-income households more than higher-income households. These negative impacts could be mitigated if revenue is directly distributed to lower-income households or used to provide services (such as transit) that improve transportation options for these groups.

M.2.5 Barriers

Pricing strategies that are perceived as increasing costs to businesses or the traveling public face significant public acceptance barriers. Enabling legislation would almost certainly be required as well.

Low public support—significant barrier. To date, the controversial nature of carbon pricing has prevented implementation of a carbon tax or cap-and-trade system at the federal level, although California, as one example, recently implemented a state-level cap-and-trade system. Opposition to cap and trade from energy-intensive industries that would be most affected by such a system has been especially intense.

Enabling legislation—moderate barrier. Any state wishing to implement carbon pricing, via either cap and trade or a carbon tax, would likely need to pass enabling legislation. This was the case in California with its landmark AB 32 climate legislation.

M.2.6 Required Lead Time

A carbon tax or cap-and-trade system could likely be implemented within a 1- to 5-year time frame, allowing time to design the tax-collection system or set up the market for carbon credits under cap and trade.

M.2.7 Qualifications

Carbon pricing would ideally be implemented at a national level since state-level application may provide unwanted incentives for businesses to move to other states where costs are lower. As the California example shows, however, some states have nonetheless chosen to consider or implement this strategy.

M.3 Alternative-Fuel Programs and Mandates

States may establish programs to promote or mandate the production of alternative fuels for use in the transportation sector. The principal motivations for such programs include diversifying energy sources, promoting economic development within the state, and reducing greenhouse gas emissions, with the relative emphasis depending on the specific policy design. Mandated programs can be structured to require the sale of minimum quantities of certain types of fuels—such as ethanol or biodiesel—or to require that fuels meet specified performance standards in relation, for example, to carbon content. Programs implemented to date are intended to regulate common liquid fuels, including petroleum or biofuels. The same concept could be applied to other fuels as well, such as synthetic fuels (e.g., gas-to-liquid or coal-to-liquid fuel), gaseous fuels (e.g., natural gas or hydrogen), and electricity. States could also pursue voluntary programs designed to promote alternative fuels through coordinated partnerships with stakeholders and information campaigns. Other potentially complementary policies—including pricing vehicles or fuels, requiring alternative-fuel use by public agencies, and public investment in the production, transport, and dispensing of alternative fuels—are assessed as separate strategies in this appendix.

M.3.1 Supportive Policies

There are at least four policy approaches that states could implement to mandate or encourage greater production and use of alternative fuels: renewable fuel standards, low-carbon fuel standards that account for life-cycle carbon emissions per unit of energy, renewable electricity portfolio standards, and outreach and information programs to encourage voluntary adoption of alternative fuels.

Renewable fuel standards. Renewable fuel standards are typically structured to require wholesale fuel producers to achieve production volume or fuel sale percentage targets for certain types of liquid renewable fuels. By reducing reliance on imported petroleum, they offer inherent energy security benefits. Optionally, RFS programs can be designed to support the goal of reducing greenhouse gas emissions by requiring that qualifying renewable fuels meet specified life-cycle GHG performance levels. At the federal level, the EPA's RFS2 program, as amended in the Energy Independence and Security Act of 2007, established specific production targets for renewable fuel volumes and a market-based compliance credit trading scheme (EPA 2007). At the state level, 12 states have renewable fuel standards or mandates in place as of 2011 (EERE 2011). Oregon's biofuels renewable fuel standard mandate, for example, requires all diesel fuel sold in the state to contain at least 5% by volume biodiesel [Oregon Department of Agriculture (ODA) 2012].

Low-carbon fuel standards. In contrast to an RFS, which specifies target production levels for specific fuels, LCFSs require fuel producers to meet, on average, specified percentage reductions in the carbon intensity of fuels sold. By focusing on carbon content, LCFS policies are explicitly oriented toward the goal of reducing greenhouse gas emissions. Additionally, LCFS mandates are generally neutral with respect to the type of fuel used to meet the performance goals, allowing industry to determine the most cost-effective combination of fuels to achieve required reductions in carbon intensity. California became the first state to adopt an LCFS, setting the goal of reducing the carbon intensity of transportation fuels by 10% by 2020 (CARB 2009). States involved in the Western Climate Initiative, the Midwestern Greenhouse Gas Accord, and the Northeast Regional Greenhouse Gas Initiative are also considering introducing California's low-carbon fuel standard [Northeast States Center for a Clean Air Future (NESCCAF) 2009, Oregon Department of Environmental Quality 2011].

Renewable portfolio standards. Also known as renewable electricity standards, RPSs are similar to low-carbon fuel standards but apply instead to electric power generation. These mandates are primarily intended to reduce emissions of greenhouse gases and local air pollutants resulting from the production of electricity; energy security is less an issue in the power sector since the vast majority of feedstocks are domestically produced. From a transportation perspective, the source of electric power becomes most relevant if battery electric or plug-in hybrid vehicles begin to gain significant market share. As of early 2012, 29 states had enacted RPS policies and 8 states had voluntary commitments in place. For example, Pennsylvania has required that 18% of all energy generated in the state come from alternative and renewable sources by 2021, including 0.5% from solar. Texas has required utility companies to generate 5,880 megawatts of renewable energy by 2015, of which 500 megawatts must come from non-wind resources (DSIRE 2012).

Programs to promote voluntary adoption of alternative fuels through outreach. States can also implement programs that promote voluntary adoption through coordination and information initiatives that seek to educate the public about the availability and benefits of transitioning to alternative fuels. Programs can be designed to encourage alternative fuels in particular industries, or they may involve interstate cooperation to develop alternative-fuel corridors. The Department of Energy's Clean Cities program supports local initiatives to adopt practices that reduce the use of petroleum in the transportation sector by coordinating a network of more than 80 volunteer coalitions, which develop public–private partnerships to promote alternative fuels and advanced vehicles, fuel blends, fuel economy, hybrid vehicles, and idle reduction (EERE 2012). At the state level, the Energy Security and Climate Stewardship Platform Plan is an initiative among Midwestern states to develop a system of coordinated signage across the region for biofuels and advanced transportation fuels and to collaborate to create regional E85 corridors (Midwestern Governors 2007).

Assumed policies for assessing programs and mandates to promote alternative fuels. In assessing this strategy, it is assumed that states will fully implement either a renewable fuel standard or a low-carbon fuel standard. States motivated mainly by climate change might choose the latter option since LCFS mandates explicitly seek to reduce greenhouse gas emissions and their flexible, fuel-neutral structure allows industry to respond in the most cost-effective manner. States more concerned with energy security or interested in promoting local production of specific fuels (e.g., biofuels in major agricultural states) to foster economic development might instead implement a renewable fuel standard. Given that the EPA has already adopted RFS2, however, the state would need to carefully consider the appropriate integration of state and federal mandates. Additionally, this assessment assumes that states concerned with climate change would also implement a renewable electricity portfolio standard if either battery electric or plug-in hybrid-electric vehicles begin to achieve significant market share. Finally, it is assumed that states will also complement alternative-fuel strategies with efforts to promote voluntary adoption through stakeholder coordination and public information campaigns.

M.3.2 Intended Mitigation Effects

Fuel mandates and alternative-fuel promotion programs are often explicitly intended to reduce GHG emissions, and they may have additional benefits for local air quality as well. However, there is still some debate on the life-cycle emissions benefits of certain types of alternative fuels, especially biofuels.

Improving air quality—moderately effective (uncertain). Though potentially promising, the net effects of an RFS or LCFS on air quality would depend on which alternative fuels are used as well as the emissions control technology of the engine or electricity generating unit. Engines powered by natural gas, for example, are generally cleaner burning than conventionally fueled engines, and biodiesel blends also show mixed life-cycle emission reduction benefits. Corn ethanol using current technology, however, may increase emissions, and greater use of electricity generated by the current fleet of power plants, including many legacy coal-fired plants, may result in higher levels of particulate matter and sulfur oxides (U.S. DOT 2010). Recent EPA estimates indicate that the federal RFS2 would result in a net increase in criteria pollutants but that the impacts would not be evenly distributed throughout the country (EPA 2010). Alternative electrical energy sources such as wind, hydro, and solar would result in far greater reductions in air pollutants than other technologies (North Carolina Utilities Commission 2006). On balance, RFS programs avoid emissions that would have resulted from conventional fossil fuel, which could improve air quality and public health. Accounting for the variety of impacts related to specific alternative fuels, however, this rating must be qualified as uncertain.

Reducing GHG emissions—highly effective (uncertain). There is general agreement that reducing the carbon content of fuels through a regulatory mandate should account for all emissions associated with the production, distribution, and consumption of fuels (Sperling and Yeh, 2009). Given this life-cycle emphasis, an LCFS should in theory prove quite effective in reducing GHG emissions. To date, however, it is too early to ascertain the effectiveness of alternative-fuel mandates. Establishing performance standards for fuels requires accepted methodology to quantify and compare the life-cycle greenhouse gas emissions from different types of fuels. It can be particularly challenging to estimate indirect emissions, especially those from land use changes due to the production of additional crops to serve as feedstocks for biofuels (Searchinger et al. 2008). While CARB and the EPA have both established life-cycle GHG factors for their respective LCFS and RFS standards (CARB, undated; EPA 2010), there is still uncertainly over associated indirect emissions, which vary depending on the specific fuel production source, refining method, and transportation requirements.

M.3.3 Intended Shaping Effects

The main motivations for policies included as part of this strategy would be to displace petroleum and increase the production and use of alternative fuels. Because they are structured as mandates, they should be very effective in achieving this end.

Reducing oil consumption—highly effective (uncertain). Both renewable portfolio standards and low-carbon fuel standards should have the effect of replacing petroleum with alternative fuels in significant quantities; the former requires fuel vendors to achieve volumetric targets of specified alternatives, while the latter involves emissions performance standards that inherently favor lower-carbon alternative fuels. Also, the mandatory structure of such programs should make them highly effective in meeting their aims. It is worth noting, though, that even a requirement could fail unless both the fuel and supporting vehicle platforms undergo sufficient advances to become at least reasonably cost-competitive with petroleum. Absent such advances, there would be strong political pressure to relax the mandate, analogous to what occurred with the electric vehicle production mandate in the early years of California's ZEV program. Because of this possibility, the rating of highly effective is qualified as being uncertain.

Promoting adoption of lower-carbon alternative fuels—highly effective (uncertain). To the extent that an RFS or low-carbon standard is effective in reducing petroleum consumption, it will achieve this through increased adoption of alternative fuels. Here again, then, such programs promise to be highly effective subject to some uncertainty in relation to the pace of alternative-fuel technology development.

M.3.4 Other Effects

The expected effects of alternative-fuel mandates on the economy, environment, and equity are both mixed and uncertain.

Economy—neutral (uncertain). Evidence on the likely economic impacts of an RFS or LCFS is mixed, resulting in a rating of neutral but uncertain. Potential economic effects encompass changes in energy and agricultural trade, air pollution and GHG reductions, and changes to farm income and food costs. The EPA estimates that the RFS2 will result in significant net economic benefits, ranging between $13 and $26 billion in 2022 (EPA 2010). For the California LCFS, CARB estimates that the displacement of petroleum-based fuels with lower-carbon-intensity fuels will result in an overall savings within the state of as much as $11 billion through 2020 (CARB 2009). The same study noted that the regulation will create costs to the state in the form of foregone transportation fuel taxes ranging from $80 to $370 million by 2020 and have an impact on annual local sales tax revenue ranging from a loss of $51 million to a gain of $2 million by 2020. The economic impacts of renewable and low-carbon fuel standards will be affected by market prices for conventional fuels and actual production costs of lower-carbon fuels, both of which are subject to high uncertainty. Either supply limitations of lower-carbon fuels or relatively low oil prices could result in overall net economic losses for LCFS programs. For example, recent estimates placed the costs of a national LCFS policy at between $80 billion and $760 million per year (Canes and Murphy 2009). Fuel mandates also result in a redistribution of economic activity, notably a shift of capital from the petroleum sector to the agricultural, chemical, electricity, and natural gas sectors (CARB 2009). With the exception of certain synthetic fuels, which may increase oil or natural gas imports, all of the fuel options discussed in this section result in decreased fossil-fuel use, in turn reducing reliance on foreign oil. To the extent that alternative fuels are produced domestically rather than from international sources, economic and national security benefits may be achieved due to the reduced threat of energy supply disruption, which would improve economic stability.

Environment and public health—moderately positive (uncertain). Overall, the promotion of alternative fuels should result in improved air quality, with related public health benefits, reduced GHG emissions, reduced waste, and resource conservation. Localized air quality improvements are likely at the point of consumption but may, depending on the fuel in question, be offset by environmental degradation at the point of production. Various environmental impacts are associated with the extraction, production, and transport of different types of alternative fuels, particularly certain biofuels. Estimates by the EPA suggest that increased biofuel production could affect wildlife habitat and water quality and availability, depending on the agricultural practices employed (EPA 2010). Based on the interaction of these factors, anticipated environmental and public health effects are rated as moderately positive but uncertain.

Equity—moderately negative (uncertain). An RFS or LCFS could lead to higher fuel and food prices, both of which would have a regressive effect for lower-income households. A fuel mandate, when designed and implemented in one state but not in others, creates issues of equity for energy consumers and producers. For example, California's implementation of its LCFS was delayed by a federal judge in 2011 for imposing unfair restrictions on interstate commerce. Similarly, without a federal framework for LCFSs, producers would face inconsistent regulations, and fuel prices for consumers could vary significantly from state to state. The increased use of biofuels, primarily corn ethanol, as an energy source can reduce domestic food supply as agricultural production is shifted to fuel stocks. This leads to an increase in food prices, which disproportionately affects low-income households. The EPA estimates that the RFS2 will increase U.S. corn prices by 3% to 8% and soybean prices by 1% to 10% by 2022, compared to a reference case, although this would have only a small impact—$10 per person per year—on U.S. food prices (EPA 2010). However, estimating the overall economic impact of ethanol production is difficult because food prices are determined by multiple factors, including the cost of fuel inputs, and the market for corn-based food products is already influenced by producer subsidies. In short, while there is some uncertainty, the effects of fuel mandates on equity appear to be moderately negative on balance.

M.3.5 Barriers

Alternative-fuel programs are potentially effective tools for enabling and accelerating market transition to alternative fuels, but they do face barriers to implementation.

Low public support—moderate barrier. Programs that impose additional costs on producers are likely to increase consumer fuel prices. Given the national sensitivity to fuel prices and broader economic impacts, fuel mandates are likely to face at least moderate challenges in terms of building public support. On the other hand, the fact that many states and the federal government have already implemented such programs indicates that this barrier should not be insurmountable.

Financial cost—moderate barrier. Fuel mandates and any accompanying voluntary promotion programs require initial public investment to set up and administer. States must provide some dedicated staff time, develop implementation guidance on the programs, and commit resources to monitor programs.

Technical risk—significant barrier. Significant additional research and development will likely be needed before low-carbon fuels are cost-competitive with petroleum. The capacity to expand production of developed biofuels, including corn ethanol and soy biodiesel, will be limited by land requirements, and second- and third-generation biofuels (such as cellulosic ethanol and algae-based biodiesel) may be required to achieve broad penetration of these fuels. Major advances are needed for fuel-cell vehicle technology and battery technology in order to make hydrogen or electricity practical for consumers as well as cost-competitive with current fuels and vehicles. In short, even if a state passes an RFS or LCFS, there is considerable risk that the technological advances needed for a successful program might not occur.

Enabling legislation—moderate barrier. Either the RFS or LCFS approach will generally require enabling and somewhat complex state legislation.

M.3.6 Required Lead Time

A state alternative-fuel mandate may be enacted immediately as a legislative action. However, designing and implementing a successful market-based program would likely require a period of 1 to 5 years.

M.3.7 Qualifications

States with significant crop-based biofuel production (e.g., corn-based ethanol) may be more likely to adopt legislation for renewable fuel standards. For states aiming to help mitigate climate change, the LCFS approach offers greater promise.

M.4 State Role in Alternative-Fuel Production or Distribution

Another possible approach for states to encourage the emergence of alternative fuels would be to take an active role in helping to produce or distribute such fuels. To fulfill internal energy needs or to meet goals related to climate change, interest from state agencies in generating or using alternative energy is growing (FHWA 2011). For example, in states with renewable energy mandates, utility companies and state DOTs are exploring options for using rights-of-way to produce energy. Some DOTs are installing alternative energy–generating capacity, such as solar and wind, on state-owned property to help power lighting, rest areas, or maintenance facilities. Other DOTs are offering incentives and support to the private sector to develop alternative energy fueling infrastructure.

When implemented at a large scale, these efforts may promote energy security and conservation and help reduce maintenance and operational costs (Poe and Filosa 2012). Primary limitations for alternative-fuel technologies are the lack of market penetration, critical mass-generating capacity, and necessary infrastructure. States, including DOTs, are well positioned to use resources to incentivize production of alternative energy sources.

M.4.1 Supportive Policies

State DOTs supervise millions of miles of public right-of-way (ROW) and state-owned buildings and other assets that have the potential to support renewable energy production, including solar, wind, and biomass (Poe and Filosa 2012). Some states are also offering financial incentives to the private sector for developing and operating refueling stations such as electric vehicle charging stations or hydrogen fueling stations (EERE 2011).

Renewable energy production. Currently, solar, wind, biomass, and geothermal technologies offer immediate opportunities for generating low-carbon, renewable energy with publicly owned assets. Other opportunities, such as waste-to-energy conversion, hydrogen fuel generation, and energy harvesting via wave-, tidal-, and vibration-capturing technologies may serve important roles in the future (Poe and Filosa 2012). State DOTs in Colorado, Massachusetts, Texas, and Ohio have been conducting comprehensive statewide renewable energy feasibility studies to identify promising energy technologies and locations to implement them (Kreminski, Hirsch, and Boand 2011, FHWA 2011). These studies map state-owned assets such as buildings and ROW against a set of resource-specific suitability criteria such as acreage, proximity to electrical transmission, slope, and ROW width and accessibility to identify potential sites for large- and small-scale wind and solar installations. The Oregon Solar Highway Demonstration Project first began generating solar electricity transmitted to the grid in 2008 (Oregon DOT 2012). Ohio DOT is installing a small, 32-kW wind turbine at a maintenance facility adjacent to Interstate 68 (FHWA 2011). The North Carolina Freeways to Fuel (F2F) National Alliance project, a joint effort between the North Carolina DOT and North Carolina State University, planted and harvested four 1-acre plots of canola and sunflower crops to produce about 600 gallons of B20 biodiesel that was used to fuel DOT fleet equipment (FHWA 2011).

Investment and incentives for alternative energy refueling infrastructure. In the area of alternative-fuel distribution, states have taken the approach of providing financial incentives to encourage private-sector development of fueling stations, pipelines, or consumer distribution points. The rationale for such incentives stems from the so-called chicken-and-egg problem of alternative-fuel vehicles—that is, that consumers will be reluctant to purchase alternative-fuel vehicles unless they have ready access to refueling infrastructure, while industry will be reluctant to develop refueling infrastructure until the alternative-fuel vehicle market is large enough to make use of the infrastructure. If states, through the provision of incentives, bear some of the initial cost and risk to develop alternative-fuel distribution networks, consumers may be more willing to purchase vehicles, and retailers may be more accepting of investment risk in yet-unproven markets. A federal example of this approach is the Department of Energy's Clean Cities program, which provides funding to state energy and transportation departments to coordinate and allocate investments in alternative-fueling infrastructure initiatives (EERE 2012). One such program is the I-65 biofuels corridor, which features over 20 dispensers providing E85 fuel from the Great Lakes to the Gulf Coast (EERE 2009). Other states, such as California, New York, and Florida, have invested in hydrogen stations, fleet vehicle demonstration projects, and state purchases of hydrogen vehicles intended to support the commercialization of this technology (TCPA 2008). The state of Washington is administering $1.32 million in seed funding from the DOE to implement the nation's first electric highway, which is a network of public-access electric-vehicle charging locations along Interstate 5 [West Coast Green Highway (WCGH) 2010].

Assumed policies for DOT involvement in energy production or distribution. In the assessments that follow, it is assumed that a state would first conduct a comprehensive statewide renewable energy feasibility study to identify the most promising options and then seek to develop at least one form of alternative energy utilizing state-owned assets. Southwestern states might understandably choose to focus on solar energy production, for example, while agricultural states might prioritize biomass production. It is also assumed that a state pursuing this strategy would provide financial incentives for the early-stage development of refueling infrastructure consistent with its selection of energy to be produced.

M.4.2 Intended Mitigation Effects

While this strategy would most likely be selected with the aim of shaping future energy outcomes, it could also help mitigate some of the potential challenges for state DOTs identified in this study. Specifically, it might play a modest role in boosting revenue, offsetting higher maintenance costs, improving air quality, and mitigating GHG emissions. However, these are all highly speculative.

Increasing transportation revenue—moderately effective (uncertain). State-owned assets could be leased to private producers, or state-produced energy could be sold to utility companies, generating a small stream of revenue for the state. To accomplish this, states would likely engage in public–private partnerships with private producers or utility companies to establish lease or sell-back arrangements. There is not yet, however, a proven prototype for generating revenue from state energy production (Poe and Filosa 2012). A recent partnership between Oregon DOT and a subsidiary company of Portland General Electric resulted in the installation of a 1.75-megawatt solar plant adjacent to a rest area on I-5. Oregon DOT receives a portion of the Renewable Energy Certificates and a small annual site license fee, but the Oregon DOT Office of Innovative Partnerships and Alternative Funding acknowledges that the project is better viewed as a possible framework for future revenue agreements (Oregon DOT 2012). However, potential revenue streams are likely to be small compared to a state's transportation investment needs and are unlikely to be bonded or applied to significant program accounts. Rather, any resulting revenue may provide supplemental funding support for agency operation and administration costs.

Reducing DOT costs—moderately effective (uncertain). Alternative energy generation capacity may be used to reduce internal electricity usage, thus saving on operating costs and mitigating price fluctuations. At the Turkey Lake Service Plaza in Florida, for example, a combination of solar electric photovoltaics, solar thermal hot water, and solar lighting systems was able to meet the electrical energy needs of the service plaza over the course of a year, eliminating utility payments and potentially generating additional revenue (Florida DOT 2010). Longer-term trade-offs between up-front capital costs and ongoing operational savings remain unclear; here again, though, the overall effect is likely to be modest at best.

Improving air quality—moderately effective (uncertain). Broad adoption of certain alternative fuels, most notably electricity and hydrogen, could lead to significant air quality improvements in concentrated activity centers where most travel occurs. That said, a state might choose instead to focus on biofuels, for example, where air quality benefits are less certain. Additionally, as described previously, the role of state production and support for the distribution of alternative fuels seems likely to play a supportive, rather than a major, role in stimulating a shift to alternative fuels. Accordingly, the effects of this strategy with respect to air quality are rated as both moderate and uncertain.

Reducing GHG emissions—moderately effective (uncertain). In comparison to gasoline and diesel, most alternative fuels should result in GHG emission reductions. Here again, though, there is insufficient evidence to argue that state production and support for distribution would exert significant influence in a shift to alternative fuels. Thus, the effects for GHG reduction are rated as moderate and uncertain.

M.4.3 Intended Shaping Effects

The primary motivation for state involvement in energy production or distribution would be to encourage a shift to domestically produced, lower-carbon alternative fuels in the transportation sector, in turn reducing reliance on imported oil.

Reducing oil consumption—moderately effective (uncertain). To the extent that this strategy proves successful in promoting the adoption of alternative fuels, it should also result in reduced oil consumption. As discussed next, though, it is not clear that this approach, by itself, would lead to a significant shift in fuel choices. The strategy does not include any form of mandate to require the production and use of alternative fuels, nor does it employ pricing to create an ongoing incentive for the adoption of alternative fuels. Thus, the anticipated effects are rated as moderate and uncertain.

Promoting adoption of lower-carbon alternative fuels—moderately effective (uncertain). Pilot projects on state facilities and roadways have demonstrated the potential for producing energy from solar, wind, and biomass. While these small-scale projects have succeeded in producing electricity to power highway lighting and state facilities and in producing fuel for vehicle fleets, the effects on promoting alternative fuels in broader markets remains unclear. To have a major effect on the market for alternative fuels, these efforts would likely have to be undertaken on a much larger scale so as to help reduce costs and increase availability. Likewise, little evidence exists to assess the effectiveness of state investments and incentives for the private sector to develop and operate alternative refueling infrastructure. It is possible, though uncertain, that such programs could complement other public policy support for alternative fuels by stimulating greater private-sector investment in alternative energy, thus helping to overcome the initial barriers of market penetration and acceptance facing some alternative fuels and vehicle technologies.

M.4.4 Other Effects

State involvement in the production and distribution of alternative fuels could have moderately positive economic and environmental effects and would likely be neutral with respect to equity outcomes.

Economy—moderately positive (uncertain). A draft programmatic environmental impact statement for solar energy projects in six states that evaluated use of existing federal land showed the economic effects of solar energy projects to be positive, generating increases in employment, income, and state tax revenues [Bureau of Land Management (BLM) 2010]. Public investment in alternative-fuel technology adoption is unlikely to crowd out private investment but rather should complement it. To the extent that alternative fuels are produced domestically and with less price volatility, macroeconomic and national security benefits could also result. The main economic downside would be the opportunity costs of state revenue invested in supporting fueling infrastructure should that investment fail to facilitate a shift to alternative fuels. Given this potential, the rating of moderately positive economic effects is described as uncertain.

Environment and public health—moderately positive (uncertain). As described previously, this strategy could support modest improvements in air quality and greenhouse gas reductions, with the former supporting both environmental and public health goals. Yet there could also be negative environmental effects. Solar arrays, for example, require large land areas and can displace existing vegetation and habitat. A study of a solar array in Brookhaven, New York, showed minor construction impacts on the local environment, although these were not identified as significant issues [Brookhaven National Laboratory (BNL) 2009]. Electric vehicles create life-cycle environmental impacts through the mining of minerals for battery production and through waste disposal. The net environmental impacts of electricity as a vehicle fuel are also dependent on the source of electrical energy generation. Wind turbines have been demonstrated to have an impact on wildlife such as migratory birds. These localized impacts are considered relatively small in comparison to providing renewable energy sources that offset conventional fuel use. Large-scale alternative energy development by states would result in reduced emissions of greenhouse gases and air pollutants, provided that the development offsets electricity generation by new fossil-fuel power plants (BLM 2010).

Equity—neutral. These strategies should not have any significant effects on equity.

M.4.5 Barriers

States interested in producing energy or supporting the development of fueling infrastructure would likely face several barriers, including up-front financial cost, technical risk, and the possible need for enabling legislation in relation to utility accommodation policies and non-compete restrictions on public entities.

Financial cost—moderate barrier. Most examples of publicly supported renewable energy generation to date have been small-scale pilot projects implemented through public–private partnerships and using state and federal tax credits or grant programs so that the DOT bears no capital costs. States currently active in generation projects, such as Oregon, have developed policies in which the state may be a partner but not the primary owner or operator of facilities, thus reducing financial exposure. However, should states choose to engage in larger projects, they may find it efficient to build and operate facilities and infrastructure without partnering, thus incurring significant capital costs. Implemented at any great scale, energy production and distribution projects will offset agency energy costs in the long run. Still, the initial up-front investment of resources presents significant opportunity costs to a DOT and is thus viewed as a moderate barrier.

Technical risk—moderate barrier. Any investment in emerging technologies is associated with risk that the selected technology or fuel type will fail to gain market success. As such, early investments in yet-unproven fuels such as hydrogen or in electric vehicle charging networks could result in very little return.

Enabling legislation—moderate barrier (uncertain). While the development of alternative-fueling infrastructure might require only a few million dollars in state matching funds (WCGH 2010), the legal structure of the public–private partnerships can be complex. Most states allow the use of highway ROW to accommodate public utility facilities (Poe and Filosa 2012, AASHTO 2005), but some only allow shared use with telecommunications (e.g., Colorado) or limit shared use of ROW to only certain state roads (e.g., Nebraska). As states become interested in the role of the public sector in alternative energy generation, other legal barriers requiring legislative remedies could arise; examples are limits on the ability of states to partner with utilities, state constitutional provisions or policies restricting public competition with private investment, and liability concerns.

Institutional restructuring—moderate barrier. Energy production and distribution fall beyond the focus areas for most DOTs. Pursuing this strategy could thus require a modest degree of institutional restructuring to bring in the necessary staff expertise to oversee such projects.

M.4.6 Required Lead Time

States should expect a lead time of at least 5 to 10 years to formalize the institutional policies and partnership agreements, to secure the investment needed, and to plan, permit, and construct energy production or distribution facilities.

M.4.7 Qualifications

Energy production strategies may be implemented in all states regardless of geographic and programmatic differences; however, some states have geographic advantages for certain alternative energy sources. For instance, Utah was the first state to grow alternative-fuel biomass in highway ROW as part of the F2F project, but ultimately, arid conditions and heavily compacted soil proved too challenging. In contrast, North Carolina and Michigan, with different climates, have had greater success (Poe and Filosa 2012). Solar, wind, and geothermal energy potential also varies considerably by region, and some states will be better positioned than others to pursue these options. Similarly, consumer markets in different regions of the country may drive alternative energy infrastructure investments. For example, liquefied natural gas as a vehicle fuel may be promoted in energy-rich states with Marcellus Shale deposits, while states with lower electricity costs and different policy priorities such as Washington and Oregon could develop more robust demand for electricity as a primary vehicle fuel.

M.5 Agency Energy Use

A number of state DOTs are pursuing energy efficiency and alternative fuels in the context of internal management and operations as part of statewide conservation or climate change action plans. Such policies aim to institutionalize energy efficiency and greenhouse gas emission reduction measures into ongoing department activities and the operations and maintenance of facilities, fleet vehicles, and heavy-duty equipment. As of August 2008, 39 states had energy efficiency requirements in place for state facilities, and 25 had energy-efficient equipment purchasing requirements (Cambridge Systematics 2009b). Potential motivations for pursuing such policies are achieving operational cost savings for buildings and fleets, serving as a role model to demonstrate the ease and feasibility of energy efficiency and alternative energy measures, and acting as an early-stage adopter to help catalyze the markets for alternative fuels and vehicle technologies. In states with energy efficiency mandates, DOTs are typically required to submit energy action plans detailing energy conservation efforts (EPA, undated; Cambridge Systematics 2009b).

M.5.1 Supportive Policies

Some of the most common energy efficiency and alternative energy measures pursued by DOTs and other state agencies are efficiency improvements for buildings and facilities, the purchase of alternative or hybrid vehicles for public-sector fleets, and the use of energy-efficient traffic lights and signals. A growing number of DOTs are using recycled materials in construction or implementing other practices to reduce emissions from construction materials. Finally, many statewide programs in energy efficiency encourage alternative work schedules or telecommuting, or set policies to limit travel for work-related business.

Facilities management. Statewide energy conservation programs often focus on reducing electricity and natural gas consumption associated with operating agency buildings and other facilities. Because DOTs operate district offices, subdistrict maintenance sites, central offices, and sometimes other modal offices, their energy consumption totals and potential conservation savings may be greater than for other state agencies. Specific improvements can include lighting upgrades, implementation of desktop power-management systems, and even solar thermal or solar photovoltaic installations. Department maintenance sheds and other facilities that have not been improved recently may be evaluated for cost savings associated with insulation and lighting improvements. Many state agencies are also participating in green building initiatives by adhering to nationally recognized standards such as the Leadership in Energy and Environmental Design (LEED) program in new construction or building retrofits. The Maryland DOT is one such example (Maryland DOT 2011).

Public-sector fleets. A significant number of state agencies, including DOTs, are under requirements to purchase alternative-fuel passenger vehicles for fleet use. The Energy Policy Act, first enacted in 1992 but since amended several times, established the State and Alternative Fuel Provider program. This program requires that for state fleets that include 50 or more vehicles, with 20 or more operating in metropolitan areas, any federally subsidized fleet purchases must include at least 75% alternative-fuel vehicles. In 2007, this program resulted in the acquisition of more than 14,000 alternative-fuel vehicles by state governments and the consumption of 4.5 million gallons of biodiesel (NREL 2008). Various state DOTs have adopted a number of other policies in their own fleets to encourage fuel efficiency, including downsizing of vehicles, programmed engine-idle shutoff switches, programming medium- and heavy-duty trucks to limit maximum vehicle speed, reducing the weight of vehicles, using performance lubricants and fuel additives, maintaining proper tire pressure and preventative maintenance schedules, using global positioning systems, carpooling when using state vehicles, and practicing defensive driving (AASHTO 2008).

Construction and operations practices. State DOTs have also pursued a number of energy efficiency measures in construction and operations activities, including using low-GHG construction materials, light-emitting diode (LED) lighting, and practices to reduce emissions from road construction activities. The use of fly ash in concrete, pavement recycling, warm-mix instead of hot-mix asphalt, and other materials is among the most effective ways in which DOTs can reduce energy use and GHG emissions—resulting in four to five times the savings from all other internal DOT practices combined (Cambridge Systematics 2009b). In addition, some DOTs have sought to reduce emissions from construction activities by amending contract language or awarding contract bonuses for contractors implementing clean diesel, air quality, and green construction practices (Connecticut DOT, undated).

Human resources. A number of state agencies have responded to increased fuel prices, state mandates to reduce fuel and energy consumption, and greenhouse gas emission requirements by introducing policies to reduce travel by state employees. Common responses include allowing the option of a 4-day, 10-hour workweek and revising department telecommuting policies. Many states also have policies in place to limit travel by state employees, either by requiring carpooling when using state vehicles, maximizing the use of teleconferences, or limiting all but essential travel, often primarily for cost-saving purposes (Cambridge Systematics 2009b).

Assumed policies for assessing agency energy use. In assessing the potential effects of energy efficiency and alternative-fuel measures in the context of state agency operations and management, it is assumed that the state would implement a consistent set of policies across all agencies, including improved energy efficiency in buildings and other facilities, the conversion of public-sector fleets to alternative-fuel vehicles or conventional vehicles with greater fuel economy, and the implementation of policies to reduce work-related travel for state employees. Beyond this core set of statewide policies, it is also assumed that the DOT would pursue additional strategies involving road construction, maintenance, and operations, such as installing lighting systems to meet the 2009 Energy Star standard for roadway lighting (Greenroads 2011) and maximizing the use of recycled materials and other low-GHG practices in construction.

M.5.2 Intended Mitigation Effects

This strategy could help state DOTs mitigate some of the challenges that might arise with certain energy futures. In particular, it could help reduce operations costs, improve air quality, and reduce GHG emissions.

Reducing DOT costs—moderately effective. Reduced building electricity usage translates to ongoing savings, the amount of which is likely to increase over time should energy prices rise as expected. A recent evaluation of LEED building standards shows that LEED buildings use 25% to 30% less energy than the national average, with even higher savings for buildings that meet the most demanding LEED standards [New Building Institute (NBI) 2008]. With regard to operations, in roadway lighting field tests, LED luminaries have shown energy savings of between 30% and 75% (Greenroads 2011). While net cost impacts depend on the material and production process, the use of recycled materials in road and building construction could help mitigate rising prices for raw materials as well as energy.

Improving air quality—moderately effective. Compared to the standard hot-mix asphalt, warm-mix asphalt can reduce plant emissions by 30% to 40% for sulfur dioxide (SO_2), by 50% for VOCs, by 60% to 70% for NO_x, and by 20% to 25% for particulate matter. It also reduces worker exposure to aerosols and hydrocarbons (U.S. DOT 2010). While these percentage improvements are impressive, road construction activities still account for just a small share of overall pollutant emissions in a region; thus, the potential effect must be judged as modest. DOTs have also implemented energy-saving practices, such as reduced equipment idling, with the aim of improving local air quality. For other energy efficiency and alternative-fuel strategies, very modest air quality benefits may be realized through reductions in vehicle travel and electricity and natural gas consumption.

Reducing GHG emissions—moderately effective. Strategies that reduce energy consumption in materials production, construction activity, and facility and fleet operations will reduce GHGs proportionately. The use of alternative fuels will also generally result in GHG reductions compared to conventional fuels. However, the overall magnitude of impact of the emissions over which a DOT and other state agencies have direct control is small compared to total emissions from vehicles operating in the transportation system.

M.5.3 Intended Shaping Effects

The potential to shape emerging energy technologies represents the main reason why a state might choose to pursue this strategy. The goal would be to foster the emergence of alternative-fuel technologies while reducing oil consumption and using electric power, much of which currently derives from fossil sources, more efficiently. The most direct influence under this strategy would be to help expand the market for alternative-fuel vehicles through fleet purchases; otherwise the amount of energy used by state agencies in relation to the broader economy is modest, with construction materials representing the greatest area of impact. This strategy also offers an opportunity for states to lead by example, hopefully providing lessons for other public and private actors to follow.

Reducing oil consumption—moderately effective. The typical state operates a large number of fleet vehicles. By purchasing more fuel-efficient conventional vehicles along with alternative-fuel models, states have the opportunity to play a modest role in helping to reduce aggregate fuel consumption.

Promoting adoption of lower-carbon alternative fuels—moderately effective. As already noted, state fleets, which include both light-duty and heavy-duty vehicles, can serve as an early market for a range of alternative fuels and vehicle technologies. Additionally, the adoption of alternative fuels within state fleets requires installing refueling infrastructure that can potentially be opened for access to the general public. This should help overcome one of the early barriers—lack of sufficient access to refueling stations—that might hinder adoption of alternative fuels within the broader population. A state agency can also leverage its impact by requiring contractors to adhere to standards for energy efficiency and alternative-fuel use.

M.5.4 Other Effects

This strategy would not be expected to have significant effects on the economy or equity. It should, though, offer some environmental benefits.

Economy—neutral. While many of the policies included under this strategy could result in net cost savings to DOTs, the overall effect on the economy is expected to be negligible.

Environment and public health—moderately positive. As noted previously, this strategy should play a positive role in reducing greenhouse gas emissions and improving local air quality, with corresponding environmental and public health benefits. Other environmental benefits primarily result from the use of recycled materials in construction, which can keep a significant volume of material from entering landfills. Some processes have the added benefit of binding potentially hazardous materials into an inert form (such as the use of fly ash from coal plants in concrete), avoiding the need for other disposal methods.

Equity—neutral. This strategy would not be expected to have any significant effects on equity.

M.5.5 Barriers

The advantage of pursuing this set of strategies to improve efficient internal management and operations is that they are typically cost-effective and relatively easy to implement without public or board review. The primary barriers are for the most part modest, and include up-front financial costs, concerns (real or perceived) over the use of technologies (e.g., materials, fuels) that are not widely tested and proven, and inertia that limits changes to internal practices even if the changes are beneficial. The first two are described in more detail in the following. The third concern can be overcome by initiative from agency staff and leadership.

Financial cost—moderate barrier. For state agencies, the up-front capital costs to implement some of these strategies are higher than doing business as usual. Even if these costs will be recouped over time, this still could create a barrier for implementation.

Technical risk—moderate barrier. Due to the large up-front purchase costs, materials and fuels that are not proven can be a risk, especially if a technology might fail to work as planned. This concern could become less important over time as technologies are demonstrated and become more widely proven.

M.5.6 Required Lead Time

With regard to facility operations, a building energy audit can be executed quickly, although it can generally take 1 to 5 years for measures to be installed that would provide for more efficient operations. Efficiency gains from public-sector fleets would be actualized within a 5- to 10-year time frame, along the natural turnover cycle for vehicle fleets. Operations and human resources practices can be implemented immediately, although it may also take 1 to 5 years for adoption and realization of efficiency benefits. In aggregate, then, it would likely take states and state DOTs around 5 to 10 years to implement the complete package of assumed policies under this strategy.

M.5.7 Qualifications

The approaches described under this strategy should be equally applicable across all states regardless of geographic context. With respect to the goal of influencing the development and adoption of alternative-fuel vehicle technologies, however, this strategy is likely to be more effective when implemented by states with larger fleets.

References

AASHTO. 2005. *A Guide for Accommodating Utilities Within Highway Right-of-Way.* Washington, D.C.

AASHTO. 2008. MNT-08-02 Survey for the Member Department of Transportation Equipment Managers. Internal survey results provided by AASHTO to Cambridge Systematics, Inc.

Babcock, B. A., K. Barr, and M. Carriquiry. 2010. *Costs and Benefits to Taxpayers, Consumers, and Producers from U.S. Ethanol Policies.* Center for Agricultural and Rural Development, Iowa State University, Ames.

BLM. 2010. Solar Energy Development Draft Programmatic Environmental Impact Statement.

BNL. 2009. Environmental Assessment for BP Solar Array Project. U.S. Department of Energy.

Cambridge Systematics. 2009a. *Assessment of Fuel Economy Technologies for Medium and Heavy Duty Vehicles: Commissioned Paper on Indirect Costs and Alternative Approaches.* National Academy of Sciences, Washington, D.C.

Cambridge Systematics. 2009b. NCHRP Project 25-25(45), "Transportation Program Responses to GHG Reduction Initiatives and Energy Reduction Program." Report prepared for AASHTO, Standing Committee on the Environment, Washington, D.C.

Canes, M. and E. Murphy. 2009. *Economics of a National Low Carbon Fuel Standard.* The Marshall Institute, Raleigh, N.C.

CARB. 2008. *Climate Change Scoping Plan, a Framework for Change.*

CARB. 2009. *Resolution 09-31: Rulemaking to Consider the Proposed Regulation to Implement the Low Carbon Fuel Standard and Initial Statement of Reasons.*

CARB. Undated. "Final Regulation Order." *California Code of Regulations Subchapter 10 Article 4 Subarticle 7: Low Carbon Fuel Standard.*

CBO. 2010. *Using Biofuel Tax Credits to Achieve Energy and Environmental Policy Goals.*

Connecticut DOT. Undated. I-95 New Haven Harbor Crossing Corridor Clean Air Construction Initiative. http://www.i95newhaven.com/commute/clean_air.aspx (accessed April 2, 2012).

DSIRE. 2012. RPS Policies. http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf (accessed March 30, 2012).

Energy and Environmental Analysis. 2008. *Market-Based Approaches to Fuel Economy: Summary of Policy Options.* National Energy Technology Laboratory.

EERE. 2009. Lessons Learned During Creation of the I-65 Biofuels Corridor.

EERE. 2011. Federal and State Incentives and Laws. Alternative Fuels Data Center. http://www.afdc.energy.gov/afdc/laws/matrix/reg (accessed March 16, 2012).

EERE. 2012. Clean Cities: Building Partnerships to Reduce Petroleum Use in Transportation. http://www1.eere.energy.gov/cleancities/ (accessed April 2, 2012).

EIA. 2009. *Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009.*

EPA. 2007. *40 CFR Part 80: Regulation of Fuels and Fuel Additives: Renewable Fuel Standard Program: Final Rule.*

EPA. 2010. *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis.*

EPA. Undated. List of States with Mandated ENERGY STAR Purchasing Efforts.

Florida DOT. 2010. A Comprehensive Solar Energy Power System for the Turkey Lake Service Plaza. Contract # BDK75-977-18.

FHWA. 2011. "Utilizing the Highway Right-of-Way to Generate Renewable Energy." *Successes in Stewardship Newsletter.*

Greene, D. and S. Plotkin. 2011. *Reducing Greenhouse Gas Emissions from U.S. Transportation.* Pew Center on Global Climate Change.

Greenroads. 2011. "Greenroads Manual, Material and Resources Goal 6: Energy Efficiency." http://www.greenroads.org/1429/33/energy-efficiency.html (accessed December 5, 2011).

Kreminski, R, A. Hirsch, and J. Boand. 2011. Assessment of Colorado Department of Transportation Rest Areas for Sustainability Improvements and Highway Corridors and Facilities for Alternative Energy Source Use. Colorado Department of Transportation.

Maryland DOT. 2011. Maryland Climate Action Plan Draft 2012 Implementation Plan.

Midwestern Governors. 2007. *Energy Security and Climate Stewardship for the Midwest.*

NBI. 2008. *Energy Performance of LEED for New Construction Buildings, Final Report.* U.S. Green Building Council.

NESCCAF. 2009. *Introducing a Low Carbon Fuel Standard in the Northeast. Technical and Policy Considerations.*

North Carolina Utilities Commission. 2006. *Analysis of a Renewable Portfolio Standard for the State of North Carolina.*

NREL. 2008. *State & Alternative Fuel Provider Fleet Programs Annual Report: Activities and Accomplishments in Model Year 2007.* Vehicle Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

ODA. 2012. ODA Measurement Standards Division: Biofuel Renewable Fuel Standard. http://www.oregon.gov/ODA/MSD/renewable_fuel_standard.shtml (accessed April 1, 2012).

Oregon Department of Environmental Quality. 2011. Oregon Low Carbon Fuel Standards Advisory Committee Process and Program Design.

Oregon DOT. 2012. Innovative Partnerships Program: The Oregon Solar Highway. http://www.oregon.gov/ODOT/HWY/OIPP/inn_solarhighway.shtml (accessed April 2, 2012).

Poe, C. and G. Filosa. 2012. "Alternative Uses of Highway Rights-of-Way: Accommodating Renewable Energy Technologies." Transportation Research Record: Journal of the Transportation Research Board, No. 2270. Transportation Research Board of the National Academies, Washington, D.C.

Searchinger, T., R. Heimlich, R. A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T. H. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change." *Science*, 319 (5867): 1238–1240.

Sperling, D. and S. Yeh. 2009 (Winter). "Low Carbon Fuel Standards." *Issues in Science and Technology.* 57–66.

TCPA. 2008. Chapter 22: Hydrogen. In *The Energy Report.*

University College Dublin. 2008a. "Differential Fuel Taxation, Sweden." *Economic Instruments in Environmental Policy.* http://www.economicinstruments.com/index.php/air-quality/article/45- (accessed May 31, 2013).

University College Dublin. 2008b. "Vehicle Fuel Tax (Denmark)." *Economic Instruments in Environmental Policy.* http://www.economicinstruments.com/index.php/air-quality/article/88- (accessed May 31, 2013).

Urbanchuk, P. 2011. *Economic Impact of Removing the Biodiesel Tax Credit for 2010 and Implementation of RFS2 Targets Through 2015.* National Biodiesel Board.

U.S. DOT. 2010. *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions.* Report to Congress.

WCGH. 2010. Electric Highways Project. http://www.westcoastgreenhighway.com/electrichighways.htm (accessed April 2, 2012).

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation