NCHRP REPORT 750

Strategic Issues Facing Transportation

Volume 5

Preparing State Transportation Agencies for an Uncertain Energy Future

Extended Summary

TRANSPORTATION RESEARCH BOARD
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NCHRP REPORT 750

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

EXTENDED SUMMARY

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transit Association
BEV	Battery-electric vehicle
CAFE	Corporate average fuel economy
CNG	Compressed natural gas
DOT	(State) Department of Transportation
E85	85% ethanol fuel blend
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EV	Electric vehicle
FCV	Fuel-cell vehicle
FFV	Flex-fuel vehicle
FHWA	Federal Highway Administration
GDP	Gross domestic product
GHG	Greenhouse gas
HEV	Hybrid-electric vehicle
HOT	High occupancy/toll
HOV	High-occupancy vehicle
ICE	Internal combustion engine
IEA	International Energy Agency
ITS	Intelligent transportation system
LCFS	Low-carbon fuel standard
LNG	Liquefied natural gas
MBUF	Mileage-based user fee
mpg	Miles per gallon
NGV	Natural gas vehicle
NHTSA	National Highway Traffic Safety Administration
NRC	National Research Council
NSTIFC	National Surface Transportation Infrastructure Financing Commission
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in hybrid-electric vehicle
RDM	Robust decision making
RFS	Renewable fuel standard
RFS2	(The current federal) renewable fuel standard
RPS	Renewable portfolio standard
TDM	Transportation demand management
TSM&O	Transportation system management and operations
V-I	Vehicle-to-infrastructure
VMT	Vehicle miles of travel
V-V	Vehicle-to-vehicle

Extended Summary

This extended summary provides an overview of the analysis and results from 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 AASHTO to examine strategic issues facing the transportation industry in the coming decades.

The intent of this study is to inform long-range planning for state departments of transportation (DOTs) in the context of uncertain but potentially significant shifts in transportation fuels through the 2050 time frame. Specific objectives for 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."

The main report for this study, *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 5: Preparing State Transportation Agencies for an Uncertain Energy Future*, provides detailed discussion of the analysis and results of the project along with several technical appendices.

The purpose of this extended summary is to provide a detailed overview of the analysis and findings that can be read within a few hours. The document is aimed at those who might benefit from engaging with the material at a deeper level but do not have time to read the entirety of the main report.

While surface transportation has depended largely on petroleum-based liquid fuels over the past century, a combination of policy concerns and technical advances could lead to large-scale adoption of alternative fuels and vehicle technologies in the coming decades. Increased global demand for oil has contributed to higher and more volatile prices, enhancing the relative appeal of non-petroleum alternatives. At the same time, concerns related to energy independence, climate change, and air quality have already prompted federal and state policies to promote alternative-fuel sources and propulsion technologies. Backed by public and private investment over the past few decades, there has been considerable effort to explore and develop a broad range of alternative fuels and vehicle technologies, encompassing natural gas, biofuels, electric vehicles, plug-in hybrids, and hydrogen fuel-cell vehicles. Many of these are already in use, albeit in limited quantities, and others are expected to be ready for the mass market within the coming decade.

Although many of these alternative fuels offer great promise, they also face obstacles such as the need to deploy new fueling infrastructure or to improve the performance and reduce the cost of certain component technologies. At the same time, advances in drilling and extraction technologies have led to expanded estimates of economically recoverable petroleum reserves from both conventional and unconventional sources, while more-stringent federal fuel economy standards will enable automobiles and trucks to travel much farther with each gallon of gasoline or diesel in future years. These developments will make it even more difficult for alternative fuels to compete with petroleum. Thus the question of which alternative fuels, if any, might achieve significant market share over the next several decades remains uncertain.

ES.1 Study Approach and Scope

To assist state DOTs in developing effective long-range plans in the context of an uncertain energy future, the research team pursued an approach consisting of three main steps:

1. Developing a broad range of plausible transportation energy scenarios, or futures, for the 2040 to 2060 time frame.
2. Examining how the future scenarios might adversely affect state DOTs given their current and evolving roles, mandates, funding, and operations.
3. 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 associated with alternate futures.

ES.1.1 Objectives of Robust Decision Making

Traditional planning analyses typically begin with an effort to predict the most likely outcomes for conditions of interest (for example, the level of population growth or economic growth), or perhaps a small set or range of potential outcomes viewed as highly probable. Based on such forecasts, the analysis can then identify policy choices designed to optimize anticipated results. Most long-range regional transportation planning exercises, for example, fit within this paradigm.

The predict-and-optimize approach can be highly effective for shorter-term planning problems with reasonably stable assumptions. For longer-term questions characterized by a greater degree of uncertainty, however, the traditional planning paradigm can be problematic. In particular, a set of decisions optimized for the most likely future may prove to be extremely poor choices if the future evolves in unexpected directions.

To avoid this pitfall, robust decision making begins by considering a wider array of potentially 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 (Lempert, Popper, and Bankes 2003). This study encompasses a long planning horizon with considerable uncertainties, motivating the adoption of RDM principles to guide the analysis. More details on the application of RDM in the analysis are provided later in the summary.

ES.1.2 Logical Flow of the Analysis

Figure ES.1 shows the logical flow of the analysis for this study, which in turn shapes the organization of this extended summary.

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, or 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, as well as appropriate policy responses. Using 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 robust decision making to construct a framework to assist state DOTs in developing 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

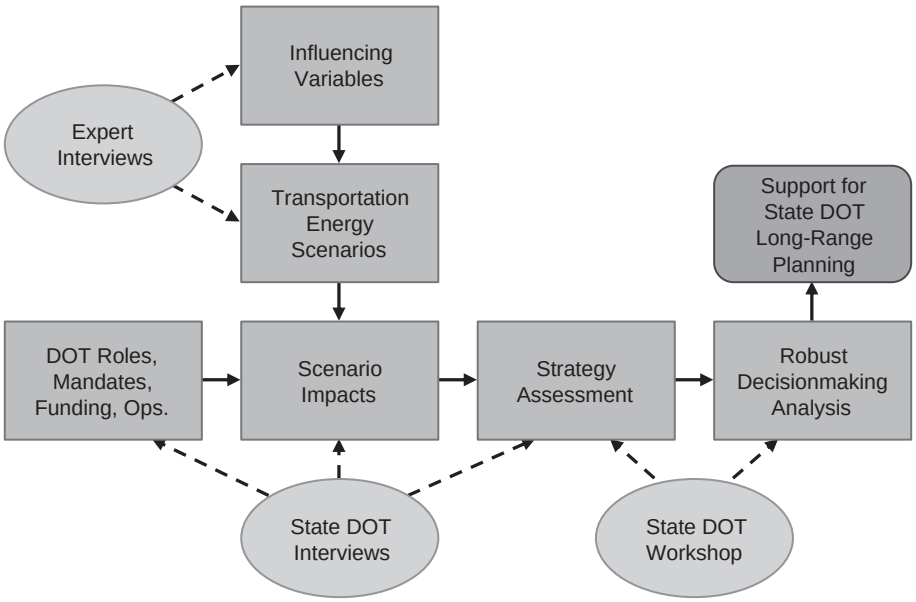

Figure ES.1. Logical flow of the analysis.

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.

ES.1.3 Scope of the Study

As further context for the material and findings contained in this report, it may be helpful to offer two caveats relating to the scope of the study. First, potential changes in fuels and vehicle propulsion technologies are not the only uncertainties 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 the future—could also affect future travel choices. 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.

ES.2 State DOT Roles, Mandates, Funding, and Operations

As a backdrop for the results and analysis that follow, it is helpful to first 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. Additional details on state DOTs can be found in Chapter 2 of the full report.

ES.2.1 Broader Themes in the Evolution of State DOTs

Like other aspects of society, state DOTs continue to evolve. Looking back over the past few decades, it is possible to discern several major trends in the evolution of state DOTs relating to roles, mandates, funding, and operations, 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 role in building, operating, and maintaining highways, however, state DOTs often assume a more collaborative support role for other modes, assisting with such functions as planning, oversight, and funding.

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, maintain, and operate safe and well-engineered roads to serve the public's rapidly expanding needs of automobility and efficient goods movement via trucks. Increasingly, however, many DOTs have been asked to incorporate additional policy goals into their decision making, including those related to such issues as economic development, equity, local air quality, greenhouse gas emissions, livability, and a greater focus on safety.

Greater funding challenges. Over the last several decades, fuel-tax rates at the federal level and in many states have not been increased enough to keep pace with inflation and improved fuel economy, 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. Growing budget gaps, deteriorating traffic conditions, and rapid advances in enabling technologies have led some states to experiment with innovative user-fee funding mechanisms intended to raise revenue and promote greater system efficiency. Examples are all-electronic tolling, congestion tolls, automated weight-distance truck tolls, and mileage-based user fees (MBUFs). Other states have sought to increase revenue from traditional sources—for example, by hiking fuel-tax rates or vehicle registration fees or by allocating more revenue from the general fund.

Greater emphasis on operating the system efficiently. Even with recent revenue initiatives, 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. 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.

ES.2.2 Contextual Variations Among States

The plausible transportation energy futures considered in this study may reinforce some of the trends outlined previously, and they may create new challenges as well. The robust decision-making analysis is intended to provide state leadership with decision support tools and clear strategic directions to develop effective responses to a shifting and uncertain transportation energy future. In conducting the analysis, 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 or that act to influence or constrain suitable policy responses. States vary, for example, in terms of their size, geography, population, economic structure, and prevailing political preferences. Based on the analysis conducted in this study, three specific contextual factors appeared to be most important:

1. **Urban versus rural.** Some of the potential impacts associated with certain plausible futures, such as worsening traffic congestion, are likely to be more problematic for states with significant urban populations than for largely rural states. Accordingly, potential strategies such as congestion pricing or investment in significant transit improvements are likely to 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, as well. At the same time, population growth translates to increased development activity, so states experiencing significant growth pressure 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 while the prevailing political attitudes within a state—and 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 so that states will have different options to consider based on their needs, preferences, and constraints.

ES.3 Preliminary Analysis for Developing Future Scenarios

To understand how future shifts in fuels and vehicle technologies could affect state DOTs given their current and evolving roles, mandates, funding, and operations, the first step was to develop a broad range of plausible transportation energy futures. To inform development of the scenarios, the team identified relevant technological, socio-demographic, and policy variables likely to influence the future outcomes of interest, explored past trends and future prospects for the variables, and then examined how the variables might interact to produce alternate transportation energy futures.

As the research team developed its approach to this work, the starting point was to determine the set of attributes to include in the definition of plausible transportation energy futures. Early on, the team recognized that it would be helpful in the subsequent analysis of impacts to encompass three broad categories of elements within the future scenarios, as follows:

1. **Energy futures.** Evolving energy trends, with a particular focus on fuels and vehicle technologies, represent the core subject for this study and in some cases may affect DOTs in significant ways. A significant shift from petroleum to alternative fuels, for example, would severely undermine current fuel-tax revenue.
2. **Travel futures.** Travel patterns, in turn, will be strongly affected by changes in fuels and vehicle technologies, and the resulting outcomes may affect DOTs directly. If future breakthroughs in electric vehicles allow for a significant reduction in the per-mile cost of driving, for instance, total travel and, in turn, traffic congestion will be apt to rise.
3. **Federal policy futures.** Federal energy, climate, and transportation funding policies, in addition to potentially influencing changes in energy use and technologies, could also affect state DOTs. If the federal government does not increase fuel taxes to offset inflation and improved fuel economy over the coming decades, states may need to raise additional revenue on their own or reduce the current level of investment in transportation infrastructure.

Having outlined the general form of the plausible transportation energy futures to be developed, the team next considered influential variables likely to affect energy use and technology adoption, travel trends, and the formation of future federal policy regimes. Through background research and an extensive set of interviews with subject matter experts, the research focused on three groupings of variables, as follows:

1. **Alternate fuels and vehicle technologies.** The team first reviewed the current status and future prospects for competing fuel types and vehicle technologies—petroleum,

natural gas, biofuels, electricity, and hydrogen. The main focus was on light-duty vehicles, but potential applications for medium- and heavy-duty vehicles were also considered.
2. **Socio-demographic trends.** The team also examined past trends and future projections for population growth, economic growth, and changes in land use.
3. **Policy challenges, trends, and debates.** Finally, the team reviewed ongoing challenges and policy debates in relation to energy, climate, and transportation funding at all levels of governance.

The remainder of this section summarizes highlights from the background research on these variables.

ES.3.1 Background Research on Fuels and Vehicle Technologies

Since the advent of the automobile over a century ago, petroleum has been the dominant source of transportation fuel, and many experts do not expect this to change for the next several decades. Yet there are strong motivations for promoting alternative fuels and vehicle propulsion technologies. With recent forecasts now suggesting that the United States will emerge as the world's leading oil producer and a net fossil-fuel exporter within the next couple of decades (IEA 2012), past concerns related to energy independence appear to be fading. The threat of high and volatile fuel prices remains, however, with negative implications for consumers and industry alike. At the same time, climate change may prove to be an even more powerful motivator for aggressive public policy interventions in the future. Anticipated advances in conventional vehicle technology, including lighter-weight materials, reduced drag, more efficient internal combustion engines (ICEs), and broader application of hybrid-electric vehicle (HEV) technology, should allow future gasoline- and diesel-fueled vehicles to achieve much higher fuel economy and, in turn, emit less greenhouse gases (GHGs). Petroleum is ultimately a finite resource, however, and does not offer a ready pathway to carbon-free (or at least very low carbon) transportation.

These considerations continue to motivate efforts to develop and deploy alternative fuels and vehicle technologies with the aim of displacing petroleum. At present, leading contenders include liquid biofuels (ethanol and biodiesel in the near term, and green drop-in gasoline and diesel replacements in the further future) and flex-fuel vehicles (FFVs) capable of running on ethanol blends of up to 85% (E85); natural gas vehicles (NGVs) running either on compressed natural gas (CNG) or on liquefied natural gas (LNG, typically limited to heavy-duty applications); electric vehicles (EVs), including battery-electric (BEVs) and plug-in hybrid-electric vehicles (PHEVs); and hydrogen fuel-cell vehicles (FCVs).

There has already been some progress. Liquid biofuel production has climbed steadily over the past couple of decades owing to the expanded use of ethanol as an oxygenate for gasoline, generous subsidies, and the federal renewable fuel standard (RFS2). NGVs have served niche transportation markets for many years, and the technology is mature. With the recent advent of horizontal drilling and hydraulic fracturing (or fracking) technologies having led to much cheaper domestic natural gas prices, NGVs could compete for much higher market share in the coming decades. In just the last couple of years, major automakers have introduced their initial BEV and PHEV offerings, and more models are slated for release in the near future. Many auto manufacturers have also announced plans to release FCVs within the next few years.

These alternative fuels and vehicle technologies offer great promise. Electricity and natural gas, at current prices, can power vehicles for a small fraction of the per-mile energy costs of gasoline or diesel, and the same could be true for hydrogen as well. BEVs and FCVs emit no harmful air pollutants while operating, a boon for urban air quality. Renewably generated electricity or hydrogen, while not yet cost-competitive with fossil feedstocks and ICEs, could one day allow for very low carbon automotive travel. Corn-based ethanol, currently the dominant liquid biofuel, does not perform particularly well in terms of GHG emissions reductions. Next-generation biofuels, however, including ethanol, renewable diesel, and even biogasoline produced from cellulosic feedstocks or from algae, are expected to yield significant reductions in life-cycle GHGs.

Despite their promise, all of the alternative fuels face one or more significant barriers that, if not overcome, may limit their commercial prospects or environmental benefits. Table ES.1 summarizes some of the main barriers related to producing and distributing fuels or associated with the cost and performance of vehicles. Barriers shown in italicized text relate to the achievement of environmental benefits.

Additional details and supporting analysis on these barriers is available in Chapter 3 and Appendices B, C, D, and E of the main report. A National Research Council (NRC) study, *Transitions to Alternative Vehicles and Fuels*, provides an excellent overview of the current status and prospects for different fuels and vehicle technologies (NRC 2013).

ES.3.2 Background Research on Socio-Demographic Variables

The research team also reviewed past and projected future trends in the population, economy, and land use, three important factors known to influence energy use and travel. Brief highlights are presented here; additional details can be found in Chapter 4 and Appendix G of the main report.

Population. Looking forward, the U.S. population is expected to grow, albeit at a declining rate compared to prior

Table ES.1. Current barriers for alternative fuels and vehicle technologies.

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 of the main report.

decades. Increased life expectancies are likely to result in a population that is older, on average, and it is anticipated that migration along with variations in birth rates among different segments of the population will contribute to a more ethnically diverse population. Regionally, populations in the West and South are projected to grow much more rapidly than populations in the Midwest and Northeast. Depending on future migration rates, which remain highly uncertain, the size of the U.S. population in 2050 could range from between 320 million and 450 million (Shrestha and Heisler 2011, U.S. Census Bureau 2005, 2009 a, b, c, d). Broadly speaking, greater growth in population corresponds to greater growth in energy use and travel, although specific effects may vary with different socio-demographic groups.

Economy. Most experts expect that the U.S. economy, stimulated by population growth and technological progress, will continue to grow in the coming decades. However, there is greater uncertainty regarding the pace of growth, especially in the wake of the most severe recession in a generation followed by a persistently sluggish recovery. In the reference case scenario from their most recent *Annual Energy Outlook*, the Energy Information Administration projects that the U.S. economy, as measured by gross domestic product (GDP), will expand at an average annual rate of 2.5% through 2040 (EIA 2013). Some economists are more optimistic about future growth, while others are more pessimistic. A concern shared by many observers is that income inequality may continue to rise in future decades [Organization for Economic Co-operation and Development (OECD) 2011]. Growth in GDP tends to correlate with goods movement activity, while passenger travel, particularly automotive travel, generally rises with household income (Santos et al. 2011).

Land use. Over the past century, and especially since World War II, the United States has experienced significant migration from rural areas to large cities. Most metropolitan growth, however, has concentrated in lower-density suburban areas rather than in higher-density central cities, resulting in development patterns often described as "sprawl" (Hobbs and

Stoops 2002). Whether this pattern will continue remains unclear. If automotive travel remains inexpensive, demand for new homes in suburban and exurban areas could persist, with households making trade-offs between cheaper land values and longer travel; there is certainly ample undeveloped land surrounding most major cities in the country.

Many states and local jurisdictions, however, are now considering or implementing smart growth policies intended to promote greater density, 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. Smart growth land-use policies, if broadly adopted, might therefore lead to an increasing share of the population living in denser and revitalized central city areas (Myers and Gearin 2001). Future trends in land use will have important implications for energy use and travel; specifically, denser land use correlates to increased use of transit, biking, and walking and corresponding reductions in automotive travel (TRB 2009).

ES.3.3 Background Research on Ongoing Policy Debates

Finally, the research team examined current challenges and ongoing policy debates related to energy, climate, and transportation funding since policy choices in these areas will also have a strong influence on energy use and travel behavior. Additional details on this material can be found in Chapter 4 and Appendix H of the main report.

Energy and climate policy. Energy policy has traditionally focused on such goals as economic development, low and stable energy prices, energy security, and air quality. With fossil fuel combustion in the power and transport sectors responsible for a major share of anthropogenic GHG emissions [U.S. Environmental Protection Agency (EPA) 2011], climate policies have become increasingly interlinked with energy polices. Taken together, energy and climate policies are the source of spirited debate and division at the federal level and in many states. One area of disagreement is the relative prioritization for different, and often competing, objectives. A few policies, such as federal fuel economy standards, are broadly effective in supporting most energy and climate objectives; others, however, such as support for expanded oil exploration or the use of carbon pricing to reduce GHG emissions, pose clear trade-offs between relevant policy goals.

Another source of division relates to the selection of policy mechanisms for pursuing energy and climate goals, with available options such as public subsidies, mandates or standards, and market mechanisms such as pricing. The first two of these are enacted with some frequency and can thus be viewed as more politically feasible. Pricing, on the other hand, remains controversial, although there are some examples of both federal and state policies relying on this approach. Debates over energy and climate policies are far from resolved, resulting in considerable uncertainty regarding future policy regimes. It is clear, however, that future policy decisions in these areas will influence commercial prospects for conventional and alternative fuels and also affect aggregate travel demand and choices among transport modes.

Transportation funding policy. Transportation funding debates are likewise unresolved. For most of the past century, federal and state fuel taxes on gasoline and diesel have provided a major share of funding for building and maintaining highways. In more recent decades, fuel-tax revenue has been allocated for transit investments as well. Over the last several decades, fuel-tax rates at the federal level and in many states have not been increased with sufficient frequency to offset inflation and improved fuel economy, resulting in growing transportation funding shortfalls (NSTIFC 2009). At the same time, building public support for increasing revenue—for example through higher fuel-tax rates—to invest in transportation has become more challenging in many states.

These factors have created great uncertainty surrounding future transportation funding policy. Key questions confronting elected officials include whether to increase federal fuel-tax rates to develop more robust federal transportation programs or instead to devolve greater responsibility for funding highways and transit to state and local jurisdictions, whether to focus more on user fees (such as fuel taxes and registration fees, but potentially including broader application of tolls or a shift from fuel taxes to MBUFs) or general revenue sources to fund transportation, how much to budget for investments in transportation, and how to allocate available funds to roads, transit, and other competing programs. Future transportation funding policy choices will have major effects on both system capacity and the cost of travel, in turn influencing total travel volumes, travel conditions, and choice among different modes (NSTIFC 2009).

ES.4 Plausible Future Transportation Energy Scenarios

Conducting background research on the potentially influential variables discussed previously provided the necessary foundation for creating plausible future scenarios. The team next enumerated specific elements—such as the cost of oil, the mix of fuels used by automobiles and trucks, total automotive travel, and future federal transportation funding policy—to include in the scenarios.

For each of the scenario elements, which were selected to help clarify the potential impacts on state DOTs, the team outlined several potential futures to characterize the range of plausible long-range outcomes. A core goal in this process was to develop scenarios consistent with past and projected

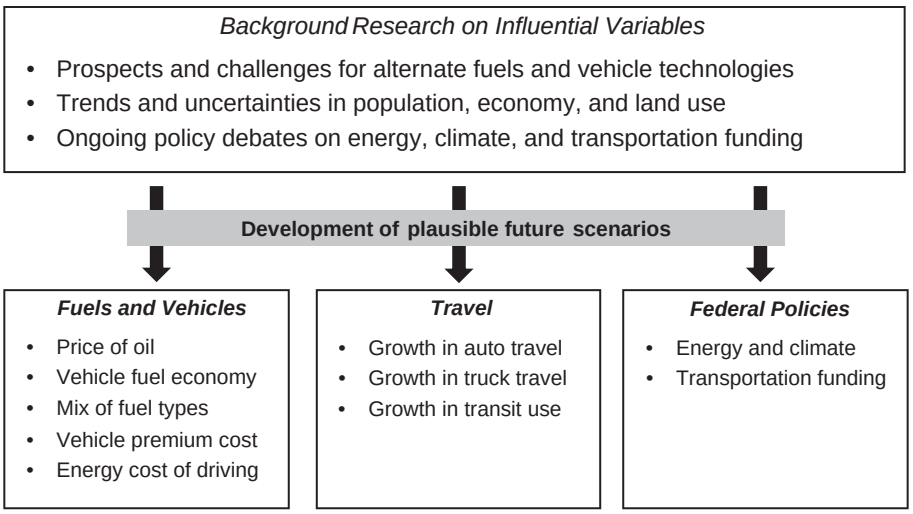

Figure ES.2. Development of plausible transportation energy futures.

trends for the influencing variables and their expected effects on future transportation energy sources, travel behavior, and federal policy choices over the next 30 to 50 years. While a few of the scenarios are described in qualitative terms, most are quantitative—that is, they are framed using specific numeric values. The numbers cited, however, are not intended to represent forecasts or even confidence intervals; rather, they are simply meant to illustrate the potential magnitude of the changes that appear plausible based on the background research conducted for the study. Figure ES.2 depicts the process for developing the future scenarios and enumerates the specific elements included.

The next three subsections describe plausible futures for the scenario elements related to fuels and vehicles, travel, and federal policies. Prices, where indicated, are expressed in 2012 dollars. Detailed discussion of the scenarios, along with narrative descriptions of the circumstances that might lead to each plausible future, are available in Chapter 5 of the main report.

ES.4.1 Plausible Fuels and Vehicle Technologies Scenarios

Energy factors within the scenarios are the price of oil, changes in vehicle fuel economy, the mix of fuels in the surface transportation sector, vehicle cost premiums, and changes in the energy cost of driving.

Price of oil. Three potential futures for the price of oil are considered, all involving extrapolations of alternate projections from the Energy Information Administration's most recent *Annual Energy Outlook* (EIA 2013): one in which oil prices decline slightly and hover in the range of $70 to $80 per barrel in the 2040 to 2060 time frame, one in which prices rise slowly but steadily to a range of $150 to $170, and one in which prices rise more rapidly to a range of $225 to $250. The corresponding cost of gasoline varies from $2.50 per gallon at the low end to $7 or more at the high end.

Vehicle fuel economy. Two scenarios for future vehicle fuel economy are considered, one in which average fuel economy doubles and one in which it quadruples by the 2040 to 2060 time frame. The most recently adopted federal corporate average fuel economy (CAFE) standards call for an average EPA rating among light-duty vehicles of 54.5 miles per gallon (mpg) by 2025, roughly doubling current fuel-economy performance. This provides a reasonable, if pessimistic, lower bound for fuel economy improvements. (It assumes that fuel economy standards will not be further increased after 2025.) More optimistically, a recent NRC analysis suggests that average vehicle fuel economy in the range of 100 mpg by 2050 is feasible (NRC 2013). This is roughly four times greater than current fuel economy and serves as an upper bound for the scenarios.

Mix of fuels. As noted earlier, many experts expect that petroleum will remain the dominant transportation fuel over the next several decades. The robust decision-making framework employed in this study, however, emphasizes consideration of a broader range of plausible futures so as to be prepared for surprises or breaks from past trends. All of the alternative fuels considered in the study are potentially promising but also face significant obstacles, and it is too early to discern which, if any, might gain significant market share. Reflecting this uncertainty, the scenarios include one future in which petroleum remains dominant, one in which biofuels achieve a 30% market share, one in which natural gas claims a 50% market share, one in which electric vehicles (a combination of BEVs and PHEVs) gain a 75% market share, one in

which hydrogen FCVs capture a 75% market share, and one in which multiple alternative fuels combine to displace over 75% of petroleum use.

Vehicle price premiums. This scenario element focuses on the degree to which the price of an average vehicle (such as an affordable mid-size sedan or pickup truck) might rise in the future 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 vehicle prices, and that the cost of new vehicles increases by about $10,000 over today's costs. Recent analysis by EPA and the National Highway Traffic Safety Administration (NHTSA) indicates that more-stringent CAFE standards are likely to increase the cost of new vehicles in 2025 by a few thousand dollars (EPA and NHTSA 2011). If CAFE standards are not further increased after 2025, it seems plausible that the cost of the technology required to meet 2025 standards could slowly decline over time, with increased 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. At the opposite end of the spectrum, the current premium for BEVs and PHEVs (and likely for FCVs when they are released) is well over $10,000 dollars. Even though such vehicles offer potentially considerable savings in fuel costs, it is difficult to envision that they will succeed in the market unless the premium can be reduced to at most $10,000.

Energy cost of travel. If alternative-fuel technologies fail to gain market share, it is possible that oil prices could at some point outpace fuel economy gains, leading to a higher energy cost for travel. On the other hand, many of the alternative fuels—most notably natural gas (with recent price declines), electricity, and potentially hydrogen—promise to significantly reduce the energy cost of travel. Three futures are therefore considered, one in which the energy cost of travel declines by at least 50% in real terms (and perhaps by as much as 75%), one in which it remains similar to what it is today, and one in which it increases by a third.

ES.4.2 Plausible Travel Scenarios

Travel factors within the scenarios are growth in passenger vehicle travel, growth in transit mode share, and growth in freight trucking.

Growth in automotive travel. The scenarios include three futures for total growth in passenger vehicle miles of travel (VMT) by the 2040 to 2060 time frame: a decline of 10%, growth of 60% (or 1.2% per year), and growth of 80% (or 1.5% per year). The latter two are based on extrapolations from two scenarios in the most recent *Annual Energy Outlook* from EIA (2013), the reference case projection and the high economic growth projection. While these rates are lower than the historical growth in passenger vehicle travel, they still lead to significant overall growth over the study time frame. The general expectation is that continued growth in the U.S. population and economy will contribute to greater automobility, but it is also plausible that some states could suffer population declines in the coming decades, perhaps due to structural changes in the economy or even as a result of climate change rendering some regions in the country less hospitable. Therefore, a scenario in which states could experience a modest decline in total vehicle travel is included.

Growth in transit mode share. With transit use accounting for just less than 2% of passenger travel, depending on the specific metric employed (Santos et al. 2011), there is little utility in considering a further decline. Instead, the scenarios consider one future in which transit mode share for the nation as a whole holds steady at around 2%, one in which it expands to 5%, and one in which it expands to 10% by the 2040 to 2060 time frame. Even the second of these would constitute an impressive change from the status quo, likely requiring major investment and policy intervention; the third would be analogous to peak U.S. transit use during the World War II era [U.S. Census Bureau 2000, American Public Transit Association (APTA) 2012].

Growth in truck travel. As with passenger vehicle travel, the annual growth rate for trucking VMT is expected to be lower in the coming decades than it has been in the past. Continuing from recent trends, however, forecasts suggest that truck VMT will still grow faster than passenger VMT. Three scenarios for total growth in truck travel by the 2040 to 2060 time frame are considered: zero growth, total growth of 125% (or 2.1% per year), and total growth of 200% (or 2.9% per year). The latter two futures represent extrapolations from the reference case and high economic growth case scenarios in the most recent *Annual Energy Outlook* (EIA 2013), while the first accommodates the possibility that some states could experience a flat or declining population.

ES.4.3 Plausible Federal Policy Scenarios

Federal policy elements within the scenarios include energy and climate, which are closely linked, and transportation funding. Both of these areas are facing significant challenges, and there is much uncertainty surrounding the future trajectory of U.S. policy responses.

Federal energy and climate policy. Reflecting current divisions in the relative prioritization that should be assigned to potentially competing goals for energy and climate policies along with uncertainty over whether and how these divisions will be resolved, the scenarios include three potential federal policy regimes. In one future, the current stalemate among competing policy goals persists, resulting in a continuation of

Table ES.2. Summary of plausible futures for the 2040 to 2060 time frame.

Future Fuels and Vehicles		
Cost of Oil	**Vehicle Fuel Economy**	**Mix of Fuels**
• $70 to $80 per barrel • $150 to $170 per barrel • $225 to $250 per barrel	• Fuel economy doubles • Fuel economy quadruples	• Petroleum remains dominant • 30% share for biofuels • 50% share for NGV • 75% share for EVs • 75% share for hydrogen • Mix of competing fuels
Vehicle Premium	**Energy Cost of Travel**	
• No additional premium • $10,000 premium	• Declines by at least half • Remains the same • Increase by a third	
Future Travel Outcomes		
Total Auto VMT	**Transit Mode Share**	**Total Trucking VMT**
• Declines by 10% • Increases by 60% • Increases by 80%	• Remains at 2% • Increases to 5% • Increases to 10%	• No growth • Increases by 125% • Increases by 200%
Future Federal Policies		
Energy and Climate	**Transportation Funding**	
• Current mix of policies • Focus on goal of low energy cost by promoting fossil fuel development • Focus on reducing climate change through carbon pricing and investment in low-carbon alternatives	• Reduced federal program with devolution to states • Renewed federal program based on higher fuel taxes with possible shift to tolls or MBUFs • Renewed federal program with shift to MBUFs and focus on congestion pricing and weight-distance truck tolls for greater system efficiency	

policies already in place, such as CAFE standards, renewable fuel standards, public investment in alternative-fuel research, and public support for increased fossil-fuel exploration and development. In another future, federal policy makers converge on the goal of lower energy prices, resulting in greater emphasis on policies to promote expanded oil production and the development of unconventional petroleum substitutes such as coal-to-liquid and gas-to-liquid fuels. In a final future, the goal of mitigating climate change is prioritized, resulting in the adoption of some form of nationwide carbon pricing and the elimination of any subsidies for fossil fuels.

Federal transportation funding and investment policy. Current debates over the future of federal transportation funding are likewise conflicted. The scenarios consider three plausible futures. In the first, federal fuel-tax revenues are allowed to stagnate even further, resulting in a smaller federal program and devolution of greater responsibility for transportation funding to state and local governments. In the second, federal policy makers determine to reinvigorate federal surface transportation, beginning with increased fuel taxes and possibly shifting to increased use of tolling or MBUFs in the coming decades. In the third, the federal government increases fuel-tax rates in the near term, implements MBUFs over the longer term, and emphasizes road pricing structures such as congestion pricing and weight-distance truck tolls to promote more efficient use of the road network.

ES.4.4 Summary of Future Transportation Energy Scenarios

Table ES.2 summarizes the plausible futures for each of the scenario elements related to fuels and vehicle technologies, travel outcomes, and federal policies.

ES.5 Potential Impacts on State DOTs

After reviewing current and evolving DOT roles, mandates, funding, and operations and developing the plausible transportation energy scenarios for the study, the team conducted a series of interviews with senior DOT staff from a number of states across the country. The researchers also interviewed several senior transportation thought leaders not attached to

specific state DOTs to gain their perspectives. The goals of the interviews were to gain greater insight into how some of the plausible futures might challenge DOTs as well as the types of policies states might pursue in response. The interviews were structured around a series of relatively open-ended questions. Some of the questions were:

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

To provide a sense of the issues, opportunities, and concerns that arose throughout the interviews, the word bubble in Figure ES.3 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 word bubble 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.)

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. Several common themes emerged, however:

- 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.

Figure ES.3. Words frequently repeated by state DOT interview participants.

- There will need to be greater focus on meeting customer expectations through preservation of existing assets and advanced operations, and less 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.

Based on the comments received during the interviews and on additional supporting research, the team distilled seven potential impacts of concern associated with one or more of the plausible transportation energy futures, as described in the remainder of this section. More detailed discussion of the potential impacts appears in Chapter 6 of the main report.

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. As noted in a recent FHWA study, two of the four identified causes for higher highway construction costs in the early to middle portion of the first decade of the 2000s were attributed to higher oil prices (FHWA 2007). (Oil is an energy input for the production of concrete and a material input for the production of asphalt.) Any significant increases 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 VMT 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 in the coming years, with negative implications for both quality of life and the efficiency and reliability of goods movement. Indeed, growth in traffic delays could exceed growth in VMT given the nonlinear behavior of traffic flows, with congestion spreading throughout more hours of the day and across a larger share of metropolitan road networks (Sorensen et al. 2008). The effects would be most pronounced in states with large or rapidly growing 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 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 the future.

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 EPA. The EPA routinely updates air quality standards as improved science on health impacts becomes available (EPA 2012).

Increasing pressure to mitigate 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 greenhouse gas 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.

ES.6 Strategic Directions for States to Consider

Based on a clearer understanding of how the plausible transportation energy scenarios could affect state DOTs, next are considered different strategies that could assist states in preparing for or responding to potential changes in transportation energy use. This section introduces these strategies and briefly summarizes the team's assessment of their strengths and limitations; the development and analysis of strategies is presented at greater length in Chapter 7 and Appendices I, J, K, L, and M of the main report.

ES.6.1 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, 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 local needs.

Constructing 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 both suggestions and ideas offered during the interviews with state DOT staff and additional options identified by the research team based on its review of the relevant literature. Note that policies that could be implemented directly by a state DOT (e.g., practices to foster greater cost-efficiency in DOT operations) and policies that might be pursued by the state as a whole, or at least would require enabling state legislation (e.g., pricing carbon emissions to encourage a shift to lower-carbon alternative fuels), are included.

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, and 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.

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, it was assumed that a state would work toward implementing congestion pricing on one or two lanes of all congested freeways and major routes under state's jurisdiction, even in cases where that would entail the conversion of general-purpose lanes to priced lanes. By laying out such assumptions, it 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 domain of local government. Rather, the assumption was that the DOT would seek a greater degree of collaboration with local agencies in achieving 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 the subset of policies likely to offer the maximum benefits—even in cases where those policies might cost more to implement, for example, or entail greater challenges with respect to public acceptance. In other words, the assumed policies were chosen in part to help illustrate the best possible results that could be attained by a state that chooses to aggressively pursue a given strategic direction.

Categories of strategic directions. After defining the strategic directions to be evaluated, they are grouped under several broader categories. The categorization has no bearing on the underlying analysis but is simply intended to help organize the presentation of the material. The five categories under which the strategic directions have been grouped are:

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

ES.6.2 Strategies Considered

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

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. (For the sake of clarity, the first three of these are referred to in the remainder of this document as tolls or mileage-based user fees, fuel taxes, and registration fees.) All could be effective in increasing available revenue, but they differ considerably in terms of their respective advantages and shortcomings.

- **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 current 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 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 expand the use of tax increment financing, special assessment districts, developer impact fees, and utility fees to augment 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 increase income taxes, sales taxes, or property taxes, with the incremental amount dedicated to 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 in turn for the right to manage and collect tolls for use of the facility over some specified period of time. It was 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.

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 circumstances, 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 various 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 is assumed that state legislators, if faced with this requirement, would direct DOT staff to pare back on 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.

Strategies to improve auto 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 set of strategic directions in this category includes road building, goods movement investments, congestion pricing, intelligent transportation systems (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 improvements.** 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 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 high-occupancy/toll (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 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 deploying such systems where they are not yet in use.
- **Traffic safety.** This strategy focuses on safety improvements for vehicle travel along with 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 is considered that a state would increase its current level of investment in such strategies to further accelerate deployment, 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.

Strategies to improve alternative modes of travel. This category focuses on strategies to improve public transportation and other non-automotive modes of travel. Options are transportation demand management (TDM), public transportation improvements, and better integration of 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 work weeks, telecommuting programs, bicycle and pedestrian improvements, and pay-as-you-drive insurance. In assessing this strategy, it was 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 land use.** This strategy aims to better align land use patterns with transportation systems. Options include prioritizing transportation funding to 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, with the general intent of achieving more compact development patterns amenable to a wider array of travel options.

Strategies to shape future energy use and technology adoption. This final category includes five strategies that states might employ with the aim of promoting greater energy effi-

ciency 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 agency operations.

- **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. The researchers assume 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 option 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 to date. 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 renewable fuel standards (RFSs), low-carbon fuel standards (LCFSs), renewable portfolio standards (RPSs) for electric power, and voluntary promotion and information campaigns. The assessment assumes that a state pursuing this direction would implement either an RFS or an LCFS, complemented by an RPS should electric vehicles begin to gain significant market share. Voluntary campaigns to promote alternative-fuel use would also be included.
- **State role in producing and distributing 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.
- **Energy efficiency and 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.

ES.6.3 Evaluation of Strategies

After defining the strategic directions, the team developed and applied a framework for evaluating their strengths and limitations. To support robust decision-making analysis in a study intended to inform long-range planning across diverse states, the framework needed to provide insight on how effectively a strategy could address relevant policy objectives, on the potential disadvantages of pursuing a strategy if it proves not to be needed, on the amount of lead time that would be needed to implement a strategy and realize its benefits, and on the applicability of the strategy across states with differing contexts. To address such questions, the team created a template for assessing each strategy that encompassed the following criteria:

- **Mitigation effects.** The team first considered how effective the strategy might be in terms of mitigating the challenges for state DOTs associated with certain plausible transportation energy futures. Specific objectives in this vein include stabilizing or increasing revenue, reducing DOT costs, reducing traffic congestion, improving safety, improving air quality, reducing greenhouse gas emissions, and enhancing alternative travel modes. Possible ratings were "highly effective," "moderately effective," and "not applicable."
- **Shaping effects.** The team next considered how effective the strategy might be in shaping, or promoting, a transition to a more sustainable energy future, one that features a reduction in total petroleum consumption, increased use of lower-carbon alternative fuels, and affordable energy costs for travel. Here again, possible ratings were "highly effective," "moderately effective," and "not applicable."
- **Effects on economy, environment, public health, and equity.** To gain a richer understanding of the potential benefits and liabilities associated with each strategy, the team also considered their expected performance in terms of broader economic, environmental, public health, and equity goals. For these criteria, potential ratings were "highly positive," "moderately positive," "neutral," "moderately negative," and "highly negative." In other words, these ratings could provide additional motivation for pursuing a strategy or alternatively suggest reasons why the strategy might not be good to pursue. Note that environmental and public health goals share certain aims, such as improved air quality, and were thus combined as a single rating.
- **Potential barriers.** The team then examined potential barriers that would need to be overcome in order to pursue a

strategy. These included public opposition, financial cost, technical risk, required legislation, and the need for institutional restructuring. For any given strategy, each of these were rated as being a significant barrier, a moderate barrier, or not applicable.

- **Lead time.** The team also considered the expected amount of time that would be needed, once political agreement to proceed has been achieved, to implement the strategy and realize its intended benefits. Possible ratings were "immediate" (interpreted as within a year), 1 to 5 years, 5 to 10 years, 10 to 20 years, and more than 20 years.
- **Qualifications.** As a final criterion, the team noted whether the strategy in question would be more applicable in some states than in others. For example, congestion pricing would not be particularly helpful in largely rural states in which traffic congestion is not a major issue of concern.

While the ratings for each of the strategies draw upon available evidence from the research literature, they are ultimately subjective in nature. Therefore, multiple members of the research team reviewed 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, ratings were characterized as uncertain.

The tables that follow summarize the ratings for each of the strategies and evaluation criteria considered. Mitigation effects are listed in Tables ES.3 and ES.4; shaping effects are shown in Table ES.5; anticipated effects on economy, environment and public health, and equity are presented in Table ES.6; barriers are summarized in Table ES.7; and required lead time and any caveats related to state context are listed in Table ES.8.

ES.7 Framework for Robust Long-Term Plans

After evaluating the strengths and limitations of potentially helpful strategies, the research team developed a framework to assist state DOTs in crafting robust long-term plans to address an uncertain energy future. This section begins by providing details on the methodological approach employed by the team to create this framework. It next summarizes, 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 local air pollutants and GHG emissions, to respond to increased demand for non-automotive travel modes, and to promote a more sustainable energy future. The results are then integrated across all of the mitigation and shaping goals to provide a comprehensive framework for developing robust long-term plans. More detailed discussion of the analysis is available in Chapter 8 of the main report.

ES.7.1 Developing the Framework

Given that some of the potential challenges for state DOTs could occur with certain plausible transportation energy futures but not others, the first step in the analysis was to consider the question of whether and when to pursue strategies aimed at mitigating specific impacts or shaping a more desirable energy future. As described earlier in the document, the logic for this analysis rested 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). 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 helpful.

The next step in the analysis was to examine which of the strategies, among the many options considered, appear to offer the greatest prospects for mitigating certain impacts, if needed, or for seeking to influence evolving transportation energy use patterns, if desired. This component of the analysis involved comparing the relative strengths and limitations of the various strategies for different objectives of interest and considering how certain strategies might complement one another or instead be largely redundant.

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 (i.e., with little chance of regret) 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

Table ES.3. 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 ES.4. 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 ES.5. 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 ES.6. 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 ES.7. 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 ES.8. 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	

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 of 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 appropriately for the future while preserving as much flexibility as possible for future planners.

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 is 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 specified signposts indicate an increasing likeli-

hood 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 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 investments 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. It is also worth noting that shaping actions aimed at promoting a more sustainable energy future may accelerate other challenges for state DOTs, such as reduced fuel-tax revenue.

Figure ES.4 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.

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 expansion of road capacity, improvements aimed at more efficient goods movement, congestion pricing, intelligent transportation system investments, transportation system management and operations practices, transportation demand management approaches, and investments in transit. In addition to considering the appropriate timing of strategies for different objectives based on RDM principles, the analysis also exam-

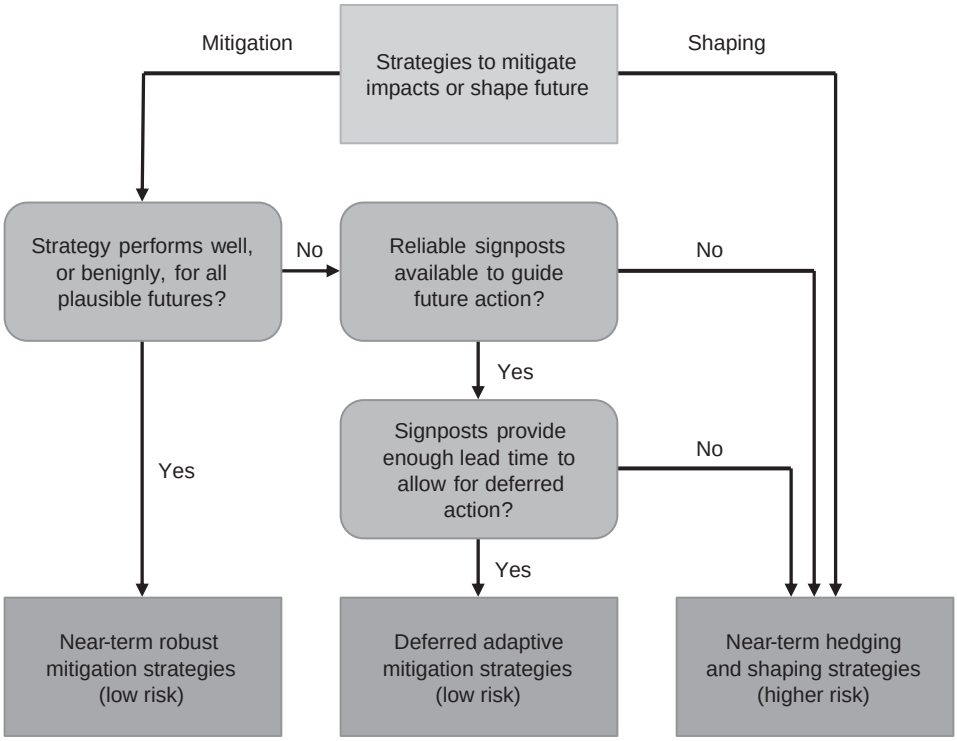

Figure ES.4. Logic for application of robust decision-making principles.

ined the question of which strategies, in combination, offer the greatest promise for each of the objectives.

The first step was to identify, for each mitigation or shaping objective, a set of candidate strategies that promised to have a positive effect in supporting the objective (based on the ratings in Tables ES.3, ES.4, and ES.5) and would be viewed by many decision makers as reasonable policy choices for addressing the objective. To illustrate the logic, consider the strategy of increasing fuel-tax rates. By increasing the overall cost of travel, higher fuel taxes can be expected to have a modest effect on reducing travel and, in turn, traffic congestion. If a state were to increase fuel-tax rates, however, the principal motivation would almost certainly be to address highway funding needs; absent revenue concerns, states would be unlikely to increase fuel taxes with a primary aim of reducing traffic. Within this analysis, then, the strategy of increasing or indexing fuel-tax rates would be viewed as a candidate strategy for stabilizing or increasing revenue, but would not be selected as a candidate strategy for mitigating traffic congestion.

After determining the sets of candidate strategies for the various objectives, the research team sought to identify the most-promising strategies for addressing each specific objective. This involved the development and application of a relative ranking system based on the assessed strengths and drawbacks for each of the candidate strategies. The potential strengths of a strategy encompass positive anticipated effects for the objective in question—for example, raising revenue or improving traffic safety outcomes—or for the broader policy goals 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 the comparison of strengths and limitations, and taking into consideration the manner in which certain policy approaches could complement one another, 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 contextual 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 higher barriers) and lower-impact optional strategies (lower benefits and lower 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 a few of the strategies ranked in this grouping may not necessarily be viewed as desirable 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.

Note that the ratings applied to a given strategy—in terms of timing and relative ranking—may differ depending on the objective in question. For example, increasing fuel taxes could be rated as a robust near-term strategy for increasing revenue and as a potentially deferred strategy for reducing GHG emissions in states where that goal is not currently prioritized but could become so in the future. Likewise, congestion pricing might be ranked as most promising for reducing traffic congestion and as a high-impact optional strategy for increasing transportation funding. States that choose not to pursue a particular strategy for one objective might subsequently choose to do so for another.

In the passages that follow, strategy ratings are developed for addressing the various mitigation and shaping goals of interest. Because of the strong degree of overlap in relevant strategies and goals, strategies to address revenue and cost concerns are considered jointly, as are strategies to improve air quality and reduce GHG emissions.

ES.7.2 Strategies to Mitigate Revenue and Cost Impacts

Potential strategies for stabilizing or increasing revenue and reducing DOT costs are considered first. Declining fuel-tax revenue is viewed as highly problematic under all of the plausible

futures outlined in this study, resulting from either significant improvements in fuel economy for conventional vehicles or a shift to alternative fuels. Increasing DOT costs based on higher oil prices, in contrast, is a less certain outcome. However, even if oil prices do not rise significantly, it seems unlikely that state DOTs would regret having taken action to reduce costs, especially efforts 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 strategies considered in this study that states might logically consider to boost revenue or reduce costs are tolling or MBUFs, fuel taxes, registration fees, beneficiary fees, general revenue, private capital, increased cost-efficiency, reduced scope of state DOT responsibility, congestion pricing, integrated land use, carbon pricing, and agency energy use. Table ES.9 summarizes the strengths and limitations of these strategies for the goals of raising revenue and reducing costs, along with their relative rankings as suggested by the research team's analysis.

The organization of Table ES.9, and of similar tables for other objectives presented later, can be described as follows. 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 in the text discussing the table.

The next two columns indicate whether the strategy should have strong effects for the specific objectives of interest—in this case, raising transportation revenue or reducing DOT 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 along any of these dimensions.

The final column summarizes 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—either strong effects for applicable policy

Table ES.9. 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.

goals or low barriers—and the presence or absence of these bullets can be used to clarify the relative attractiveness of the options. Strategies that include bullets across all of the columns can be viewed as highly desirable, offering strong benefits and only modest barriers. 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 barriers 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 since they face high barriers but offer limited positive effects in return. This does not happen to be the case with 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 these summary ratings and drawing on more detailed findings from the strategy assessments in Appendices I through M of the main report, 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 costs 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, and natural gas (all of which potentially allow for at-home refueling and might, therefore, prove more difficult to tax as transportation fuels) 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 ES.9 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, although 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 DOT 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 more specifically aimed 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 optional, rather than as a complementary strategy in the most promising group, given that the choice to pursue a greater private role in funding transportation may vary with philosophical attitudes in a state in relation to 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 could prove 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.

ES.7.3 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 presented earlier, 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 as hedging actions, 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 specific 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 economy recovers.
- 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 study, those that states would most likely consider as logical candidates for mitigating traffic congestion include road expansion, goods movement improvements, congestion pricing, ITSs, TSM&O, TDM, and investments in public transportation. Table ES.10 summarizes the rankings, along with the benefits and barriers, for these 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 of the main report, 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 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, or heavy truck traffic along certain corridors—goods movement investments could serve as a helpful complement to congestion pricing. And

Table ES.10. 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.

because congestion pricing may pose equity concerns, it would also be valuable to include public transportation improvements and TDM programs. 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, though 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 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.

ES.7.4 Strategies to Improve Traffic Safety

Travel in the United States is safer than in many other countries, but the number of crashes and fatalities on the nation's road network is still dismaying 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 increase based on projected gains in passenger vehicle and truck travel in some of the plausible futures outlined in this study. In other words, even if ongoing state efforts are successful in improving traffic safety rates, this could be more than offset by the effects of greater total VMT.

It is also the case, although this is more speculative, that a shift to smaller passenger vehicles and larger trucks could lead to an increased rate in crash-related fatalities. (Note, though, that with CAFE standards now based on vehicle footprint such that auto makers need not produce smaller vehicles to meet fuel economy targets, 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 evaluate 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 might simply choose to monitor total crash and fatality statistics and make the determination to increase safety investments if these numbers begin to rise.

The set of strategies that states would likely consider as logical candidates for reducing the rates of crashes and fatalities include goods movement improvements, ITSs, TSM&O, and traffic safety measures. The strengths and limitations of these strategies, along with their rankings, are summarized in Table ES.11.

As shown in the table, all four strategies are ranked as most promising. Of these, the traffic safety and ITS strategies offer the greatest potential safety benefits. TSM&O and goods movement investments promise 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.

ES.7.5 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 section. 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 districts.
- 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.

Strategies that states might logically consider to reduce local air pollutants or GHG emissions include goods movement improvements, TDM, public transportation, land use, vehicle feebates, carbon pricing, alternative-fuel mandates and programs, state production and distribution of alternative fuels, and greater energy efficiency and alternative-fuel use within agencies. The expected performance and rankings of these strategies are summarized in Table ES.12.

Drawing on the strategy assessment information within the table along with the more detailed analyses in Appendices I through M of the main report, the ratings and logic for the potential strategies to mitigate air quality concerns and reduce GHG 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,

Table ES.11. 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.

Table ES.12. 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.

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, and other sources of renewable power.

Goods movement improvements, TDM investments, and land use reforms to promote more compact, mixed-use development patterns could be effective complements to feebates and carbon pricing. 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 may not, therefore, 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, fuel mandates could be viewed as redundant, although 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 initiated in the near term, if needed, as discretionary hedging actions to play a helpful role in reducing emissions in the coming decades.

ES.7.6 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 to 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 role in improving alternative travel options include 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 ES.13.

Based on the strengths and barriers of the strategies summarized in the table, along with the more detailed strategy analyses in Appendices I through M in the main report, 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 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—although they also face greater barriers in terms of public opposition, financial cost, and technical risk. Note that congestion pricing would also raise sig-

Table ES.13. Ranking strategies to improve alternative 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.

nificant revenue, some of which might help fund 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.

Among 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 over the next several decades.

ES.7.7 Strategies for Shaping Future Energy Outcomes

In addition to considering strategies to mitigate the challenges associated with certain plausible transportation energy futures, some states may wish to pursue strategies with the aim of supporting a transition to a more sustainable energy future. Such a decision presents a higher degree of risk, however, in the sense that the efforts of an individual state may have little influence on global energy outcomes. Additionally, to the extent that a state succeeds in promoting the adoption of alternative fuels, it may well hasten the onset of other challenges such as reduced fuel-tax revenue.

Yet there are strong environmental arguments for promoting cleaner alternative fuels and vehicle technologies, and nurturing the emergence of supporting industries could yield economic benefits over the longer term. For states interested in pursuing this path, potential strategies include vehicle feebates, carbon pricing, alternative-fuel mandates and programs, state production and distribution of alternative fuels, energy efficiency and use of alternative fuels by agencies, fuel taxes, public transportation investments, and integrated land use. Table ES.14 summarizes potential benefits and barriers associated with these strategy options, along with their relative rankings.

Based on the relative strengths and barriers summarized in the table and the more detailed strategy assessments in Appendices I through M in the main report, the logic for the rankings shown in the table 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 category for energy shaping objectives focuses on strategies that offer significant benefits but only face modest barriers, such as feebates, fuel taxes, and land use. Assuming that the dividing line between fees on vehicles with lower fuel economy and rebates on vehicles with higher fuel economy is ratcheted up 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 address revenue shortfalls. (Note, though, that fuel taxes would not support the objective of lowering the energy cost of

Table ES.14. 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.

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.

ES.7.8 Integration of Robust Strategies

Based on the preceding analysis, 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 ES.15. The framework encompasses near-term strategies for addressing highly probable impacts (declining revenue with a possibility of higher

Table ES.15. 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. The use of *italicized text* denotes higher-risk hedging and shaping strategies.

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 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.

ES.8 Developing State-Specific Plans

Although the general framework presented in Table ES.15 is intended to be broadly applicable across states, individual DOTs may wish to customize the selection and prioritization of strategies to better meet their own contextual needs. Options in this vein include:

- **Selecting a preferred set of strategies to address an objective.** For each of the mitigation and shaping objectives, the team compared the expected benefits and likely barriers for available strategies and also considered the manner in which different strategies might work to complement one another. Based on this analysis, and with the aim of providing generally applicable guidance, the strategies for each objective were ranked in the categories of most promising, optional, and fallback. In practice, however, the preferred mix of strategies is likely to vary from one state to the next based on differing policy priorities and contextual constraints. As a general rule, pursuing any of the available strategies for a given objective—be they ranked as most promising, optional, or fallback—will usually be preferable to taking no action at all.
- **Omitting strategies based on state characteristics.** Most of the strategies considered in the study could prove to be helpful for any state. A small share of the strategies, though, will be most relevant in states with major metropolitan areas, in states experiencing rapid population growth, or in states with major ports or trade corridors. States that do not meet one or more of these characteristics might choose to omit certain strategies from their long-range plans. As a rather obvious example, a largely rural state would derive little benefit from congestion pricing.
- **Choosing whether to defer strategies to mitigate uncertain impacts.** Many of the potential impacts for state DOTs identified in this report are associated with some plausible futures but not 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. While some of the plausible futures could lead to worsening traffic congestion, for example, traffic is already quite severe in most states with large metropolitan areas. Likewise, voters and stakeholders 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 uncertain impacts or take near-term action if the underlying issues are already viewed as meriting action.
- **Selecting signposts for deferred strategies.** To ensure that states have the ability to implement deferred strategies when it becomes apparent that they will be needed, states will need to develop signposts to be monitored on an ongoing basis. This study has suggested examples of the types of signposts that might be monitored for early indication that the future is moving in one direction or another. The selection and development of specific indicators to track, however, may vary from one state to the next based on differing views as to what constitutes sufficient evidence that a given impact is becoming more or less likely or on the availability of state-level data that could be helpful in constructing and monitoring the signposts.
- **Determining whether to pursue higher-risk hedging and shaping strategies.** Both hedging strategies and shaping strategies entail higher degrees of risk. Hedging strategies aimed at uncertain impacts must be implemented, due to their long lead times, before it becomes clear that they will be helpful, while shaping strategies to promote a sustainable energy future may either succeed or prove to be unsuccessful or superfluous. In considering whether to adopt higher-risk hedging and shaping strategies, planners can contrast the potential regret of failing to take action that would have been very useful with the potential regret of implementing a strategy that proves to be unhelpful 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, such as financial cost or public acceptance challenges. The relative prioritization of these factors is likely to vary from one state to the next, in turn leading to different decisions on whether to pursue certain hedging or shaping strategies.

- **Selecting alternate policies in pursuing a strategic direction.** The strategies examined in this study, as described earlier, have been constructed from small sets of policies that share similar aims and approaches. In order to evaluate the strengths and limitations of each strategy, the team needed to make certain assumptions about which of the component policies a state would implement in pursuing the strategy, and in what manner they would be pursued. As a general rule, the team assumed that states would be fairly aggressive in selecting specific policies to maximize the benefits of the 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 differing priorities and constraints in their own states. For example, states choosing to pursue the congestion pricing strategy could simply aim to convert existing high-occupancy vehicle (HOV) lanes to HOT lanes in place of a more ambitious effort to establish managed lanes on all congested highways. It should be stressed, however, that changing the mix of policies within a strategy in such a manner could alter the profile of assessed benefits and barriers associated with that strategy as shown in Tables ES.3 through ES.8.

As a final consideration, 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 appear likely to require enabling state or even federal legislation. As summarized in Table ES.7, 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—for addressing other potential objectives. Thus, while state DOT planners can employ the logic developed in this study to map out a long-range plan that identifies potential 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.

Given this consideration, 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. First, most of the strategies encompass multiple policies, only a subset of which might require state 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 strategies marked in Table ES.7 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 component policies that DOTs could implement on their own under existing authority.

Another option would be to select alternative 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 right 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.

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