Moving Cooler

AN ANALYSIS OF TRANSPORTATION STRATEGIES FOR REDUCING GREENHOUSE GAS EMISSIONS

Cambridge Systematics, Inc.

ULI Urban Land Institute

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An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions

Prepared for
***Moving Cooler* Steering Committee**

Prepared by
Cambridge Systematics, Inc.

July 2009

Urban Land Institute

About the Urban Land Institute

The mission of the Urban Land Institute is to provide leadership in the responsible use of land and in creating and sustaining thriving communities worldwide. ULI is committed to

- Bringing together leaders from across the fields of real estate and land use policy to exchange best practices and serve community needs;
- Fostering collaboration within and beyond ULI's membership through mentoring, dialogue, and problem solving;
- Exploring issues of urbanization, conservation, regeneration, land use, capital formation, and sustainable development;
- Advancing land use policies and design practices that respect the uniqueness of both built and natural environments;
- Sharing knowledge through education, applied research, publishing, and electronic media; and
- Sustaining a diverse global network of local practice and advisory efforts that address current and future challenges.

Established in 1936, the Institute today has more than 35,000 members worldwide, representing the entire spectrum of the land use and development disciplines. ULI relies heavily on the experience of its members. It is through member involvement and information resources that ULI has been able to set standards of excellence in development practice. The Institute has long been recognized as one of the world's most respected and widely quoted sources of objective information on urban planning, growth, and development.

Recommended bibliographic listing:

Cambridge Systematics, Inc. *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions*. Washington, D.C.: Urban Land Institute, 2009.

Urban Land Institute
1025 Thomas Jefferson Street, N.W.
Washington, D.C. 20007-5201

ULI Catalog Number: M87

ISBN: 978-0-87420-118-5

10 9 8 7 6 5 4 3 2 1

Printed in the United States of America.

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Cambridge Systematics, Inc., specializes in transportation, dedicated to ensuring that transportation investments deliver the best possible results. It is recognized as a leader in the development and implementation of innovative policy and planning solutions, objective analysis, and technology applications. Cambridge Systematics works to build the capacity of the transportation community to understand and address both sides of the climate change challenge: to develop strategies to reduce greenhouse gas emissions from transportation, and to prepare for the potential effects of climate change on transportation systems.

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Preface

TWO RECENT STUDIES HAVE TAKEN a look at transportation and climate change issues: the 2007 McKinsey & Company and Conference Board report, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* and *Growing Cooler: The Evidence on Urban Development and Climate Change*, published by the Urban Land Institute in 2008. Respectively, these studies offer insight into the potential effects that strategies related to advances in technology and fuels have on greenhouse gas (GHG) emissions and how land-use strategies affect emissions through changes in travel behavior. To date, little research has taken a critical look at the full range of transportation measures that would influence greenhouse gas emissions, by reducing the amount of vehicle-miles traveled, reducing fuel consumption, and improving the performance of the transportation system. *Moving Cooler* is an effort to fill this knowledge gap.

The intent of the *Moving Cooler* study is to assess the potential effectiveness of a broad variety of transportation strategies—under a wide range of different assumptions—to reduce greenhouse gas emissions. This study was not intended to result in any specific recommendations about the direction of transportation and climate change policies. Therefore, the report does not purport to provide any interpretations about the implications of the *Moving Cooler* findings.

We wish to acknowledge the co-sponsors who funded the study, worked with the research team to identify and define the strategies and assumptions to be assessed, provided access to data, tested conclusions, and prepared for the release of the report:

- American Public Transportation Association
- Environmental Defense Fund
- Federal Highway Administration
- Federal Transit Administration
- Intelligent Transportation Society of America
- Kresge Foundation
- Natural Resources Defense Council
- Rockefeller Brothers Fund
- Rockefeller Foundation
- Shell
- Surdna Foundation
- Urban Land Institute
- U.S. Environmental Protection Agency

In addition, we wish to thank W. Steve Lee, with Collaborative Strategies Group, for project facilitation.

We also extend our thanks to the peer reviewers who helped evaluate the study results and the final report:

- Robert B. Cervero, PhD, MCP, MS, University of California at Berkeley
- Emil H. Frankel, LLB, Bipartisan Policy Center and Independent Consultant
- Michael D. Meyer, PhD, MS, Georgia Institute of Technology

While the work presented in *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions* has benefited from these contributions, the views and findings expressed in this report are solely the responsibility of Cambridge Systematics, Inc., and do not necessarily reflect the views of the report co-sponsors or peer reviewers.

Cambridge Systematics, Inc.
July 2009

Sponsors of the Study

American Public Transportation Association

American Public Transportation Association (APTA) is a nonprofit international association of 1,500 member organizations, including public transportation systems; planning, design, construction, and finance firms; product and service providers; academic institutions; and state associations and departments of transportation. APTA members serve the public interest by providing safe, efficient, and economical public transportation services and products. APTA members serve more than 90 percent of persons using public transportation in the United States and Canada.

Environmental Defense Fund

Environmental Defense Fund, a leading national nonprofit organization, represents more than 500,000 members. Since 1967, Environmental Defense Fund has linked science, economics, law, and innovative private sector partnerships to create breakthrough solutions to the most serious environmental problems.

Federal Highway Administration

The Federal Highway Administration (FHWA) is an agency of the U.S. Department of Transportation. FHWA strives to improve mobility on U.S. highways through national leadership, innovation, and program delivery.

Federal Transit Administration

The Federal Transit Administration (FTA) is an agency of the U.S. Department of Transportation. FTA supports locally planned and operated public transportation systems throughout the United States through grants and technical assistance.

Intelligent Transportation Society of America

The Intelligent Transportation Society of America (ITS America) was established in 1991 as a not-for-profit organization to foster the use of advanced technologies in surface transportation systems. It is the leading advocate for technologies that improve the safety, security, and efficiency of the nation's surface transportation system.

Kresge Foundation

The Kresge Foundation is a private, national foundation that seeks to influence the quality of life for future generations through its support of nonprofit organizations in six fields of interest: health, the environment, community development, arts and culture, education, and human services.

Natural Resources Defense Council

The Natural Resources Defense Council (NRDC) is an international nonprofit environmental organization with more than 1.2 million members and online activists. Since 1970, its lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC has offices in New York City, Washington, D.C., Los Angeles, San Francisco, Chicago, and Beijing.

Rockefeller Brothers Fund

Founded in 1940, the Rockefeller Brothers Fund (RBF) encourages social change that contributes to a more just, sustainable, and peaceful world. The RBF's grant making is organized around three themes: democratic practice, sustainable development, and peace and security, and three pivotal places: New York City, western Balkans, and southern China. On October 12, 2006, the RBF trustees approved a new cross-programmatic grant-making initiative on energy.

Rockefeller Foundation

The work of the Rockefeller Foundation for the 21st century is to enable "smart globalization." It attempts to harness the creative forces of globalization to ensure that the tools and technologies that have significantly improved the human condition in many parts of the world during the past half century are accessible today to more people, more fully, in more places. It seeks to shape efforts in planning, finance, infrastructure, and governance to manage a world in which, for the first time in history, more people live in urban communities than rural ones.

Shell

Shell Oil Company is part of the Royal Dutch Shell group of companies (collectively referred to as Shell), which is a global group of energy and petrochemical companies. With around 102,000 employees in more than 100 countries and territories, Shell helps to meet the world's growing demand for energy in economically, environmentally, and socially responsible ways. In the United States, Shell has exploration and production, refining, chemical, lubricants, distribution, retail, natural gas, power, and alternative energy operations.

Surdna Foundation

Surdna is a family foundation that makes grants in the areas of environment, community revitalization, effective citizenry, the arts, and nonprofit sector support. The Surdna Foundation's Environment Program is national in scope and supports a healthy natural environment, the foundation upon which human communities flourish. It believes that the social and economic concerns of communities are inextricably, and crucially, linked to the natural world. The program's goals include: building support for programs to stabilize climate change at the local, state, and national level; and improving transportation systems and patterns of land use across metropolitan areas, working landscapes, and intact ecosystems.

Urban Land Institute

The Urban Land Institute is a global nonprofit education and research institute supported by its members. Its mission is to provide leadership in the responsible use of land and in creating and sustaining thriving communities worldwide. Established in 1936, the Institute has more than 35,000 members representing all aspects of land use.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) leads the nation's environmental science, research, education, and assessment efforts. The mission of the EPA is to protect human health and the environment. Since 1970, EPA has been working for a cleaner, healthier environment for the American people.

Executive Summary

THE DEBATE ON HOW TO MEET the nation's climate change challenge is well underway, and ambitious goals for greenhouse gas (GHG) reductions are likely to be established. Proposals under discussion would set national targets for reductions in GHG emissions, from all sectors of the economy, of up to 83 percent from 2005 levels by 2050—equivalent to a reduction of more than 5,900 million metric tonnes (mmt) of GHGs during this period of time. Transportation contributes roughly 28 percent of the United States' total GHG emissions—and transportation emissions have been growing faster than those of other sectors. In fact, between 1990 and 2006, growth in U.S. transportation GHG emissions represented almost one-half (47 percent) of the increase in total U.S. GHGs. Success in reducing GHGs through transportation strategies will be critical to meeting national goals.

Moving Cooler was commissioned by a wide range of agencies and interest groups who seek objective information about the potential contributions of transportation strategies to meet these GHG reduction goals. Considerable research has been conducted on the role of advanced vehicle and fuel technologies in reducing the carbon footprint of transportation. However, there is less information about the potential contribution of transportation actions and strategies to reduce the amount of vehicle travel that occurs, or to make changes to the transportation system and services that improve fuel efficiency. *Moving Cooler* provides information on the effectiveness and costs of almost 50 of these types of strategies and combinations of strategies. The results of the *Moving Cooler* findings can help shape effective, integrated approaches for reducing GHG emissions nationally, regionally, and locally, while meeting broader transportation objectives as well.

Transportation GHG emissions are the result of the interaction of four factors: vehicle fuel efficiency, the carbon content of the fuel burned, the number of miles that vehicles travel, and the operational efficiency experienced during travel. Therefore, the range of transportation strategies that can be used to reduce GHGs fall into four basic approaches, as follows:

- **Vehicle Technology**—Improving the energy efficiency of the vehicle fleet by implementing more advanced technologies,
- **Fuel Technology**—Reducing the carbon content of fuels through the use of alternative fuels (for instance, natural gas, biofuels, and hydrogen),
- **Travel Activity**—Reducing the number of miles traveled by transportation vehicles, or shifting those miles to more efficient modes of transportation, and
- **Vehicle and System Operations**—Improving the efficiency of the transportation network so that a larger share of vehicle operations occur in favorable conditions, with respect to speed and smoothness of traffic flow, resulting in more fuel efficient vehicle operations.

The focus of *Moving Cooler* is on strategies that fall within these last two approaches to reducing transportation GHGs.

Research Approach

The *Moving Cooler* analysis estimates the potential effectiveness of strategies to reduce GHG emissions by reducing the amount of vehicle travel that occurs, by inducing people to use less fuel-intensive means of transportation (e.g., walking, bicycling, riding in a bus or train, or carpooling), or by reducing the amount of fuel consumed during travel through transportation system improvements. Strategies are first assessed individually, and are then combined into "bundles" that illustrate the potential cumulative effects that could be achieved. Finally, bundles are examined using an economy-wide pricing overlay that analyzes the effect of fuel tax and carbon pricing and other nationwide pricing measures.

For both the individual strategies and the bundles, the analysis examined the following performance outcomes:

- **GHG Reduction**—What level of GHG reduction could be achieved during what time frame?
- **Implementation Costs**—What are the costs to implement the strategy or bundle?
- **Change in Vehicle Costs**—What would be the effects on the costs of vehicle ownership, maintenance, and fuel from a nationwide perspective?
- **Equity Effects**—How would implementation of various bundles affect different groups of people, and how might inequitable effects be addressed?

Moving Cooler Strategies

The strategies considered by *Moving Cooler* are grouped into nine categories, as follows:

- **Pricing and taxes.** Strategies raise the costs associated with the use of the transportation system, including the cost of vehicle miles of travel and fuel consumption. Both local and regional facility-level pricing strategies (e.g., congestion pricing) and economy-wide pricing strategies (e.g., carbon pricing) are considered.
- **Land use and smart growth.** Strategies focus on creating more transportation-efficient land use patterns, and by doing so reduce the need to make motor vehicle trips and reduce the length of the motor vehicle trips that are made.
- **Nonmotorized transport.** Strategies encourage greater levels of walking and bicycling as alternatives to driving.
- **Public transportation improvements.** Strategies expand public transportation by subsidizing fares, increasing service on existing routes, or building new infrastructure.
- **Ride-sharing, car-sharing, and other commuting strategies.** Strategies expand services and provide incentives to travelers to choose transportation options other than driving alone.
- **Regulatory strategies.** Strategies implement regulations that moderate vehicle travel or reduce speeds to achieve higher fuel efficiency.

- **Operational and intelligent transportation system (ITS) strategies.** Strategies improve the operation of the transportation system to make better use of the existing capacity; strategies also encourage more efficient driving.
- **Capacity expansion and bottleneck relief.** Strategies expand highway capacity to reduce congestion and to improve the efficiency of travel.
- **Multimodal freight sector strategies.** Strategies promote more efficient freight movement within and across modes.

Deployment Levels Used to Test Strategy Effectiveness

Each of the individual strategies is defined at three levels of deployment to test their effectiveness at different degrees of implementation. These levels of deployment are defined in terms of: (1) *Geographic scale*—Where and how broadly are these strategies implemented? (2) *Time frame*—How quickly are these strategies deployed, and when will they take effect? and (3) *Intensity*—How aggressively are these strategies structured? Using this combination of factors, three levels of deployment were defined to estimate potential GHG emission reductions for each strategy and bundle of strategies:

- **Expanded Current Practice,** which assumes the steady expansion of existing practices that could reduce GHG emissions focused predominately on major metropolitan areas;
- **Aggressive,** which assumes that the strategies are implemented sooner, more broadly geographically, and more aggressively than under the expanded current practice deployment; and
- **Maximum Effort,** which assumes that the strategies are implemented within the framework of major changes in national policy and levels of investment consistent with a singular commitment to reduction in GHG emissions nationally, regionally, and locally.

The intent of defining these levels of deployment is to provide insight into the magnitude of GHG reductions and other socioeconomic impacts that might occur over a wide range of "what if" assumptions.

Moving Cooler Strategy Bundles

In practice, most strategies would typically be implemented as part of a package of transportation activities. To test the combined impact of strategies, *Moving Cooler* developed six illustrative bundles of strategies and estimated the total GHG reductions that might be achieved through an integrated set of actions. Each bundle was designed to bring together strategies that emphasize a common thrust or action plan.

The six strategy bundles used for the *Moving Cooler* analysis are as follows:

1. **The Near-Term/Early Results Bundle** focuses on strategies that could be implemented broadly in the short term (i.e., before 2015) and that could result in early GHG reduction benefits. Examples of the variety of strategies that can be implemented relatively quickly include: reduced speed limits, increases in urban center parking fees, increased transit level of service, eco-driving programs, and truck stop electrification.
2. **The Long-Term/Maximum Results Bundle** focuses on maximizing efforts to reduce GHG emissions without regard to cost, scale, or time frame of the implementation. This "all-out" bundle includes most of the *Moving Cooler* strategies assessed for this study: both near-term strategies, as well as land use changes, infrastructure investment to expand transportation services, pricing measures, operational improvements, and freight strategies.
3. **The Land Use/Transit/Nonmotorized Transportation Bundle** emphasizes the interaction of urban area-focused strategies that increase density and encourage travelers to shift to more energy efficient modes, with shorter average trip lengths and increased walking and biking, which would eliminate some vehicle trips.
4. **The System and Driver Efficiency Bundle** focuses on strategies that improve multimodal system efficiency by adding capacity, removing bottlenecks, reducing congestion, and improving traffic flow.
5. **The Facility Pricing Bundle** focuses on local and regional pricing and incentive strategies (e.g., tolls, congestion pricing, parking fees) that will induce changes in travel behavior by changing the cost of travel. These strategies also could be coupled with service expansion.
6. **The Low Cost Bundle** focuses on achieving GHG emission reductions through the deployment of strategies that are more cost-effective.

While these bundles represent logical combinations of strategies, any number of other combinations could also be designed and tested. The purpose of evaluating bundles in the *Moving Cooler* study is to provide analyses that demonstrate potential GHG reductions that could be achieved by combining multiple strategies.

The *Moving Cooler* Baseline

The effectiveness of each strategy in reducing GHG emissions is measured against a baseline developed by the authors of *Moving Cooler* that projects GHG emissions from years 2010 to 2050 (Figure ES.1). This baseline is based on an annual rate of vehicle and fuel technological change, consistent with forecasts of the U.S. Department of Energy in its "Annual Energy Outlook" and the U.S. Department of Transportation's examination of alternative Corporate Average Fuel Economy (CAFE). This baseline shows that innovations in vehicle and fuel technology will have a substantial impact on GHGs, but that these gains will largely be offset by increases in travel along with growth in the U.S. population. Consequently, the *Moving Cooler* baseline shows GHG emissions remaining roughly at 2005 levels through 2050.

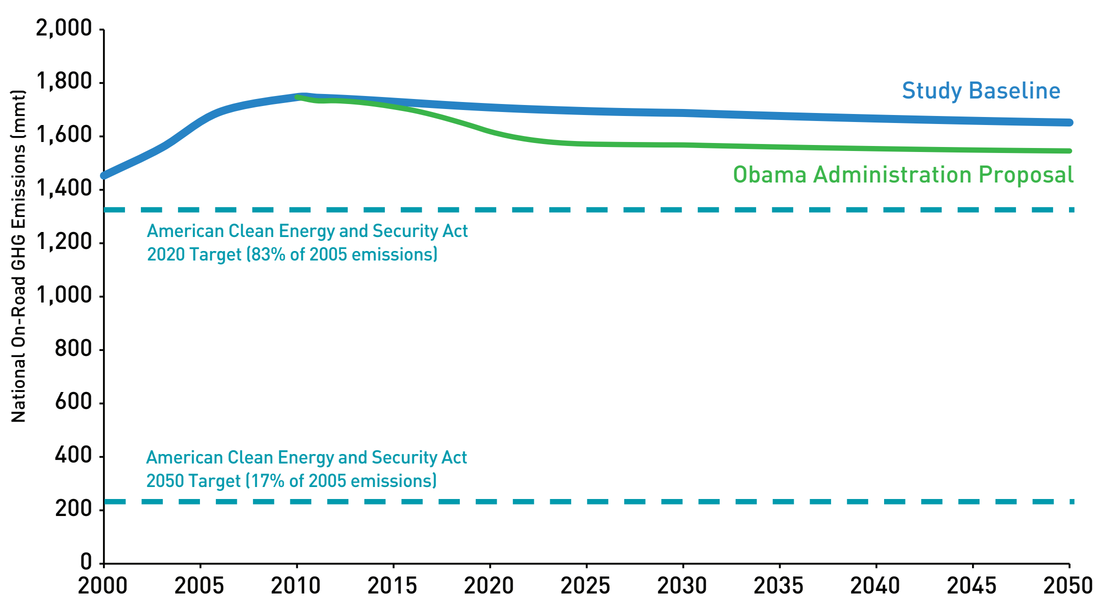
The reductions in GHG emissions estimated to result from implementation of the *Moving Cooler* strategies and bundles are expressed as a percentage reduction from this baseline.

Figure ES.1 illustrates the relationship between the *Moving Cooler* baseline and some targets for national GHG emission reductions. The American Clean Energy and Security Act (HR 2454) (ACESA)[1] sets economy-wide GHG reduction targets in 2012, 2020, 2030, and 2050, compared with 2005 emission levels. The *Moving Cooler* baseline projects GHG emissions that are 104 percent of 2005 emissions; this level is 21 percent short of the ACESA target for 2020 (assuming that the ACESA reduction targets are distributed proportionately across all sectors).

Because the results of the strategy analysis are tied to the values in the baseline, and in recognition of the degree of uncertainty associated with a forecast that extends more than 40 years, three alternative baseline scenarios were developed to investigate the sensitivity to differing baseline assumptions of individual strategy and strategy bundle GHG reduction estimates. The results fall under these assumed scenarios: (1) high fuel prices and low VMT growth; (2) low fuel prices and high VMT growth; and (3) high-technology and fuel economy combined with high VMT (Figure ES.2).

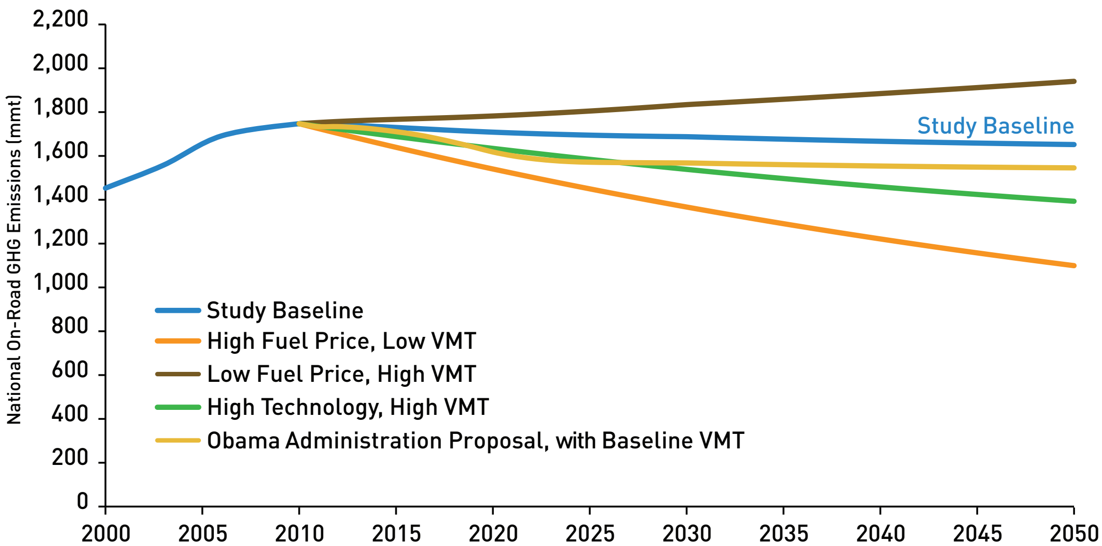
The recent national fuel efficiency standard proposal from President Obama was also extrapolated beyond 2016, assuming the same VMT growth

Figure ES.1 ***Moving Cooler*** **Baseline: Projected On-Road GHG Emissions**



Note: This figure displays National On-Road GHG emissions as estimated in the *Moving Cooler* baseline, compared with GHG emission estimates based on President Obama's May 19, 2009, national fuel efficiency standard proposal of 35.5 mpg in 2016. Both emission forecasts assume an annual VMT growth rate of 1.4 percent. The American Clean Energy and Security Act of 2009 (HR 2454) identifies GHG reduction targets in 2012, 2020, 2030, and 2050. The 2020 and 2050 targets, with an example application to the on-road mobile transportation sector, are shown here.

Figure ES.2 ***Moving Cooler* National GHG Emissions Baseline and Baseline Sensitivity**



Note: This figure displays National On-Road GHG emissions as estimated in the *Moving Cooler* baseline, compared with the study's three sensitivity analysis baselines and with the GHG emission estimates, based on President Obama's May 19, 2009, national fuel efficiency standard proposal of 35.5 mpg in 2016.

rate as in the *Moving Cooler* baseline to calculate GHG emissions. Under this scenario, GHG emissions are projected to be 98 percent of 2005 emissions, or 15 percent short of the 2020 target. The Obama Administration proposal thus falls within the range of sensitivity analyses conducted by the *Moving Cooler* study.

Findings

Combining Strategies to Reduce GHGs

An integrated, multistrategy approach—combining travel activity, local and regional pricing, operational, and efficiency strategies—can contribute to significant GHG reductions. Implementation of a complete portfolio of *Moving Cooler* strategies without economy-wide pricing could achieve annual GHG emissions ranging from less than 4 percent to 18 percent (Aggressive Deployment) and as high as 24 percent (Maximum Effort Deployment) less than projected baseline levels in 2050 (Figure ES.3). Such reductions would, however, involve considerable—and in some cases major—changes to current transportation systems and operations, travel behavior, land use patterns, and public policy and regulations.

Within these illustrative bundles, the strategies that contribute the most to GHG reductions are local and regional pricing and regulatory strategies that increase the costs of single occupancy vehicle travel, regulatory strategies that reduce and enforce speed limits, educational strategies to encourage eco-driving behavior that achieves better fuel efficiency, land use and smart growth strategies that reduce travel distances, and multimodal strategies that expand travel options.

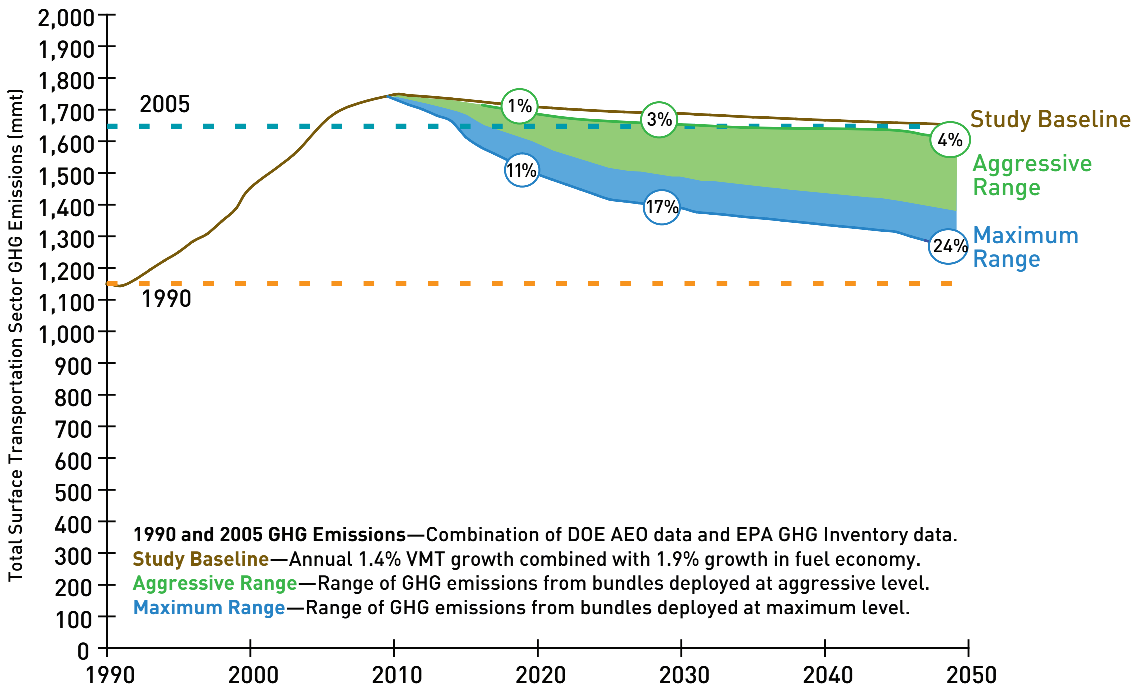
The analysis also shows that some combinations of strategies could create synergies that enhance the potential reductions of individual measures. In particular, land use changes combined with expanded transit services achieve stronger GHG reductions, than when only one option is implemented.

These results demonstrate that transportation agencies and other decision makers could create effective combinations of transportation strategies that provide high-quality transportation services, while achieving meaningful GHG reductions.

Implementation Costs and Vehicle Costs Savings

The costs of implementing many of the Moving Cooler strategies are substantial. So too are the direct vehicle cost savings realized nationally, through reduced travel and reduced fuel consump-

Figure ES.3 **Range of Annual GHG Emission Reductions of Six Strategy Bundles at Aggressive and Maximum Deployment Levels**
2010 to 2050



Note: This figure displays the GHG emission range across the six bundles for the aggressive and maximum deployment scenarios. The percent reductions are on an annual basis from the study baseline. The 1990 and 2005 baselines are included for reference.

tion. For five of the six bundles examined (the facility pricing bundle being the exception), the estimated average annual savings in direct vehicle costs (i.e., ownership, maintenance and repair, and fuel) exceed estimated implementation costs by up to $72 billion for an aggressive level of deployment and up to $112 billion for a maximum level of deployment during a 40-year time frame. Figure ES.4 illustrates this effect for one bundle.

Relevant to energy independence, reduced fuel consumption realized nationally through these strategies translates to an average annual savings of 85 million to 470 million barrels of oil at an aggressive level of deployment, and to a savings of as much as 110 to 660 million barrels a year at a maximum level of deployment.

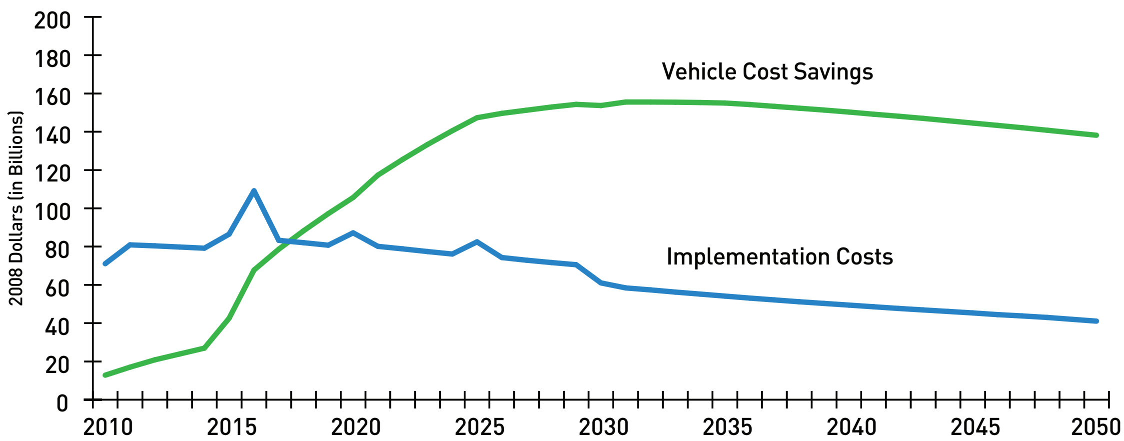
It is important to note that this comparison of implementation costs to vehicle cost savings is not a full assessment of costs and benefits, because the *Moving Cooler* analysis did not address other important benefits and costs, such as changes in mobility, travel time, safety, user fees, environmental quality, economic development, and public health.

Pricing Measures

Strong **economy-wide** pricing measures, beyond the local and regional pricing strategies included in some of the illustrative bundles, could generate GHG reductions well beyond those that could be achieved by the bundles. For example, an additional fee (in current dollars) starting at the equivalent of $0.60 per gallon in 2015 and increasing to $1.25 per gallon in 2050 (Aggressive Deployment) could result in an additional 17 percent reduction in GHG emissions in 2050; a much higher fee similar to current European fuel taxes, starting at $2.40 a gallon in 2015 and increasing to $5.00 a gallon in 2050 (Maximum Effort Deployment) could result in an additional 28 percent reduction in GHG emissions in 2050.

Two factors would drive this increased reduction in GHG as a result of pricing signals: reductions in vehicle-miles traveled (VMT) and more rapid technology advances. Implementation of both Pay as You Drive insurance (PAYD) and/or a direct VMT fee would increase consumers' cost

Figure ES.4 **Implementation Costs and Vehicle Cost Savings for the Long-Term/ Maximum Results Bundle at Aggressive Deployment**
2010 to 2050



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings [reduction in the costs of owning and operating a vehicle from reduced vehicle-miles traveled (VMT) and delay]. Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

per mile of travel, and would result in a national reduction in VMT. Pricing of carbon-based fuel leads to higher fuel costs that depress VMT, and also creates market conditions that encourage the purchase of more fuel-efficient vehicles.

Individual *Moving Cooler* Strategies

When evaluated individually, almost all of the strategies could achieve some GHG reductions. In particular, measures that reinforce efficient driving—either through regulation (speed limit reductions) or education (eco-driving)—could achieve a cumulative (from 2010 to 2050) 1.1 to 3.6 percent reduction from the baseline GHG emissions, depending on the level of deployment. Strategies that aim to reduce VMT by raising the cost of travel (PAYD insurance and VMT fees) could have a comparable effect—a 1.2 to 4.4 percent reduction from cumulative baseline GHG emissions, depending on the level of deployment assumed.

An integrated set of land use strategies achieves cumulative GHG reductions from 0.3 to 2.1 percent improvement from the baseline. Because these strategies take many years to implement and will involve the participation and acceptance of many parties to achieve, the benefits accrue quite slowly in the short-term, before beginning to escalate significantly in the later years.

Transit capital investments, such as urban transit expansion and intercity and high-speed rail, could produce cumulative GHG reductions ranging from 0.4 to 1.1 percent of baseline emissions. This expansion of service requires sustained investment over and above the current levels of investment.

Implementation of a full set of operational and ITS improvements could achieve 0.3 to 0.6 percent cumulative reductions.

If implemented individually, many of the strategies are estimated to achieve cumulative national reductions of less than 0.5 percent from the *Moving Cooler* baseline by 2050, even at maximum levels of deployment. However, the effectiveness of these strategies should be viewed relative to the scale of their potential deployment. *Moving Cooler* measures GHG reduction against a national baseline. At the local and regional scale, many *Moving Cooler* strategies result in greater relative reductions in GHG emissions and could be useful techniques to help meet regional GHG objectives, while enhancing transportation service.

Other Social, Economic, and Environmental Goals

The fact that many individual strategies will likely make only small contributions to national GHG reductions does not indicate that they should be

discarded. In addition to making a contribution to reducing GHGs, many strategies achieve other important objectives, such as expanded travel options, reduced congestion, greater accessibility, improvements in the livability of urban areas, improved equity, improved environmental quality, enhanced public health, and improved safety. The analysis shows, for example, that additional investment in highway capacity and bottleneck relief could result in GHG reductions through 2030 and a negligible increase in GHG through 2050. Review of other cost-benefit studies demonstrates that higher levels of investment in public transportation and highways have returns of two or three times to one in terms of benefits in relation to the costs of these strategies.

Near-Term Reductions

Many of the strategies analyzed in *Moving Cooler* could be implemented within a few years and could begin to generate reductions in GHG prior to 2020. For example, near-term strategies such as lower speed limits, congestion pricing, eco-driving, operational improvements, and improved transit level of service, if implemented, are among strategies that would achieve GHG reductions relatively quickly. Achieving early results would reduce the cumulative GHG reduction challenge in later decades. Near-term actions could give the sector an early start in reducing GHGs, while creating the impetus for more aggressive innovation in vehicle and fuel technology.

Land Use and Improved Travel Options

While some *Moving Cooler* strategies could be implemented quickly, others would require many years to put in place. This observation is particularly true for bundles that involve changes in development patterns and land use to increase density and reduce the distance or need for vehicle travel. The analysis demonstrates that over time, changes in land use and investments in improved transit and transportation options can improve the efficiency and quality of travel, reduce trip lengths, and reduce GHG emissions. The notable reductions for these strategies are realized in the outer decades of this analysis, in 2030 and beyond. These strategies would require changes in development policies and significant funding because of the capital costs of expanded transit services, but these actions could achieve meaningful GHG reductions by 2050, ranging from 9 percent to 15 percent without economy-wide pricing.

Equity Effects

The direct costs of implementing strategy bundles will vary, with different costs incurred by government, consumers, and businesses. If properly designed, highway, public transportation, ride-sharing, and operations investments can be implemented to benefit all income groups and all user groups.

Without mitigating policies, the pricing strategies would potentially create serious equity issues, because of their disproportionate effects on lower-income groups and on those travelers with limited mobility options. Lower income groups spend as much as four times more than higher income groups of their income on transportation; implementation of pricing strategies would exacerbate this inequity.

One solution to this problem could involve taking the revenues from pricing strategies and reinvesting them in additional strategies that address equity concerns, particularly through investments in public transportation and highway investments that benefit lower income and disadvantaged communities to reduce the effects of higher fees. Other income transfer approaches also could be used to address the effects on lower-income groups.

Future Research

Ongoing research is needed in several areas, including further evaluation of the effectiveness of GHG measures in specific contexts, research and evaluation of effective means to develop and deploy new strategies and technologies, and research on the economic effects of different strategy approaches. The interactions of land use, urban form, and transportation are complex, particularly when attempting to project the long-range effects of investment choices on travel behavior. Development of more refined modeling tools that combine GHG and economic analyses could help decision makers more effectively examine investment and planning scenarios, in terms of GHG effects and overall societal benefits and costs.

Note

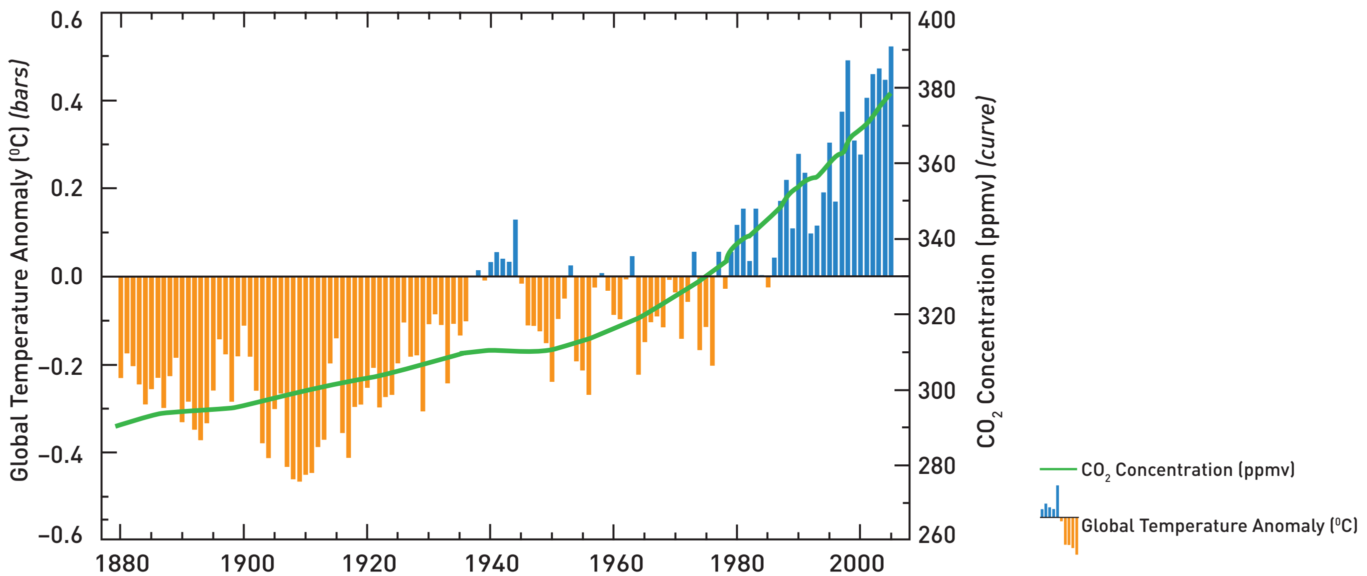
1 American Clean Energy and Security Act of 2009, HR 2454, 111th Cong., 1st sess., *Congressional Record* 155, no. 98, daily ed. (June 26, 2009): H 7471.

1.0 Introduction

1.1 Context of Study

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) states that greenhouse gas (GHG) emissions from human activity are unequivocally warming the planet's climate. Global atmospheric concentrations of carbon dioxide (CO_2), the most abundant GHG, have increased from 280 parts per million (ppm) in preindustrial times to 379 ppm in 2005,[1] as shown in Figure 1.1.[2] The IPCC projects that global temperatures will rise 2.0°F to 11.5°F by 2100, and global sea level will rise some 7 to 23 inches. This warming will have many effects on ecosystems, food production, coastlines, human settlements, health, and water availability. Even with a stabilization of GHG concentrations at current levels, global warming will lead to potential irreversible effects.[3]

Figure 1.1 **Average Surface Air Temperature and CO_2 Concentrations since 1880**

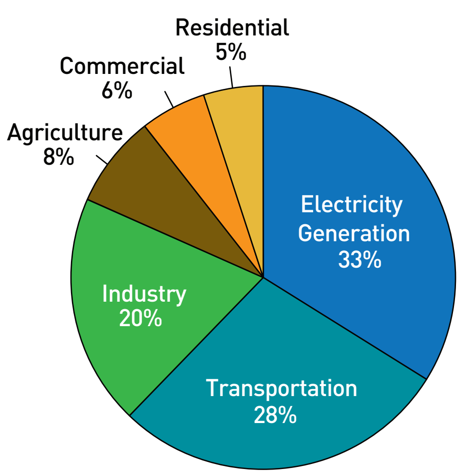


Source: Transportation Research Board (TRB), *Potential Impacts of Climate Change on U.S. Transportation*, TRB Special Report 290, Committee on Climate Change and U.S. Transportation (Washington, DC: Transportation Research Board, Division on Earth and Life Sciences, National Research Council, 2008).

There has been a growing awareness of the need to take action on reducing GHG emissions. In April 2007, the U.S. Supreme Court ruled in *Massachusetts v. EPA*[4] that CO_2 can be regulated under the Clean Air Act. This spring, President Barack Obama proposed stricter new standards for on-road vehicles. For the past several years, Congress has proposed cap- and-trade bills. In fact, Congress will vote this year on the American Clean Energy and Security Act of 2009 (the Waxman-Markey Bill), which requires that economy-wide GHG emissions be reduced by 83 percent from 2005 levels by 2050. Thirty-six U.S. states have completed or are working on climate action plans that identify options for reducing GHG emissions or enhancing carbon "sequestration," a means to capture and safely dispose of CO_2 emissions. At a local level, nearly 1,000 mayors across the nation, representing a total population of more than 80 million citizens, have signed the U.S. Conference of Mayors Climate Protection Agreement.[5]

Transportation is an important component of the climate change issue: the U.S. transportation sector is the second largest source of U.S. GHG emissions, accounting for 28 percent[6] (Figure 1.2), as well as 7 percent of the world's total GHG emissions and one-third of the world's transportation GHG emissions.[7] Transportation emissions are growing as well: from 1990 to 2006, GHG emissions from the transportation sector increased 28 percent—considerably faster than the economy-wide 15 percent increase over the same period. In fact, between 1990 and 2006, growth in U.S. transportation GHG emissions represented almost one-half (47 percent) of the increase in total U.S. GHGs.

Figure 1.2 **U.S. GHG Emissions by End Use Economic Sector** 2006



Source: Environmental Protection Agency (EPA). "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007," April 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

Despite the importance of this sector, regulatory activity is only now beginning to focus on reducing transportation GHG emissions; most of the previous emphasis has been on stationary sources. The Regional Greenhouse Gas Initiative (RGGI) in the northeast, the first mandatory, market-based effort in the United States to reduce GHG emissions, only deals with the electric power sector. In the European Union, which has the world's largest GHG emission trading scheme, transportation is not yet part of the cap covered by the Emissions Trading System (ETS). For now, the ETS covers only about one-half of the EU's total CO_2 emissions, applying to power plants and five major industrial sectors (oil, iron and steel, cement, glass, and pulp and paper).

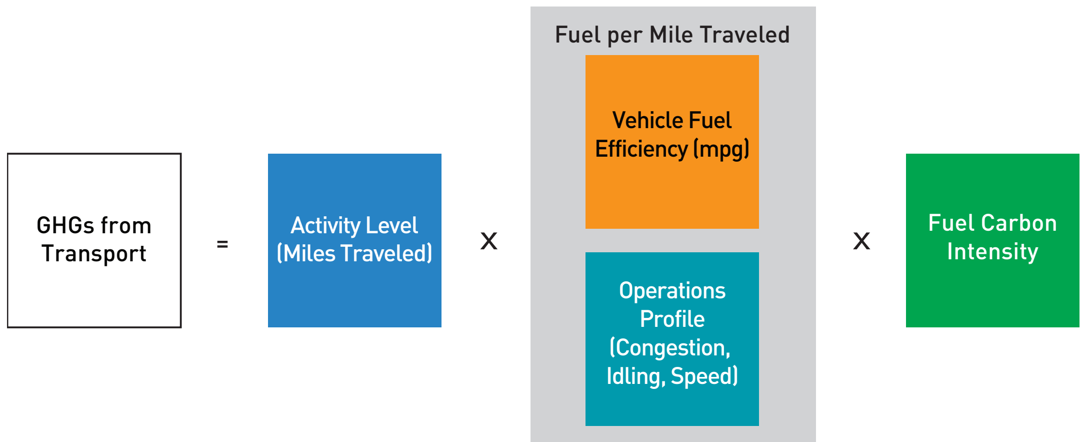
Initial steps are being taken. On May 19, 2009, President Barack Obama announced aggressive new standards that would significantly increase fuel economy and lower GHG emissions for cars and trucks by 2016. Those new standards would increase the average mileage requirements for new light-duty vehicles to 35.5 miles per gallon (mpg) (39 mpg for new cars and 30 mpg for new light-duty trucks) from the 2009 light-duty fleet average of 25 mpg. The Waxman-Markey Bill provides support for electric vehicles and emission standards, and would require states to establish goals for GHG emissions reductions from the transportation sector. In Europe, progress also is being made: air transport will be incorporated into the ETS in 2011, maritime emissions may be included in the near future, and automobile manufacturers in the EU have implemented voluntary GHG emissions standards.

This study examines the potential of a number of transportation strategies to reduce GHG emissions.

1.2 Reducing GHGs from Transportation

Transportation GHG emissions are the result of the interaction of four factors: (a) the number of miles that vehicles travel (activity level), (b) vehicle fuel efficiency, (c) the operational efficiency experienced during travel, and (d) the carbon content of the fuel burned. As shown conceptually in Figure 1.3, emissions can be described as the product of these factors.

Figure 1.3 **Steps in Calculating GHG Emissions from Transportation**



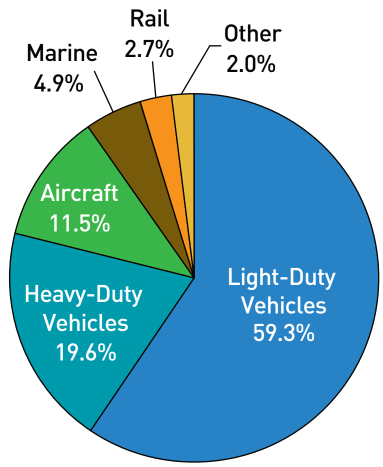
- The **activity level** is the first step in the equation and represents the number of miles traveled by each vehicle.
- The **fuel consumed per mile traveled** is determined by two factors:
  — The **vehicle fuel efficiency** measures the number of miles per gallon (mpg) the vehicle achieves during normal operation; and
  — The **operations profile** encompasses a number of operational and system efficiency factors. This profile includes the effects of congestion (with its increase in inefficient acceleration/deceleration cycles), idling, and excessively high- and low-speed driving—all of which decrease fuel economy for many vehicles.
- The **carbon intensity** of a fuel is a measure of how much carbon is emitted per unit of energy released. Natural gas, for instance, has a lower carbon intensity than gasoline as a result of its chemical makeup.

This relationship holds true for all modes of transportation, although the composition of the individual parameters may vary. In the United States, highway on-road vehicles (light- and heavy-duty vehicles) represent the majority of such transportation emissions, accounting for 79 percent of the total U.S. transportation GHG emissions in 2006 (see Figure 1.4). Light-duty highway vehicles, which include passenger cars and light-duty trucks (sport utility vehicles, pickup trucks, and minivans), accounted for almost 75 percent of the on-road emissions, while heavy-duty highway vehicles (primarily freight trucks) contributed the remaining 25 percent. Other modes generate GHG emissions as well. Air travel accounted for 11.5 percent of U.S. transportation emissions, while the maritime sector accounted for another 4.9 percent and rail movements accounted for 2.7 percent.

1.3 Scope of *Moving Cooler*

The interaction among the four factors described above makes it clear that there are a number of different ways to reduce GHG emissions from

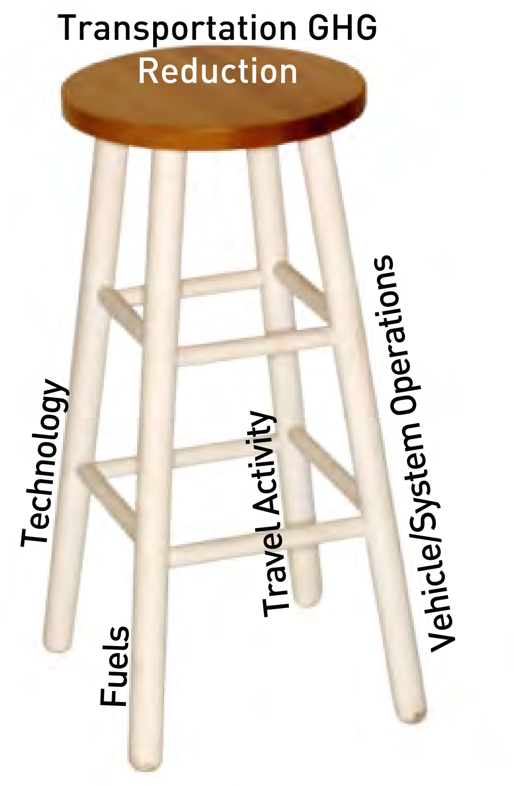
Figure 1.4 **2006 GHG Emissions Breakdown by Mode**



Source: Environmental Protection Agency (EPA). "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007," April 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

Note: Light-duty vehicles includes passenger cars and light-duty trucks (sport utility vehicles, pickup trucks, and minivans). Heavy-duty vehicles include most remaining highway vehicles, primarily freight trucks.

Figure 1.5 **GHG Reduction Strategies**



transportation. The key approaches to the four factors, or the four legs of the GHG reduction "stool" (Figure 1.5), are as follows:

1. **Technology—**Improving the energy efficiency of the vehicle fleet by implementing more advanced technologies to produce more efficient vehicles;
2. **Fuels—**Reducing the carbon content of fuels through the use of alternative fuels (for instance, natural gas, biofuels, and hydrogen);
3. **Travel Activity—**Reducing the number of miles traveled by transportation vehicles, or shifting those miles to more efficient modes; and
4. **Vehicle/System Operations—**Improving the efficiency of the transportation network, so that a larger share of vehicle operations occurs in the most favorable conditions, with respect to speed and smoothness of flows, resulting in more fuel efficient vehicle operations.

Advances in vehicle and fuel technologies are anticipated to be major drivers to reduce GHG emissions and have generally been the main focus of study and policy development to date. For example, the U.S. Department of Energy in its "Annual Energy Outlook" and the U.S. Department of Transportation in its examination of alternative CAFE standards have evaluated scenarios with substantial increases in the fuel efficiency of passenger cars and light trucks during the next 20 to 30 years. Those scenarios, if extrapolated further to 2050, could result in a doubling or greater of fleet fuel efficiency.

However, under these conditions, improvements in fuel efficiency alone do not generate large enough declines in total transportation sector GHG emissions in the coming decades to reach proposed economy-wide targets for reducing GHG emissions (targets as high as an 83 percent reduction from 2005 levels). Two reasons for this challenge are the growth in vehicle travel and the degradation of system efficiency from increasing congestion.

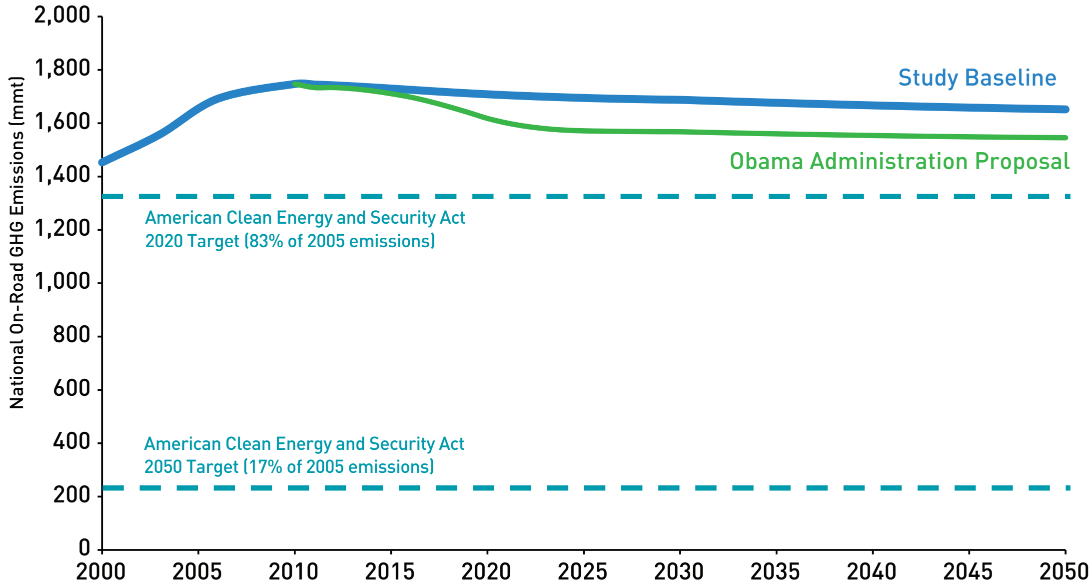
Figure 1.6 shows the projection of GHG emissions from on-road vehicles that is used as the baseline for assessing *Moving Cooler* strategies. The *Moving Cooler* baseline is constructed using assumptions of vehicle-miles traveled (VMT) and fuel economy growth rates consistent with the 2009 Annual Energy Outlook approaches. According to this baseline, which is described more fully in Section 3.0, the combined effects of fuel and vehicle technology improvements are forecast to generate only a slight decline in GHG emissions during the next 40 years, because of continued growth in VMT during the same period.

Figure 1.6 also illustrates the relationship between the Moving Cooler baseline and some targets for national GHG emission reductions. The American Clean Energy and Security Act (HR 2454) (ACESA)[8] sets economy-wide GHG reduction targets in 2012, 2020, 2030, and 2050, compared with 2005 emission levels. The *Moving Cooler* baseline projects GHG emissions in 2020 that are 104 percent of 2005 emissions; this level is 21 percent short of the ACESA target for 2020 (assuming that the ACESA reduction targets are distributed proportionately across all sectors).

The recent national fuel efficiency standard proposal from President Obama is extrapolated beyond 2016, assuming the same VMT growth rate as in the *Moving Cooler* baseline to calculate GHG emissions. Under this scenario, GHG emissions are projected to be 98 percent of 2005 emissions, or 15 percent short of the 2020 target.

Transportation behavioral and operational strategies, in conjunction with technology and fuel strategies, enable the transportation sector to achieve the greatest potential levels of GHG emis-

Figure 1.6 **Projected On-Road GHG Emissions**



Note: This figure displays National On-Road GHG emissions as estimated in the *Moving Cooler* baseline, compared with GHG emission estimates based on President Obama's May 19, 2009, national fuel efficiency standard proposal of 35.5 mpg in 2016. Both emission forecasts assume an annual VMT growth rate of 1.4 percent. The American Clean Energy and Security Act of 2009 (HR 2454) identifies GHG reduction targets in 2012, 2020, 2030, and 2050. The 2020 and 2050 targets applied to the on-road mobile transportation sector are shown here.

sions reductions. There are a number of reasons this holistic approach may be needed:

- **Reduction Potential—**Projected advances in vehicle technology and fuels alone are not sufficient to achieve the targets being discussed for reducing GHG emissions, such as the target of 83 percent below 2005 levels by 2050 proposed in the Waxman-Markey Bill or targets of 80 percent below 1990 levels by 2050, which have been set in California and Florida.[9] Although those targets are economy-wide, and the transportation sector's share of reductions is not specified, meeting these overall targets will likely require significant reductions from the transportation sector.
- **Time Frame—**Both near-term and longer range strategies will be required, because (unlike other air pollutants) the cumulative effect of GHG emissions over decades is the determinant of their effect on the climate. Implementation timelines for the technology strategies are necessarily limited by fleet turnover rates—the light-duty vehicles sold now will be on the road for an average of 14 years, and it takes more than 20 years for vehicle fleets to be fully replaced. In that light, some behavior and operations strategies can bring results more quickly than can be achieved with new technologies for vehicles or with new fuel sources. Thus, those strategies can make valuable contributions to GHG reductions sooner, as well as add to the cumulative long-term reductions.
- **Relationships among Strategies—**Beneficial interactions between travel behavior and operations measures on the one hand and technology and fuel strategies on the other hand can enhance their effectiveness. For example, electric vehicles with a limited range and lower top speed become more practical if land use policies have resulted in more compact land uses, shorter trips, and less reliance on high-speed freeways. Similarly, aggressive pricing strategies can create market forces that will accelerate the market penetration of emission-reducing technologies and fuels. They can interact in more strategy-specific ways as well.

- **Co-Benefits and Equity—**Policy makers are interested in travel behavior and operations strategies for their other benefits, including pollution reduction, safety, congestion relief, economic development, and mobility. In addition, they want to address equity concerns, by maintaining mobility and purchasing power for low income groups who may be affected by higher prices for travel, and by maintaining access to employment opportunities and opportunities for those low-income groups. It is vital to recognize the value of these co-benefits and equity considerations when appraising GHG reduction strategies.

1.4 Goal of *Moving Cooler*

Moving Cooler is designed to provide an objective analysis of opportunities for reducing GHG emissions, and focuses on the last two legs of the stool: travel activity and system efficiency. Specifically, it provides an analysis of the effectiveness and cost implications of almost 50 specific strategies and combinations of strategies to reduce GHG emissions. It also describes the potential equity effects of the strategies, as well as how those strategies might contribute to other societal goals.

The findings of this analysis do not advocate for implementation of any particular strategy or set of strategies, nor for any policy, funding, or institutional changes that might be needed to achieve implementation. This analysis also does not evaluate the likelihood of any strategy or set of strategies being implemented. In fact, to explore the potential effect of the strategies on GHG emissions and the costs and benefits of their implication, each strategy is intentionally examined in the context of a wide range of implementation levels: from an expansion of current practice to maximum deployment. The results of this study can serve as a tool for the following:

- Policy makers who are charting national initiatives,
- Transportation planners and managers who are assessing options for climate action strategies, and
- Researchers who need to better understand the magnitude of potential reductions.

1.5 Organization of This Report

The remainder of this report is structured as follows:

- **Section 2.0** describes the strategies for reducing GHG emissions as analyzed in the study;
- **Section 3.0** explains the methodology used in estimating the potential for reducing GHG emissions and the costs associated with various strategies;

- **Section 4.0** presents the findings of the study, including the potential for various strategies and strategy bundles to reduce GHGs, the magnitude of costs in implementing them and the vehicle cost savings, other benefits and costs, and the equity implications of these strategies; and
- **Section 5.0** organizes the conclusions of these findings and considers the implications for setting future transportation policy.

This report provides an overview of the approach and results of this study. Those interested in a more detailed description of the work, its methodology, and other supplementary materials are directed to a set of technical appendices, which are available at www.movingcooler.info.

Notes

1 Intergovernmental Panel on Climate Change (IPCC), *Fourth Assessment Report, Climate Change 2007: Synthesis Report* (Valencia, Spain: IPCC, 2007).

2 Transportation Research Board (TRB), *Potential Impacts of Climate Change on U.S. Transportation*, TRB Special Report 290, Committee on Climate Change and U.S. Transportation (Washington, DC: Transportation Research Board, Division on Earth and Life Sciences, National Research Council, 2008).

3 IPCC, *Fourth Assessment Report. Climate Change 2007 Synthesis Report*, *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team*, edited by R.K. Pachauri and A. Reisinger. (Geneva, Switzerland: IPCC, 2007).

4 *Massachusetts v. Environmental Protection Agency*, 1120 U.S. 415 F3d 50 (2006).

5 U.S. Conference of Mayors, "U.S. Conference of Mayors Climate Protection Agreement," 2008, http://www.usmayors.org/climateprotection/agreement.htm.

6 This figure does not include combustion emissions of ethanol or fugitive emissions of methane, CH_4, from pipelines.

7 Environmental Protection Agency (EPA), "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007," April 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

8 American Clean Energy and Security Act of 2009, HR 2454, 111th Cong., 1st sess., *Congressional Record* 155, no. 98, daily ed. (June 26, 2009): H 7471.

9 The Pew Center on Climate Change, "A Look at Emissions Targets," 2009, http://pewclimate.org/_s_being_done/targets; and Pew Climate Center, "The American Clean Energy and Security Act (Waxman-Markey Bill)," 2009, http://pewclimate.org/acesa.


19
POWELL AND MARKET
FISHERMANS WHARF
MARKET STREET
4
FISHERMANS WHARF
ticket sales
CABLE CARS

2.0 Transportation Strategies Assessed

2.1 Overview

This study has examined almost 50 strategies that are aimed at reducing GHG emissions from surface transportation. But what does it mean to "implement a strategy"? How widely will that implementation be applied, and over what time frame? If the strategy involves a new user cost or a new fee, how much will it be and who will pay? To understand how the strategies will help to achieve the reduction of GHG, assumptions need to be made about the implementation, as follows: when, where, and how each strategy will be deployed, in the context of where Americans choose to live, work, and travel.

This section explains how the strategies were identified, describes what each strategy actually entails, and provides details on three levels of implementation that assume increasingly aggressive timing and scale of deployment.

2.2 How Were the Strategies Developed?

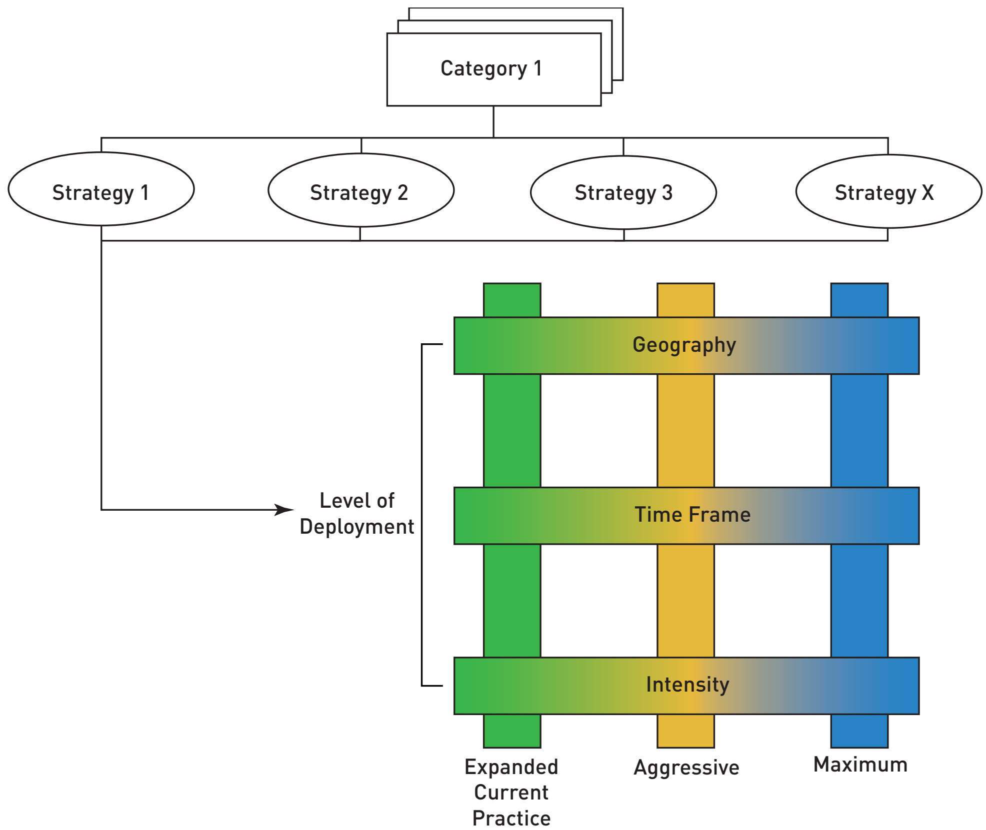
As described in Section 1.0, *Moving Cooler* focuses on changes to travel behavior and to the operation of the transportation system that could reduce GHG emissions by either reducing the amount of travel or by improving the efficiency of system operations, and thereby reducing the quantity of fuel that needs to be consumed by that travel, or both. In keeping with the legs of the transportation GHG reduction "stool" shown in Figure 1.5, achieving these reductions will entail strategies that can:

- **Reduce travel activity**. This strategy includes reducing the number of trips taken in personal vehicles or trucks, decreasing the average length of trips made by vehicles, increasing the average occupancy of personal vehicles and transit vehicles, encouraging freight mode shifts to more efficient modes, and increasing freight payloads per vehicle.
- **Improve vehicle/system operations**. This strategy includes relieving congestion and delay to save fuel that is lost in stopping, starting, and changing speeds; changing driver behavior to operate vehicles more efficiently; implementing roadway technology to improve freight movements; and improving freight logistics.

To evaluate the possible GHG reduction opportunities that fit into these two legs of the stool, a broad range of strategies was compiled, based on findings from previous implementations of the strategies both domestically and abroad, literature reviews, and discussion among the study team and the *Moving Cooler* Steering Committee. Based on that effort, nine categories of strategies emerged, as described in more detail in Section 2.3. Within these nine categories, almost 50 individual strategies were identified.

The next step focused on how, where, and when to implement each individual strategy. As described in Section 2.4, there are three levels of deployment that were considered, representing increasingly intense and broader scale implementations of the strategies. The three levels of deployment considered how quickly the strategies could be put into place, their geographic scope (whether applied to large urban, smaller urban, or rural areas), and the magnitude of implementa-

Figure 2.1 **Hierarchy of Strategies and Deployment**



tion. Figure 2.1 shows the hierarchy of the strategies assessed in *Moving Cooler*, beginning with the overall categories and then moving to how each strategy could be implemented.

Finally, as described in Section 2.5, illustrative groupings, or "bundles," of strategies were then defined and tested for their ability to work together to achieve the reduction of GHG. This bundling of strategies is a key component of the report, and provides policy makers a way to think across modal and policy lines, examine more comprehensive packages of strategies that might be implemented to reduce GHGs, and evaluate the interactions experienced when multiple strategies are implemented simultaneously.

2.3 Strategy Categories

The individual strategies considered in *Moving Cooler* as potential ways to help reduce GHG emissions are grouped into nine categories:

- Pricing strategies,
- Land use and smart growth strategies,
- Nonmotorized transportation strategies,
- Public transportation improvement strategies,
- Regional ride-sharing, car-sharing, and commuting strategies,
- Regulatory strategies,
- Operational and intelligent transportation system (ITS) strategies,
- Bottleneck relief and capacity expansion strategies, and
- Multimodal freight strategies.

The general characteristics of each of these nine categories and the specific strategies included in each one are discussed in greater detail below.

Pricing Strategies

This category of strategies focuses on raising the costs associated with use of the transportation system, in terms of the cost of vehicle miles of travel and fuel consumption. It also includes strategies focused on managing existing capacity more efficiently and decreasing fuel consumption through improved system operations and ITS.

The revenues generated from pricing strategies can be reinvested in transportation infrastructure, potentially covering the costs of implementing GHG reduction strategies. A broad range of pricing strategies, tolls, and taxes can influence traveler's transportation decision-making:

- **Parking pricing**. Parking fees would be charged for all parking in central business districts (CBD), employment areas, and retail centers to encourage "park once" behavior or reduce single occupant trips. Other approaches include the introduction of taxes or higher fees on otherwise free private parking lots and parking management approaches, including requirements for residential parking permits, as well as permits for delivery and service vehicles and for visitors.
- **Cordon pricing**. Tolls would be paid by motorists who pass through a "cordon" around CBD or other major employment or retail areas.
- **Congestion pricing.** Tolls would be paid for the use of congested facilities, with tolls set to achieve a desired level of service on the roadway segments.
- **Intercity tolls.** All rural interstate highways or other limited access roads would be tolled on a per-mile basis, similar to the tolls on existing limited access toll facilities.
- **Pay-as-you-drive (PAYD) insurance.** PAYD would charge drivers their insurance premium costs based in part on how many miles their vehicles are driven in a given year. Other insurance rating factors would continue to apply, so high-risk drivers would pay more than lower-risk drivers, but all drivers would have the opportunity to save money by driving fewer miles.
- **Vehicle-miles traveled (VMT) fee.** Like PAYD, drivers would be charged based on how many miles they drive. Periodic odometer readings (automatic or manual) would be the basis for determining the level of fees a driver must pay.
- **Motor fuel tax or carbon price.** Motor fuel taxes (currently the primary source of revenue for highways) would be increased to send price signals that increase the cost of carbon-based fuels. Carbon prices would be set economy wide, either as a fuel tax or as a result of a cap-and-trade system. Very high levels of either carbon prices or motor fuel taxes also may affect fuel efficiency or fuel types, as well as travel choices.

Land Use and Smart Growth Strategies

This category focuses on creating more transportation-efficient land use patterns. By doing so, drivers can reduce the need to make motor vehicle trips or the length of the motor vehicle trips that are made.[1] For example, compact neighborhoods that incorporate residential, employment, and retail areas allow people to walk or bicycle more to meet their daily needs, rather than having to drive a motor vehicle. Reusing infill sites instead of building on "greenfield" locations and creating communities that have a balance of jobs and housing can shorten trip lengths to jobs and other regional destinations. Transit ridership can be increased by focusing higher-density development around rail transit stations and bus corridors. Achieving these kinds of land use patterns would require plans that target new development at higher levels of density and other supportive plans and policies that encourage nonmotorized or public transportation alternatives, such as the provision of sidewalks, pedestrian- and bicycle-friendly routes, and attractive streetscapes. Metropolitan planning organizations (MPO) or other regional planning agencies would work with local governments to cooperatively develop a regional transportation and land use plan and to develop consistent local plans that support VMT reductions, including the following:

- Adoption of growth boundaries around urban areas,
- Minimum targets for the amount of new development in multifamily, attached, or small-lot detached units in pedestrian- and bicycle-friendly neighborhoods featuring sidewalks, bicycle facilities, good connectivity, mixed-use commercial districts, and high-quality transit,
- Zoning and planning standards that support increased population densities and pedestrian-friendly and transit-oriented development designs, and
- Incentives for agencies, such as funding for local planning or related implementation activities, to help achieve these types of objectives.

Nonmotorized Transportation Strategies

Strategies in this category are intended to encourage greater levels of walking and bicycling as an alternative to driving, and include the following:

- Adoption of "complete streets" (sometimes called "routine accommodation") policies that help make roadways safe, attractive, and comfortable for all users, including pedestrians and bicyclists, as well as drivers,
- Provisions for bicycling, parking, and bike-accessible transit, as well as on-street bicycle accommodations to create a continuous network of routes and "bike stations" that provide services, including parking, rentals, repair, clothes-changing facilities, and information,

- Inclusion of buffered sidewalks (in all new urban development areas) with pedestrian amenities such as curb cuts, good lighting, and marked or signalized pedestrian crossings at key intersections, and
- Introduction of traffic calming measures in business districts and denser neighborhoods.

Public Transportation Improvement Strategies

Strategies for improving public transportation can include subsidizing fares, increasing service on existing routes, building new infrastructure, and providing new service in and between urban areas. These strategies include the following:

- Lower fares and discounted passes,
- Increased level of service on existing routes and improved travel times through reduced headways, signal prioritization, and limited stop service,
- Provision of new service through expanded investments in commuter rail, heavy rail, light rail, bus rapid transit, general bus service, and demand response service, and
- Expansion of existing intercity bus and rail services and addition of new routes, including high-speed rail.

Regional Ride-Sharing, Car-Sharing, and Commuting Strategies

Regional ride-sharing and car-sharing strategies are comprised of different approaches aimed at getting drivers to use HOV lanes or to use a shared car service, such as Zipcar, as follows:

- High-occupancy vehicle (HOV) lanes would be introduced on congested expressways; in cases where HOV lanes are only designated as such during certain hours of the day and days of the week, full HOV designation would become permanent (i.e., 24 hours per day, seven days per week) over time, and
- Support would be provided to start up public, private, or nonprofit car-sharing organizations, including public street parking, either subsidized or free, for the shared vehicles.

Some commuting or carpool measures may not require a significant investment to realize reductions in VMT and GHG. This group of strategies focuses on incentives to encourage commuters to choose different transportation options instead of driving alone to work, including:

- Employer- and government agency-based telework and compressed work-week programs would reduce the number of days employees travel back and forth to their places of work,
- On-line ride matching, vanpool services, and guaranteed ride home programs would be established,
- Monthly transit passes would be made available through employers at discounted rates,
- Single-occupant vehicle (SOV) reduction programs would be mandatory for employers of a certain size, and
- Employer outreach programs would educate their employees about the commute strategies available.

Regulatory Strategies

This category includes various regulatory measures to moderate vehicle travel and encourage more efficient driving, as follows:

- Nonmotorized zones would be established in CBDs and regional employment and retail centers, transforming these areas to transit malls, linear parks, or other nonmotorized zones,
- Parking restrictions would be imposed in urban areas, capping the absolute number of commuter spaces in a CBD and other regional employment and retail centers, with potential exceptions for carpools, and
- The national speed limit would be lowered with increased enforcement and may vary for light-duty vehicles and heavy-duty vehicles.

Operational and Intelligent Transportation System Strategies

There is a broad-ranging set of strategies and techniques that can educate and provide information to drivers, and improve the operation of the transportation system to better use the existing capacity and reduce congestion and fuel lost to traffic delays, as follows:

- **"Eco-driving" training programs.** These would be implemented to train drivers in techniques that can reduce gas consumption, such as avoiding rapid acceleration and braking, reducing speeds, changing gears properly, and using cruise control. These programs would also provide training on proper vehicle maintenance, such as tire pressure, wheels, motor oil, and could include funding for public awareness campaigns and new driver education. Such eco-driving training programs have been in place since the late 1990s in the Netherlands and Sweden.
- **Freeway management.** Roadway capacity would be better managed through the combination of real-time information and operational adjustments based on that information. These

operational techniques include the implementation of ramp metering to regulate the flow of traffic entering a freeway to maintain a desired level of service; active traffic management based on traffic conditions, to dynamically change the speed limit on roadway segments or temporarily converting shoulders to travel lanes; and finally, integrated corridor management to use technology to coordinate a variety of intelligent transportation system (ITS) technologies across multiple corridors to reduce congestion.

- **Incident management.** A variety of technologies would help to identify, respond to, and clear incidents, including detection algorithm and free cell call systems, closed-circuit TV cameras, on-call service patrols, and transportation management centers.
- **Road weather management.** Coordinated weather advisories, speed reductions, and snow and ice treatments would be implemented to promote safe operations when conditions become severe.
- **Traffic management center (TMC).** A TMC would be the "hub" of a transportation system where information is collected and used to manage the system, including incidents or other events.
- **Arterial management.** Techniques that would help manage traffic arterial networks include signal timing and management and variable message signs (VMS).
- **Traveler information.** Timely and accurate information would be provided to travelers about roadway conditions and incidents, closures, and special events, as well as alternate routes. The information would be communicated through various systems, including VMS, advisory services (such as 511 systems), and traveler information call centers. These systems would be deployed concurrently with freeway and arterial management strategies.
- **Vehicle infrastructure integration (VII) or IntelliDrive℠.**[2] Vehicles would be equipped with technologies that communicate with the roadside and would help the drivers avoid other vehicles or roadway obstructions.

Bottleneck Relief and Capacity Expansion

Infrastructure investments would be made in the nation's existing highway bottlenecks, which have been identified already. Additionally, cost-effective highway investment would be implemented to improve traffic flow and to reduce congestion and fuel lost to delay.

Multimodal Freight Strategies

Freight plays a critical role in the nation's economy, and finding a balance among effective freight movement, economic vitality, and GHG reductions could require a variety of strategies:

- **Modal diversion.** Diversion of some freight from trucks and into rail cars and the waterways will reduce GHG emissions, while requiring investment in new and expanded rail capacity and in the inland waterways, Great Lakes, and coastal waterways.
- **Mode optimization.** Expanded eligibility and use of overweight load permits for distances up to 250 miles would allow movement of shipping containers from port facilities inland on trucks. A comparable strategy includes increasing the eligibility and use of permits for longer combination vehicles carrying natural resources on designated non-interstate roads. Weigh-in-motion (WIM) systems would minimize delays and reduce truck idling by eliminating the need to stop at weigh stations. Electronic credentialing would allow vehicles to bypass weigh stations and safety inspections. Electrification would be provided at truck stops and battery-operated heating and cooling systems would be required in all sleeper cabs. Truck-only toll lane networks would move these vehicles more effectively through congested areas.
- **Logistics.** Trucking companies would make further improvements to their logistics systems through the establishment of Urban Consolidation Centers, time-of-day restrictions would be instituted on most deliveries to CBDs, and permitting systems would be required for less-than-truckload and parcel deliveries to CBDs.

2.4 Levels of Deployment

The questions of where, when, and how each strategy is implemented will determine the extent to which each strategy might effectively reduce GHGs. There are three key dimensions considered in strategy deployment:

- **Geography.** Strategies can be selectively focused on major population centers, or they can be more broadly applied. This study looks at deployment options among regions classified as large (more than one million in population), medium (population between 400,000 and one million), and small (population between 50,000 and 400,000), as well as nonurban areas. Each of these regions is also classified in terms of per capita baseline transit usage and population density, because the level and use of existing

Table 2.1 **GHG Emission Reduction Strategies at Three Deployment Levels**

GHG Reduction Strategy	A. Expanded Current Practice	B. More Aggressive	C. Maximum Effort
Pricing Strategies			
Parking pricing	Price street parking starting in 2015, complete in 8 years.	Price street parking starting in 2010, complete in 6 years. Tax free private parking with >100 spaces. Require residential parking permit ($200).	Price street parking starting in 2010, complete in 4 years. Tax free private parking with >50 spaces. Require residential parking permit ($400).
Cordon pricing	Implement area pricing in large CBDs starting in 2015.	Implement area pricing in large and medium CBDs starting in 2015.	Implement area pricing in all CBDs starting in 2010.
Congestion pricing	Include all large regions by 2015; complete in 15 years. Average peak hour per mile price of $0.49 on congested segments	Include all large and medium regions by 2015; complete in 10 years. Average peak hour per mile price of $0.65 on congested segments.	Include all regions by 2015; complete in 10 years. Average peak hour per mile price of $0.65 on congested segments.
Intercity tolls	Toll all intercity interstate highways at a minimum of $0.02 per mile by 2020.	Toll all intercity interstate highways at a minimum of $0.03 per mile by 2015.	Toll all intercity interstate highways at a minimum of $0.05 per mile by 2010.
Pay-as-you-drive (PAYD) insurance	Require all states to permit the offering of per-mile insurance rates by 2010.	At least 50 percent of policies converted to PAYD by 2015, increasing to 75 percent by 2025.	At least 75 percent of policies converted to PAYD by 2015, increasing to 100 percent by 2025.
Vehicle-miles traveled (VMT) fee	$0.01 per mile ($0.21 per gallon indexed to fuel economy) VMT fee (2015).	$0.03 per mile ($0.63 per gallon indexed to fuel economy) VMT fee (2015).	$0.12 per mile ($2.53 per gallon indexed to fuel economy) VMT fee (2015).
Motor fuel tax and carbon price	Increase fuel taxes or carbon price by $0.01 per mile (current $0.02 per mile) (new tax at $0.40 per gallon indexed to fuel economy).	Increase fuel taxes or carbon price by $0.03 per mile (current $0.02 per mile). (new tax at $0.82 per gallon indexed to fuel economy).	Increase fuel taxes or carbon price by $0.12 per mile (current $0.02 per mile). (new tax at $2.71 per gallon indexed to fuel economy)
Land Use and Smart Growth Strategies			
Combined land use strategies	At least 43 percent of new development in compact, pedestrian- and bicycle-friendly neighborhoods with high-quality transit.	At least 64 percent of new development in neighborhoods as described under (A).	At least 90 percent of new development in neighborhoods as described under (A).
Nonmotorized Transportation Strategies			
Combined strategies—pedestrian	"Complete streets" policies. Audit and retrofit for pedestrian accessibility.	Same as Level A, but with more extensive audits and retrofits.	Same as Level B, but with more extensive traffic calming.
Combined strategies—bicycling	Bike lanes and paths at one-mile intervals in high-density areas (> 2000 persons per sq. mi.)	Bike lanes and paths at one-half-mile intervals in high-density areas (> 2000 persons per sq. mi.)	Bike lanes and paths at one-quarter-mile intervals in high-density areas (> 2000 persons per sq. mi.)
Public Transportation Improvement Strategies			
Fare measures	Fares decreased by 25% in large regions by 2015.	Fares decreased by 33% in large and medium regions by 2015.	Fares decreased by 50% in all regions by 2010.
Increased levels of service and improved travel times	Increase transit level of service by 1.5 times current revenue mile growth rate, improve travel speeds by 10%.	Increase transit level of service by 2 times current revenue mile growth rate, improve travel speeds by 15%.	Increase transit level of service by 4 times current revenue mile growth rate, improve travel speeds by 30%.
Expanded Urban Public Transportation	Increase services proportional to 3% per year ridership growth by 2010.	Increase services proportional to 3.53% per year ridership growth by 2010.	Increase services proportional to 4.67% per year ridership growth by 2010.
Intercity Bus and Rail and High-Speed Rail	Increase funding over baseline by 5% per year for 20 years. High speed rail in 3–5 corridors implemented over 20 years.	Increase funding over baseline by 10% per year for 20 years. High-speed rail in 5–7 corridors implemented over 15 years.	Double funding over baseline in 2010 and increase by 10% per year for 20 years. High-speed rail in up to 12 corridors implemented over 15 years.
Regional Ride-Sharing, Car-Sharing, and Commuting Strategies			
High-Occupancy Vehicle (HOV) lanes	Initiate HOV expansion in all urban regions by 2020, with implementation during a 10 year period.	Initiate HOV expansion in all urban regions by 2020, with implementation during an 8 year period.	Initiate HOV expansion in all urban regions by 2015, with implementation during a 4 year period.
Car-sharing	Programs in all regions by 2020.	One car per 2,000 inhabitants in 10 years.	One car per 1,000 inhabitants in 5 years.
Employer-based telework and compressed work week programs	Provide employer goals and tax incentives.	Require employer-based travel demand management (TDM) programs; 4-day work weeks for government agencies.	Require employer-based TDM; 4-day work weeks for government agencies.
Employer-based TDM requirements, outreach, and support	Provide on-line ride matching and vanpool services.	Reduce single-occupancy vehicle (SOV) trips by 10% (employers with 50+ employees).	Add taxes on all commercial parking spaces combined with Level A and B strategies.
Regulatory Strategies			
Urban nonmotorized zones	In 10 years, convert 2% of CBD streets.	In 10 years, convert 4% of CBD streets.	In 10 years, convert 6% of CBD streets.
Urban parking restrictions	Parking freeze on new parking spaces by 2025.	Parking freeze on new parking spaces by 2020.	Parking freeze on new parking spaces by 2015.
Speed limit reductions	National speed limit of 60 mph by 2020.	National speed limit of 55 mph by 2020.	National speed limit of 55 mph by 2015.

GHG Reduction Strategy	A. Expanded Current Practice	B. More Aggressive	C. Maximum Effort
Operational and Intelligent Transportation System (ITS) Strategies[a]			
Eco-driving training programs	Implement program. 10% of population reached, 5% net adoption by drivers.	Implement program. 20% of population reached, 8% net adoption by drivers.	Implement program, and fund public awareness campaigns and new driver education. 50% of population reached, 20% net adoption by drivers.
Ramp metering (centrally controlled)	Implement in large urban areas where V/C > 1.05 by 2030 with new and expanded Traffic Management Centers (TMCs).	Implement in large and medium urban areas where V/C > 1.0 by 2025 with new and expanded TMCs.	Implement in all locations where V/C > 0.90 by 2020 with new and expanded TMCs.
Variable message signs (VMS)	Implement where V/C > 1.05 by 2030.	Implement where V/C > 1.0 by 2025.	Implement where V/C > 0.9 by 2020.
Active traffic management	Not deployed.	Implement in large and medium urban areas where V/C > 1.0.	Implement in all locations where V/C > 0.9.
Integrated corridor management	Not deployed.	Implement in large and medium urban areas where V/C > 1.0 by 2025.	Implement in all locations with V/C > 0.9 by 2020.
Incident management	Implement where V/C > 1.05 by 2030 with new and expanded TMCs.	Implement where V/C > 1.0 by 2025 with new and expanded TMCs.	Implement where V/C > 0.9 by 2020 with new and expanded TMCs.
Road weather management (snow, ice, and fog)	Fully deployed on freeways by 2030.	Fully deployed on freeways by 2025.	Fully deployed on freeways by 2020.
Arterial management	Upgrade when V/C > 1.0 by 2030.	Upgrade when V/C > 1.0 by 2025.	Upgrade when V/C > 0.9 by 2020.
Traveler Information (511 and DOT website)	Implement where V/C > 1.05 by 2030.	Implement where V/C > 1.0 by 2025.	Implement where V/C > 0.9 by 2020.
Vehicle infrastructure integration (VII)[b]	50 percent of light-duty vehicles equipped by 2025, 100 percent by 2040.	50 percent of light-duty vehicles equipped by 2020, 100 percent by 2030.	50 percent of light-duty vehicles equipped by 2015, 100 percent by 2020.
Bottleneck Relief and Capacity Expansion Strategies			
Bottleneck relief	Improve 25 percent of top 200 bottlenecks to Level of Service E by 2030.	Improve 50 percent of top 200 bottlenecks to Level of Service E by 2030.	Improve 100 percent of top 200 bottlenecks to Level of Service D by 2020.
Capacity expansions	25 percent of the economically justified investments increased over current funding levels.	50 percent of the economically justified investments increased over current funding levels.	100 percent of the economically justified investments increased over current funding levels.
Multimodal Freight Strategies—Modal Diversion			
Rail capacity improvements	Capacity restrictions are reduced by 20 percent by 2025.	Capacity restrictions are reduced by 30 percent by 2025.	Capacity restrictions are reduced by 50 percent by 2025.
Marine transportation system maintenance and improvement	Maintain the current state of the system.	Restore major components of the system to a state of good repair.	Restore the entire system to a state of good repair.
Multimodal Freight Strategies—Mode Optimization			
Overweight load permits for trucks carrying shipping containers	In all states, allow indivisible load permits for trucks carrying shipping containers for distances up to 250 miles by 2025.	In all states, allow indivisible load permits for trucks carrying shipping containers for distances up to 250 miles by 2020.	In all states, allow indivisible load permits for trucks carrying shipping containers for distances up to 250 miles by 2015
Overweight load permits for longer combination vehicles (LCVs).	In all states, allow divisible load permits for LCVs up to 105,500 lbs by 2020.	In all states, allow divisible load permits for LCVs up to 129,000 lbs by 2020.	In all states, allow divisible load permits for LCVs up to 129,000 lbs by 2010 and up to 138,000 lbs for 8-axle B-trains by 2020.
Weigh-in-motion (WIM) screening at weigh stations	Implement by 2025 at all 24-hour truck weigh stations.	Implement by 2020 at all 24-hour truck weigh stations.	Implement by 2015 at all truck weigh stations.
Electronic credentialing to allow vehicles to bypass weigh stations and safety inspections	Expand to cover all 49 mainland states by 2025.	Expand to cover all 49 mainland states by 2020.	Expand to cover all 49 mainland states by 2015.
Truck stop electrification	Allow truck drivers to plug in to local power at 1,500 (out of 5,000) truck stops by 2025.	Allow truck drivers to plug in to local power at 3,000 truck stops by 2020.	Allow truck drivers to plug in to local power at all truck stops by 2015.
Battery-operated heating and cooling systems for sleeper cabs (APUs)	Require installation in all sleeper cabs by 2025.	Require installation in all sleeper cabs by 2020.	Require installation in all sleeper cabs by 2015.
Truck-only toll lane networks	Complete by 2025; new facilities should cover 10 percent of large urban area interstate VMT.	Complete by 2025; new facilities should cover 25 percent of large urban area interstate VMT.	Complete by 2025; new facilities should cover 40 percent of large urban area interstate VMT.
Multimodal Freight Strategies—Logistics			
Urban consolidation centers	Establish in large urban areas by 2025.	Establish in large urban areas by 2020.	Establish in large urban areas by 2015.

Note: Where not otherwise indicated, all measures are cumulative with lower levels of implementation.

[a]Notes on Operational and ITS Strategies: (1) Different congestion thresholds are used to get distinction in the scenarios; (2) Deployment of strategies except for VII is assumed to occur continuously throughout the analysis period; and (3) V/C = Volume to capacity ratio, a measure of roadway congestion that compares the traffic volumes to the roadway capacity. [b] VII deployment is based on the deployment curve in Volpe VII BCA Report (http://www.intel-lidriveusa.org/documents/vii-benefit-cost-analysis-(Draft).pdf). Projected Phase-In of VII Equipped Vehicles in the U.S. Fleet. The "More Aggressive" scenario uses these forecasts and they are adjusted for the "Expanded Current Practice" and "Maximum Effort" scenarios.

transit service and density (which are related factors) also influence how effective a strategy may be. For example, some strategies may make sense for earlier deployment in large urban areas that already have well-utilized transit systems, rather than in smaller areas without much transit service.

- **Time Frame.** When a strategy is implemented will affect how quickly reductions in GHG begin to accrue. Some strategies can be quickly and relatively easily implemented, while others will take more time to implement and to generate benefits. Four different strategy "start-up" years are analyzed in this study—2010, 2015, 2020, and 2025—to quantify the cumulative reduction of GHGs achieved by 2030 and by 2050.
- **Intensity.** Different assumptions can be made about how aggressively a strategy is implemented. For example, how much will be charged in new or higher tolls, fees, or taxes? What target levels of transit services must be achieved? This study has identified, for each strategy, varying levels of implementation intensity.

These three dimensions are combined in three different levels of deployment that assume increasingly aggressive geographic breadth, timing, and intensity of implementation. The three levels all represent practices that will go beyond—and sometimes well beyond—current transportation policy and investment practices:

A. **Expanded Current Practice: Expansion of Current Trends and State of Innovation.** This level of deployment assumes that the strategies are expanded and steadily implemented, consistent with existing practices for reducing GHG emissions, and focusing predominantly on major metropolitan areas.

B. **More Aggressive: Faster, Broader, Stronger Implementation**. Strategies are implemented sooner, more broadly, and more intensively. For example, pricing strategies would be implemented in a wide range of metropolitan areas, and requirements would be established for the penetration of PAYD in all 50 states.

C. **Maximum Effort: Comprehensive, Rapid, Intense Implementation.** At this level, substantial policy changes and significantly increased levels of investment—consistent with a singular commitment to reduction in GHGs—are assumed to implement strategies at very high levels of intensity nationwide.

Table 2.1 details the assumptions for each group of strategies assessed in this study, by the three different levels of deployment. Further detail is included in the Supplemental Technical Reports, available at www.movingcooler.info. As an example of this approach, Figure 2.2 illustrates the deployment differences for just one strategy (cordon pricing). As shown, depending on the deployment level, the geographic scope, timing, and intensity would vary.

It is important to note that three strategies in Table 2.1, PAYD, VMT fees, and gas tax/carbon price are considered in *Moving Cooler* as "economy-wide" strategies. These strategies are tested as overlays to the results of the bundle analysis approach, as described in Section 3.5.

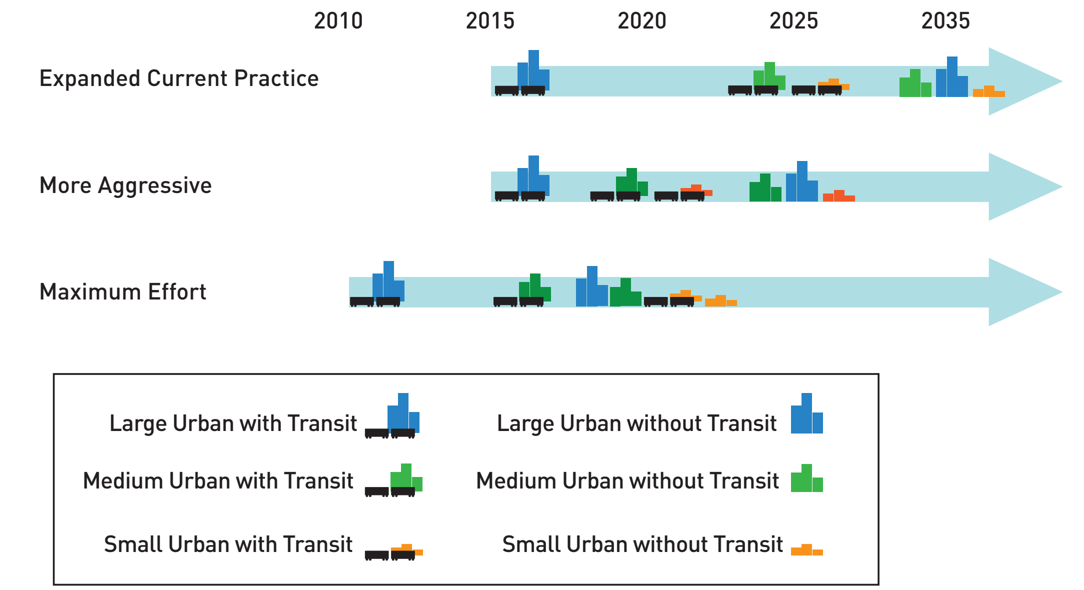
2.5 Strategy Bundles

Individually, each strategy can help achieve reductions in the amount of driving and fuel consumption and associated GHG emissions. These strategies are able to do this to varying degrees, at more or less cost, and during different time frames. But any GHG mitigation approach is likely to implement a collection of strategies at the same time—a "bundle" of strategies. The individual components of such a bundle of strategies are not all additive—many will be enhanced by the presence of supporting activities. Other components will show decreased individual effectiveness from overlapping reduction opportunities, but they will achieve greater reductions in total. Bundling strategies provides a way to think about how different strategies might be implemented together, and what the results would be.

Six illustrative bundles that represent different, potential combinations of strategies from multiple categories are examined in *Moving Cooler*. Each bundle is designed to bring together strategies that emphasize a common thrust or action plan—emphasizing common themes or comprehensive approaches for reducing transportation sector effects on GHG emissions. For example, there is a "Near-Term/Early Results" bundle that looks at the ability of ready-to-go strategies to reduce GHGs by 2015. Conversely, there are other bundles that include strategies that require more time to implement, but are expected to result in larger reductions in GHGs. It will simply take more time to achieve these reductions. Bundles also focus on sets of strategies with established interactions, specifically those related to land use, transit, and nonmotorized modes (bicycles and walking).

Several of the pricing strategies—carbon pricing, VMT fees, and PAYD—can be imposed nationally, in addition to any of the combinations of strate-

Figure 2.2 **Deployment Level Options—Varying Geographic Scope, Timing, and Intensity—for Cordon Pricing**



gies considered in these bundles. These function as "economy-wide" market strategies and would apply to all drivers. As discussed later in this report, depending on the prices set, pricing strategies can exert a strong effect on travel behavior. For this reason, each of the bundles is assessed with and without an economy-wide market strategy to isolate the impact of each bundle from the pricing effects.

The six strategy bundles used for the *Moving Cooler* analysis are as follows:

- **Near-Term/Early Results** focuses on strategies that can be implemented broadly in the short term (i.e., prior to 2015) and that will result in early GHG reduction benefits.
- **Long-Term/Maximum Results** focuses on maximizing efforts to reduce GHG emissions without regard to cost, scale, or time frame of implementation.
- **Land Use/Transit/Nonmotorized Transportation** emphasizes the interaction of urban area-focused strategies that increase density and encourage mode shifts to energy efficient modes, shorter average trip lengths, and increased walking and biking, thereby eliminating some vehicle trips.
- **System and Driver Efficiency** focuses on strategies that improve multimodal system efficiency by reducing vehicle speeds and improving driving efficiency, maximizing the use of existing capacity, expanding capacity across modes, and reducing congestion.
- **Facility Pricing** focuses on local and regional pricing and incentive strategies (e.g., tolls, congestion pricing, and parking fees) that induce changes in travel behavior by changing the cost of travel, coupled with transit service and highway capacity expansion.
- **Low Cost** focuses on achieving GHG emission reductions through the deployment of strategies that are more cost-effective.

While these bundles represent logical combinations of strategies, any number of other combinations could also be designed and tested. The purpose of the *Moving Cooler* study is to provide example analyses that demonstrate the potential reductions that can be achieved by combining multiple strategies. At the state and regional level, these analyses can provide insight into the priority strategies transportation planners might consider, based on their specific context and other program goals.

The combined effects of these illustrative bundles are presented in Section 4.0.

Notes

1 Compact development can also reduce building energy use and associated GHG emissions because of smaller building footprints, shared walls, etc., although these benefits are not analyzed in this report.

2 U.S. Department of Transportation (US DOT), Research and Innovative Technology Administration, "Initiative Overview," Intelligent Transportation Systems, http://www.its.dot.gov/intellidrive/intellidrive_overview.htm.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3.0 Methodology Summary

3.1 Overview

The purpose of this section is to explain the methodology used to estimate the reductions in GHG emissions that might occur with implementation of each of the almost 50 strategies and the six strategy bundles defined in Section 2.0. This section includes a description of the methods used to estimate the range of costs that could be incurred to implement these strategies. This section also identifies some of the other effects of the strategies and bundles, including the effects on vehicle ownership and operating costs, other less easily quantified costs and benefits, and equity considerations. Figure 3.1 depicts the research methodology used for the *Moving Cooler* analysis.

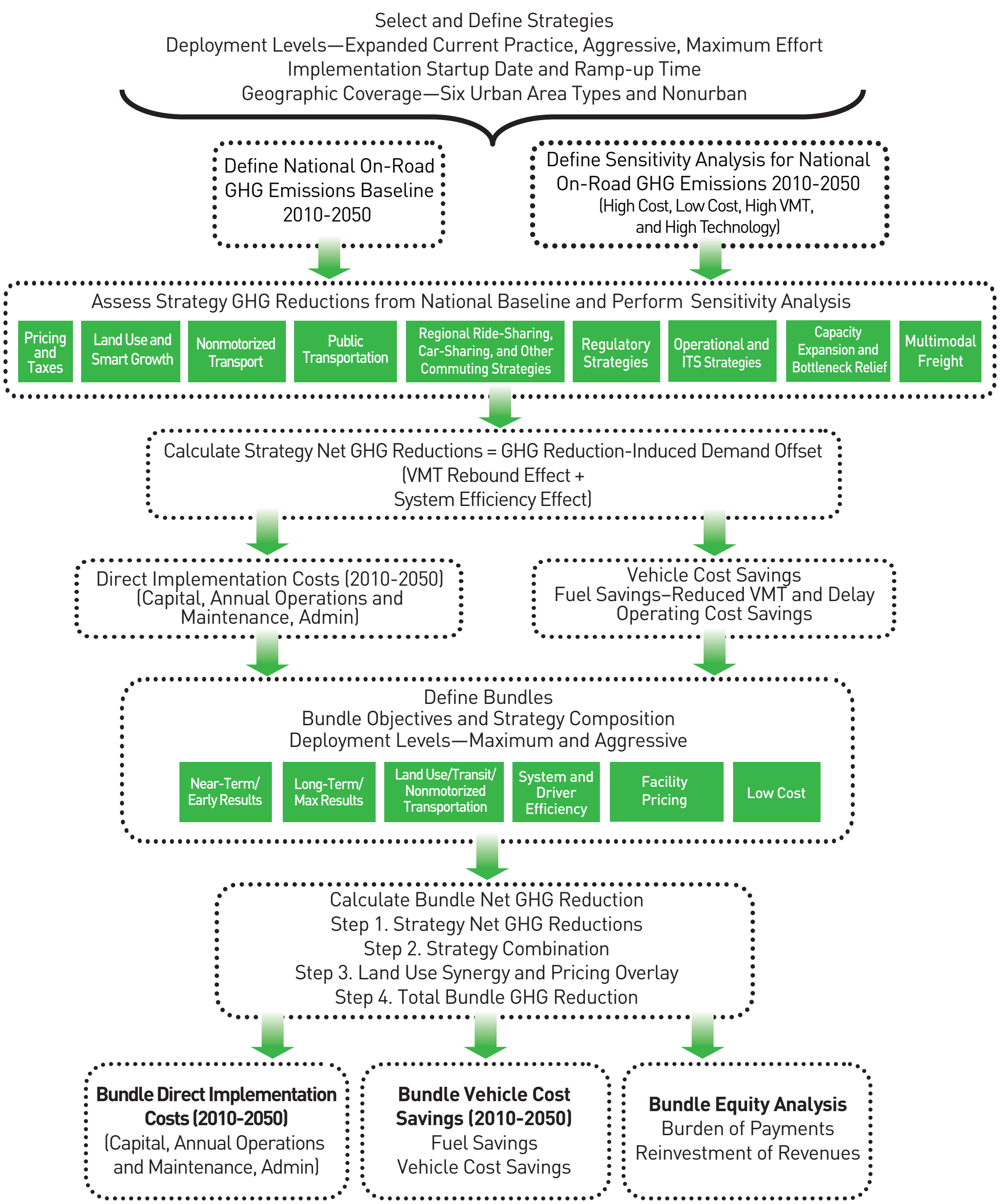
The fundamental relationship used to estimate potential GHG reduction from travel behavior and transportation system operation improvements was previously described in Section 1.2. In brief, the strategies analyzed in *Moving Cooler* affect GHG emissions by reducing VMT, fuel consumption rates, or sometimes both.

The change in VMT and fuel consumed per mile that is expected to result from the implementation of each *Moving Cooler* strategy was estimated first, and that change was then translated into a reduction in GHG emissions. Because vehicle and fuel technology assumptions will have a significant effect on the benefits that can be achieved from behavioral and operations strategies, the sensitivity of results to a range of vehicle and fuel technology scenarios was tested. However, *Moving Cooler* did not attempt to model the reduction benefits of different vehicle and fuel technologies, and assumed only a steady improvement in fleetwide fuel economy from the evolution of vehicle technology and fuels. A detailed examination of vehicle and fuel technology can be found in McKinsey & Company's *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*[1]

To implement this approach requires first the development of a baseline estimate of GHG emissions from transportation during the study period (2010–2050). The baseline developed for this study is described in Section 3.2.

In Section 3.3, the analytical tools used to estimate changes in VMT and fuel consumption and the translation of these changes into GHG reductions are described. While the basic equation for estimating GHG emissions from transportation is straightforward, the analysis becomes complex as variables are introduced. When this equation is applied to the almost 50 strategies and six strategy bundles during a time period that extends to the year 2050, and it is applied in a variety of geographic settings at different points in time and with various degrees of aggressiveness (i.e., levels of deployment), the analytical challenge is substantial. In fact, even within the context of a given strategy, estimation of the changes in VMT or fuel consumption rates may require the use of multiple analytical tools and databases. The methods used in *Moving Cooler* to estimate potential changes to VMT and fuel consumption necessarily use existing tools and data, but future research should focus on further enhancements to these methods.

Figure 3.1 **Methodology Flowchart**



Section 3.4 describes how estimates were reached for the costs of implementing the strategies, and the vehicle ownership and operating cost savings that could accrue with reductions in VMT and fuel consumption. Estimates of implementation costs are based on the definition of the strategies themselves and vary by the level of deployment. The estimates of potential vehicle ownership and operating cost savings were developed for two reasons. First, *Moving Cooler* is intended to be a companion piece, with comparable analyses, to the McKinsey & Company study cited above and *Growing Cooler*. This latter work included estimates of effects on vehicle ownership and operating costs

associated with land use and smart growth strategies that were aimed at reducing GHGs. Second, the effects on vehicle ownership and operating cost savings can be directly estimated from the other results generated by the study (i.e., changes in VMT and fuel consumption). These effects are important considerations and potential benefits from the strategies outlined in section 3.4.

The obvious caution in including these types of costs and savings in the analysis is that they are not the only costs and savings possible, nor necessarily the most significant of the economic and social consequences of these strategies. While only these costs and savings are estimated and reported in *Moving Cooler*, other benefits and costs of implementing these strategies are qualitatively described, with particular attention paid to the equity effects.

Finally, one of the most important considerations in examining these GHG reduction strategies is the distribution of the costs and benefits among different segments of the population, and how possible inequities can be addressed. Section 3.5 describes the types of equity considerations that are inherent with implementation of the travel behavior and system operations strategies, and how these equity considerations are assessed in this study.

Given the breadth and complexity of the work done for *Moving Cooler*, complete documentation of the methodology used is not provided in this report. Instead, an overview of the methodology is provided in this section, along with identification of the analytical tools and other resources that were used. Detailed documentation of the methodology is provided in a separately published set of technical appendices that are available at www.movingcooler.info.

3.2 Baseline GHG Emissions

The starting point for the *Moving Cooler* analysis of GHG reductions is referred to as the study "baseline." Estimates of the GHG reductions from individual strategies and from bundles of strategies are reflected as changes from the study baseline. The study baseline is represented by annual forecasts through 2050 of national on-road vehicle-miles traveled, gasoline equivalent average on-road fuel economy, and average on-road vehicle GHG emissions per mile. In the baseline forecast, long-term average growth rates are used, and it is recognized that the baseline does not include shorter-term fluctuations that occur due to fuel price changes and economic cycles. The baseline data points for the years 2010 and 2050 are shown in Table 3.1 and are based on the following primary assumptions.

- The study baseline assumptions for future travel are annual rates of 1.4 percent growth for highway vehicle-miles of travel and 2.4 percent growth for transit ridership, consistent with recent historical trends.[2]
- The study baseline fuel price is assumed to begin at $3.70 in 2009 and then to increase annually at 1.2 percent (in real dollars). This price and its growth rate is based on the Department

Table 3.1 ***Moving Cooler* Baseline VMT and Fuel Economy Summary**

Vehicle Type	Vehicle-Miles Traveled (trillions)	Average CO_2e per Vehicle-Mile[a]	Gasoline-equivalent Average On-Road Fuel Economy[b]
Cars and Light-Duty Trucks			
2010	2.830	0.46 kg/mile	20.3 mpg
2050	5.110	0.21 kg/mile	43.3 mpg
Medium and Heavy-Duty Trucks			
2010	0.236	1.75 kg/mile	6.0 mpg
2050	0.411	1.36 kg/mile	7.8 mpg

[a] Represents average amount of GHG emissions per vehicle-mile. CO_2e is a measure of GHG emissions expressed as carbon dioxide equivalent units.

[b] Represents average fuel economy for the full vehicle fleet (old and new vehicles), not for new vehicles entering the fleet in that model year.

Source: Cambridge Systematics, Inc. analysis, for *Moving Cooler* technical appendices, available at www.movingcooler.info, July 2009.

of Energy's (DOE) Annual Energy Outlook (AEO) 2008 high fuel price case.[3]

- The study baseline assumption for light-duty vehicle fuel economy[4] is an annual growth rate of 1.91 percent, somewhat higher than the DOE forecasts (and more consistent with the Obama Administration's proposed fuel economy standards). For medium- and heavy-duty trucks, an annual growth rate of 0.61 percent was used, consistent with DOE forecasts in the Annual Energy Outlook (AEO).

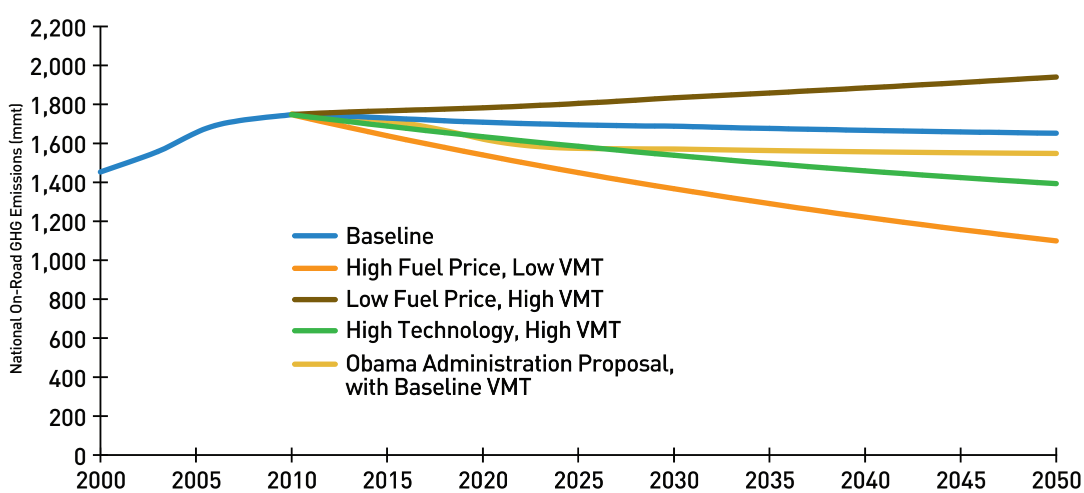
Because the results of the strategy analysis are tied to the values in the baseline, and in recognition of the degree of uncertainty associated with a forecast that extends more than 40 years, three alternative baseline scenarios were developed to investigate the sensitivity of strategy and strategy bundle GHG reduction estimates to differing baseline assumptions. Costs of fuel and of vehicle and fuel technology are the three primary drivers of future VMT and fuel economy and hence transportation GHG emissions, so the alternative scenarios for sensitivity analyses were defined as follows:

- **High fuel price, low VMT.** This alternative scenario assumes that fuel prices are higher than baseline, growing at a rate of 3.6 percent annually. These higher prices result in a lower VMT growth rate of 1 percent per year, in addition to markedly better fuel economy (improving by 2.8 percent per year).
- **Low fuel price, high VMT.** This alternative scenario assumes that fuel prices are lower than baseline, increasing at only 0.7 percent annually. Lower prices drive higher VMT growth, which increases at 1.6 percent per year, and markedly lower fuel economy, improving at a rate of 1.6 percent annually.
- **High-technology and fuel economy, high VMT.** This alternative scenario assumes that technology (including both fuel economy and noncarbon fuels) progresses rapidly, improving at a rate of 2.8 percent annually. The resulting reduction in the cost of driving results in higher VMT growth (1.6 percent per year) but with lower GHG emission effects due to technology improvements.

Figure 3.2 charts the baseline GHG emissions by year for the study baseline and for the three alternative baseline scenarios, plus the anticipated effect of the recent Obama Administration's proposal, applied to *Moving Cooler* baseline VMT growth. The baseline case shows a moderate decline in GHGs from 2009 to 2050 of 5 percent. The high technology and fuel economy, high VMT alternative scenario shows a greater decline of 20 percent, reflecting more rapid improvements in fuel economy than was assumed in the baseline. The high fuel price, low VMT alternative scenario shows the greatest reduction, at 37 percent. Only the low fuel price, high VMT alternative scenario shows an increase in GHG emissions, with an 11 percent increase over 2009 emissions.

Logically, the estimated effectiveness of different strategies will vary based on the assumptions used for the study baseline. Generally speaking, as fuel efficiency increases, the incremental effect of travel behavior strategies is somewhat reduced.

Figure 3.2 **National GHG Emissions Baseline and Baseline Sensitivity**



Conversely, under assumptions that fuel prices decline and VMT increases, the relative contribution of strategies designed to counteract those trends increases.

3.3 Analyses of the Individual Strategies

The individual strategies described in Section 2.0 were separately analyzed for their effectiveness in reducing VMT, in improving fuel efficiency through transportation system improvements, or for both. Reductions in VMT are achieved through changes in travel behavior, which includes a variety of mechanisms: reductions in the number of light-duty vehicle trips taken, reductions in the lengths of trips, or increases in the number of passengers or tons (for freight) transported per trip. These relationships were modeled and translated into a percentage change in total VMT for each year of the study period. For those strategies that result in transportation system efficiency improvements; that is, reductions in congestion and delay or changes in vehicle operations that affect fuel economy, these relationships were modeled and then translated into a percentage change in miles per gallon from baseline estimates.[5]

Methods and Sources

The *Moving Cooler* analysis relies almost exclusively on actual experience with the GHG reduction strategies studied, on research reports on these various strategies, on existing analytical tools, and on standard publications that supply the base data. Rather than extensive development of new analytical tools for each of these strategies, the innovation achieved in this study was to adapt existing and widely accepted analytical tools and other resources to tackle the specific challenge of estimating the GHG emissions in a consistent manner. This comparative analysis has not been done before for this broad range of strategies.

Wherever possible, existing and well-accepted transportation planning tools and methods were used to estimate the magnitude of transportation-generated GHG reductions. In some cases, however, documented case studies and research findings were used to make reasonable assumptions about likely GHG reduction effects. Among the tools and methods used are the following:

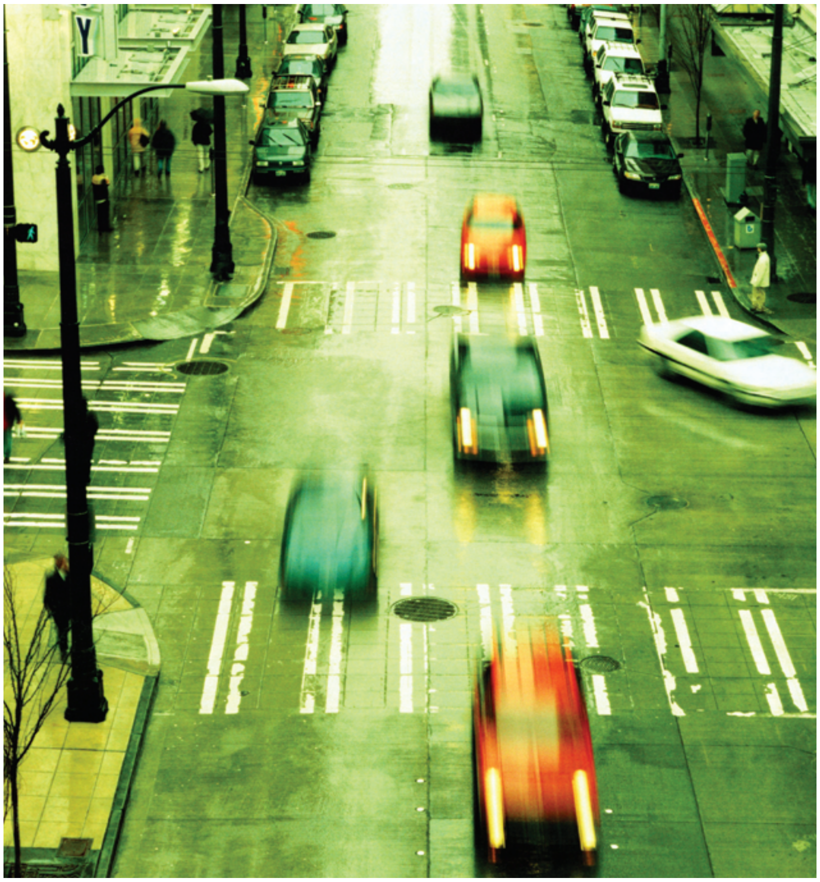
- Models: Federal Highway Administration's (FHWA) HERS Model, including its Operations Preprocessor[6]; FHWA's ITS Deployment Analysis System (IDAS) Model[7]; the University of South Florida Center for Urban Transportation Research (CUTR) VMT Model[8]; the U.S. EPA's COMMUTER Model[9]; U.S. EPA's Smart Growth INDEX Model[10]; and information from Federal Transit Administration's (FTA) Transit Economic Requirements Model (TERM)[11].
- Elasticities and Effectiveness Factors: Victoria Transportation Policy Institute's (VTPI) Transportation Elasticities[12]; FHWA Condition and Performance Report price elasticities; elasticities documented in *Travel and the Built Environment* (Ewing and Cervero)[13] and in *Bicycle Commuting and Facilities in Major U.S. Cities* (Dill and Carr)[14].
- Documentation of Experience and Research: Wagner University's *Dynamics of Onstreet Parking*[15]; *Growing Cooler*'s land use analysis; *The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction* transit and land use analysis (Transit Cooperative Research Program Project J-11); Massachusetts DOT I-93 HOV Lane Studies; Los Angeles and San Francisco Bay Area HOV lane evaluations; New York City DOT telecommuting evaluation; Phoenix trip ordinance evaluation; ITS Deployment Tracking data; Oregon DOT's *Greenlight Emissions Testing Project*; Georgia DOT's *Truck Only Lane Study*.
- Data Sources: FHWA's Highway Performance Monitoring System; FHWA's *Highway Statistics;* American Public Transportation Association's (APTA) *Transit Data Book,* FTA's *National Transit Database;* DOE's *Annual Energy Outlook.*

Limitations were encountered, of course, with the existing models, research, and data. In these cases, new methods and reasonable assumptions about the relationships between specific strategies and changes in VMT or fuel economy were developed, combining professional judgment with available data.

A detailed bibliography for the models, documentation, and data sources cited above is provided in the technical appendices, found at www.movingcooler.info.

Deployment Sequences for Each Strategy

In addition to the method used to estimate how a strategy might affect VMT or fuel economy, the analysis needed to determine the context in which the strategy would be implemented. Some strategies are assumed to be implemented in only some urban areas; others are assumed to be implemented in all urban areas or in urban and



nonurban areas, but with differing impacts in these different settings. To capture these differences in geographic application and effect, the country was divided into six different types of urban areas, distinguished by population and transit use, and one type of rural area.

This geographic division provides a way to model different levels of deployment for each strategy. For instance, a strategy might be initially implemented in large metropolitan areas (population greater than 1 million) starting in 2010. Beginning in 2015, as implementation ramps up further, it could be introduced to medium-sized metropolitan areas (population between 400,000 and 1 million). In 2020, it would be further introduced to small metropolitan areas (population between 50,000 and 400,000). Thus, during the 10-year period, the strategy would be implemented through a steadily greater share of national population and travel.

Induced Demand

For some strategies, an additional adjustment was made to account for induced demand. Induced demand in transportation refers to the increase in travel that occurs when the level of service on a roadway (or other facility) improves. Travelers respond to the faster travel times and decreased costs of travel by traveling more, resulting in increased VMT. For example, for highway system improvements that reduce congestion and delay, the net change to fuel consumption and GHG includes two countervailing estimates. First, the fuel-efficiency benefits of the reduced congestion are estimated; and second, the induced VMT and its corresponding increase in fuel consumption are estimated. The two estimates are then combined to produce an estimate of the net change in fuel consumption and in GHG. This adjustment is made to all strategies related to greater operational efficiency enabled by such strategies as congestion relief and new capacity.

This induced demand (or rebound effect) was included for all VMT-related strategies (including transit), except for the pricing strategies. VMT-reducing pricing strategies do not yield induced demand effects because the calculated reduction is "net" of any such effects; specifically, the value of the improved level of service equilibrates with the increased cost per mile of driving introduced by the pricing strategy. A more detailed discussion of the induced demand methodology is included in the technical appendices, found at www.movingcooler.info.

3.4 Approach to Assessing Costs

Two types of costs were estimated for each strategy as part of this study. One is the cost of implementing each of the strategies; the other is the cost of fuel and vehicle operations.

Implementation Costs

The cost to implement each strategy is a function of the actions that are taken, the extent of those actions, and the geographic location and timing of those actions. Implementation costs include the costs of construction, operation and maintenance, and management and administration. Using unit costs from previous experience with the various strategies, the cost for each strategy was developed based on the definition of the strategy and the scale or level of deployment. Taxes, tolls, subsidies, and other fees or incentives do not change the total societal cost of a given GHG reduction strategy, but rather affect (sometimes significantly) the costs to individual actors—effectively, they are transfers from one actor to another. Therefore, these costs are not included in the cost estimates, but are emphasized in the analysis of the equity implications of implementing the strategies. All of the included implementation costs were discounted to state them in net present value terms. GHG emission reductions are not discounted, which is consistent with the standard approach for calculating the reduction in GHG emissions per dollar of strategy implementation cost.

Vehicle Costs

The cost of vehicle ownership and operation will decline with implementation of the GHG reduction strategies, as a result of reductions in the amount of travel that occurs and in the rate of fuel consumption during travel. This analysis takes into account only those vehicle cost savings attributable to the implementation of the strategies, and not from vehicle and fuel technological advances. Calculation of these costs are based on the outputs of the analysis of effects on GHG emissions, which are estimates of changes in VMT and fuel consumption by year, during the life of each strategy. Vehicle ownership and operating costs used by the Internal Revenue Service and the cost per gallon of fuel included in the study baseline forecast were used to convert reductions in VMT and fuel consumption to vehicle ownership, fuel, and other operating cost savings. These costs were estimated for each year of strategy implementation and were then discounted to derive a net present value estimate of vehicle fuel and operating cost savings.

Other Costs and Benefits

The separation of implementation costs and vehicle cost savings is done in recognition of the fact that other costs and benefits will be generated by the implementation of each strategy. For example, the scope of *Moving Cooler* did not encompass quantification of commonly monetized costs and benefits, such as the value of changes in travel time, safety (fatalities, injuries, and property damage), and environmental quality. Other externalities include public health, mobility, the economic implications of trips not taken, energy security, and economic vitality. Because these and other potential benefits and costs are very important to a final analysis of the strategies, they are noted in the Section 4.0 findings, but were not quantified.

3.5 Analysis of Strategy Bundles

In addition to defining and evaluating the individual strategies, six strategy bundles also were developed and evaluated. The purpose of defining these strategy bundles is to illustrate the fact that, in all likelihood, a combination of strategies, rather than a single strategy, will be implemented to effect a reduction in GHG emissions. The bundles therefore represent the magnitude of GHG emission reductions that might be achieved when the strategies are used in combination.

Bundle Interactive Effects and Synergies

The assembly and analysis of the strategies as bundles were done in a way to capture the interactive effects of combining strategies. The strategy bundles were defined by including mutually reinforcing, rather than counteracting, strategies in a single bundle, except where equity issues arising from a measure could be addressed by including it and other measures in a bundle. For example, pricing measures will have potential equity impacts on low-income groups, but transit, carpool, highway, and operations improvements funded with revenues from pricing can compensate those groups for the higher monetary costs of travel due to pricing.

The cumulative effect of each bundle on GHG emissions was not done by simply adding the GHG reductions that might be achieved with the implementation of each individual strategy. For many combinations of strategies, an additive approach would result in double-counting of the emissions reduction opportunities. To avoid this, the effects of individual strategies are combined using a multiplicative approach. For example, imagine that implementing strategy A results in a 10 percent reduction in VMT from the study baseline. Implementing strategy B on its own also would result in a 10 percent reduction. However, if strategy B is implemented in addition to strategy A, it will reduce 10 percent of the 90 percent of VMT remaining—or 9 percent. That is, the combined effect will be a $0.90 \times 0.90 = 0.81$, or a 19 percent combined reduction, rather than the 20 percent that would occur if the reductions were simply added. (The order of the multiplication of strategies does not affect the results.) This adjustment is particularly important in those bundles that include a large number of individual strategies.

An effort was also made to capture the synergies among strategies within a given bundle that could result in GHG reductions greater than the sum of the GHG reductions of the individual strategies. The focus of this analysis of synergies was on the interactions of land use with alternative transportation modes, such as nonmotorized travel, car sharing, and urban public transportation. These interactions have been widely analyzed and documented by other research efforts.

Economy-Wide Pricing and Fuel Efficiency Impacts

Economy-wide pricing mechanisms could be added to any of the combinations of strategies considered in these bundles. In order to separately evaluate the effect of economy-wide market strategies, each of the bundles is assessed with and without economy-wide pricing.

Three economy-wide strategies were assessed: carbon pricing, VMT fees, and PAYD. Each of these strategies, if implemented, will reduce VMT by raising the cost of each mile driven. However, carbon pricing will also affect the fuel efficiency of the vehicle fleet, by sending market incentives that encourage the purchase of more fuel efficient vehicles (which will have lower operating costs). Although technological change in vehicle fuel efficiency or evolution of fuels is not the focus of *Moving Cooler*, ignoring this effect would present an incomplete picture of the GHG reduction potential of carbon pricing. Therefore, for carbon pricing, both VMT and fleet fuel efficiency effects have been identified and estimated. (It should be noted that these fuel efficiency changes would also occur if equivalent levels of motor fuel taxes were applied instead of carbon pricing.)

The methodology used to estimate the effects of nationwide carbon pricing on future fuel efficiency is based on the experience of the U.S. light-duty fleet compared to the European light-duty fleet. *Moving Cooler* estimated the highest levels of nationwide carbon pricing on the basis of the current European motor fuel taxes. To evaluate this pricing, it was assumed that those levels would be gradually phased in as the basic structure of the highest level of nationwide carbon pricing. It was further assumed that the percentage changes in the future U.S. fleet miles per gallon will be proportionate to the comparison of U.S. versus European fuel prices and fleet fuel efficiencies.

3.6 Equity

Equity is an important concern in the evaluation of all strategies and bundles of strategies. Equity is a common factor in decisions about all transportation plans and programs, whether national, state, regional, local, or for specific modes. Equity considerations and outcomes will vary depending on the specific application of a strategy, since any policy or program could be applied equitably or inequitably across geographic areas or across stakeholder groups.

The *Moving Cooler* analysis identified the equity issues that need to be considered if any of the strategies are pursued further. A thorough literature review was conducted of the state-of-the-practice of equity effects, with respect to transportation system changes, focusing in particular on pricing, because it was clear that the pricing measures raise the most serious equity concerns. A summary of the equity effects of each of the strategy bundles and of pricing strategies in particular is provided in Section 4.0. A more detailed explication of the equity considerations is provided in the technical appendices, found at www.movingcooler.info.

Notes

1 McKinsey & Company, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* U.S. Greenhouse Gas Abatement Mapping Initiative, Executive Report. (Washington, DC: McKinsey & Company, 2007).

2 The long term VMT annual growth rate forecast of 1.4 percent is supported in the literature by: AASHTO's 2009 Bottom Line report; Steve Polzin's VMT forecasting spreadsheet model of CUTR; and the 2008 *Annual Energy Outlook* of the U.S. DOE Energy Information Administration, in its high fuel price case. *Moving Cooler* also assumed that freight traffic grows at the same rate of 1.4 percent per year according to data from FHWA's Highway Statistics publication. The public transportation base case growth in ridership of 2.4 percent is the growth rate between 1995 and 2007. See Appendix B, Section 1 at www.movingcooler.info.

3 As with all of the baseline forecasts, short-term market volatility in fuel prices is assumed to continue, but this volatility is not assumed to impact the long-term trends. Although the base fuel price would be considered high at the time of publication of this report, it is consistent with 2008 fuel prices.

4 Used for convenience to express GHG emissions per mile. This assumption includes the effects of both vehicle technology improvement and an increase in the use of fuels with lower carbon contents.

5 A change in operating fuel consumption rates is separate and distinct from a change in vehicle technology. For example, truck stop electrification does not reduce the miles driven to transport goods, but reduces the gallons of fuel required to move those goods because fuel is not consumed by a truck idling at a rest stop. However, a change in vehicle technology and engine improvements would reduce fuel consumption, regardless of how the vehicle was operated.

6 Federal Highway Administration's FHWA HERS Model, available at http://www.camsys.com/tp_planpro_hers.htm or http://www.fhwa.dot.gov/infrastructure/asstmgmt/.

7 Federal Highway Administration's FHWA IDAS Model, available at http://www.fhwa.dot.gov/crt/lifecycle/idas.cfm.

8 Polzin, Steven E. "A Critical Juncture in U.S. Travel Behavior Trends" (Tampa, FL: The Case for Moderate Growth in Vehicle Miles of Travel: Center for Urban Transportation Research, University of South Florida, April 2006).

9 U.S. Environmental Protection Agency's COMMUTER Model, available at http://www.epa.gov/oms/stateresources/policy/pag_transp.htm.

10 U.S. Environmental Protection Agency's Smart Growth Index, available at http://www.epa.gov/dced/topics/sg_index.htm.

11 FTA TERM Model, http://wwwcf.fhwa.dot.gov/policy/2006cpr/appc.htm.

12 Victoria Transportation Policy Institute's (VTPI) Transportation Elasticities, Todd Litman, "Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior," Victoria Transport Policy Institute, November, 2008. (http://www.vtpi.org/elasticities.pdf).

13 Ewing, Reid, and Robert Cervero. "Travel and the Built Environment," *Transportation Research Record, 1780*: 87-114. 2001.

14 Dill, Jennifer, and Theresa Carr, *Bicycle Commuting and Facilities in Major U.S. Cities*, (Washington, DC: Transportation Research Board 82nd Annual Meeting, January 12–16, 2003).

15 de Cerreño, A.L. "The Dynamics of On-Street Parking in Large Central Cities" (New York: Rudin Center for Transportation Policy and Management, New York University Robert F. Wagner Graduate School of Public Service, December 2002).

4.0 Findings—What Is the Potential of *Moving Cooler* Strategies to Reduce GHGs?

ALMOST ALL OF THE STRATEGIES assessed can make some contribution to reducing GHG from transportation by achieving reductions in the amount of driving and by reducing fuel consumption. However, the strategies vary considerably in terms of the amount of reductions achieved, the cost of these reductions, and the time frame in which they achieve results. Section 4.1 summarizes how well each strategy is expected to do individually in helping attain GHG reductions by 2050, and the implementation cost and vehicle cost savings of these strategies.

The strategies have a greater impact on GHGs when implemented in combinations, or bundles. In fact, to achieve significant reductions, a range of GHG reduction strategies would need to be implemented. As described in Sections 4.2 and 4.3, six combinations of strategies (bundles) have been examined to illustrate how individual strategies might work in concert to achieve both GHG reduction goals, as well as other societal goals. Sections 4.4 through 4.9 provide an overview of each bundle, including an assessment of GHG benefits related to direct costs and cost savings, and the co-benefits and equity implications of each bundle. Section 4.10 compares the strengths and weaknesses of the six illustrative bundles.

The remaining sections look at the sensitivity of bundle results to different assumptions regarding fuel price and VMT growth (Section 4.11) and the additional impact of adding economy-wide pricing measures to the bundles (Section 4.12). Section 4.13 discusses the issues related to the equity of the strategies, particularly the potential effects on low-income populations.

Throughout this chapter, the reduction potential of each individual strategy and combined strategy bundle is presented in terms of million metric tonnes (mmt) or gigatonnes (Gt) and percentage reductions as compared to the study baseline (previously defined in Section 3.2). Results are provided both for annual "snapshot" years as well as for the cumulative reduction achieved over time.

4.1 What Is the Potential of Individual Strategies to Reduce Greenhouse Gases?

As noted in Section 3.0, analysis of the potential for transportation strategies to reduce GHG emissions starts by analyzing the individual strategies. A summary of the results of this analysis, along with estimates of the implementation costs and vehicle cost savings associated with each strategy, is shown in Table 4.1. These results reveal that the behavioral and operational strategies studied for *Moving Cooler* differ significantly both in their ability to reduce GHG emissions and in their implementation costs, vehicle-related cost savings, and other social and economic implications. Most of the strategies result in a reduction in vehicle fuel usage, GHG emissions,

How much is a tonne?

We are not used to thinking in terms of tonnes of carbon dioxide equivalents, let alone million metric tonnes (mmt). Just what does it mean when we say a strategy can reduce emissions by 1 mmt, or 100 mmt, or 1,000 mmt?

Let's start with a few round numbers for comparison. The U.S. transportation sector emits almost 2,000 mmt of CO_2e annually. So, 1 mmt of CO_2e is equivalent to 0.05 percent of the annual transportation emissions; 1 Gt, or 1,000 mmt is about one-half the annual emissions.

What does that mean in terms of energy consumption? Eliminating one mmt of CO_2e is equivalent to reducing gasoline consumption by more than 100 million gallons of gasoline, or taking 200,000 light-duty vehicles off the roads for one year. One mmt of CO_2e is also equivalent to about 2.4 million barrels of oil, or about as much oil as the U.S. consumes in three hours.

and the costs of owning and operating vehicles. These reductions are achieved because implementation of the strategies lower VMT, increase fuel economy, or both. For many of the strategies, the direct vehicle cost savings are greater than the costs of implementation, although vehicle cost savings will not accrue equally among interest groups, and are not the only costs or benefits that will need to be considered when developing action plans. Analysis of the equity implications and the types of other costs and benefits of implementing the strategies are discussed in the context of the findings on bundles in Sections 4.4 through 4.9.

Note that these results for individual strategies cannot simply be added together to estimate the effects of combining strategies; the interactive impacts of bundling strategies are discussed in the next section.

As shown in Table 4.1, economy-wide pricing strategies—especially gas or carbon pricing—have the potential to do more than any other individual strategy to reduce GHG emissions; depending, of course, on the magnitude of the increase in the cost of travel. It is also notable that these strategies offer substantial savings in vehicle costs in excess of their implementation costs. The non-pricing strategy with the highest cumulative effect on GHGs is the reduction and increased enforcement of speed limits. How widely each strategy can be applied has a significant effect on the magnitude of GHG reductions. For example, pricing and speed limits can apply to all drivers; therefore, the strategies have broad effects. In contrast, freight strategies apply to a smaller universe of VMT, and therefore have a more limited effect on all transportation GHG emissions. Only one strategy, bottleneck relief and capacity expansion, is projected to result in an increase in GHG emissions by 2050, due to the new demand induced over time by the improved roadways.

Highlights of the analysis of individual strategies include:

- **Pricing strategies**, in particular the economy-wide pricing implemented through **PAYD**, a **VMT fee**, and **gas or carbon pricing** have the largest potential to reduce GHGs. This potential is dependent on the level of prices that are set, which are substantial for this analysis. Among these options, pricing carbon fuel has by far the largest effect because it not only prompts reductions in travel, but also spurs significant improvements to fuel economy as the use of more fuel-efficient vehicles occurs.

  Pricing can also be implemented at a local and regional level to influence different types of travel behavior at specific locations or at particular times of day. Of the regional measures evaluated, **congestion pricing** results in the largest impact on reducing GHG emissions, mainly because more than one third of U.S. highway travel now occurs on the congested major roads where this strategy applies. As compared to baseline levels, cumulative reductions in GHG emissions for congestion pricing range from 0.8 percent to 1.8 percent, varying as a function of the level of deployment. Of course, in the context of the regions in which congestion pricing is implemented (versus this study's national perspective), the relative impact on GHGs will be greater.
- An integrated set of **land use strategies** achieves cumulative GHG reductions, ranging from 0.2 percent to 2.1 percent improvement from the baseline. Because these strategies take many years to implement and will involve the participation and acceptance of many parties to achieve, the benefits accrue slowly in the short term, before beginning to escalate significantly in the later years. The effects of land use changes can be expected to endure many years beyond

Table 4.1 *Moving Cooler* Cumulative GHG Reduction, Implementation Costs, and Change in Vehicle Costs by Strategy (at Expanded Current Practice, Aggressive, and Maximum Deployment Levels) by 2050

	Expanded Current Practice Deployment (2010 to 2050)			Aggressive Deployment (2010 to 2050)			Maximum Deployment (2010 to 2050)		
Strategy Description	**GHG Reduction (mmt)[a]**	**Implementation Cost Estimate[b] ($B 2008)**	**Change in Vehicle Cost Estimate[c] ($B 2008)**	**GHG Reduction (mmt)[a]**	**Implementation Cost Estimate[b] ($B 2008)**	**Change in Vehicle Cost Estimate[c] ($B 2008)**	**GHG Reduction (mmt)[a]**	**Implementation Cost Estimate[b] ($B 2008)**	**Change in Vehicle Cost Estimate[c] ($B 2008)**
Pricing Strategies									
CBD/Activity Center on-street parking	33	< $0.05	$(26.8)	41	< $0.05	$(36.2)	42	< $0.05	$(37.8)
Tax/higher tax on free private parking	N/A	N/A	N/A	18	< $0.05	$(14.7)	31	< $0.05	$(26.8)
Residential parking permits	N/A	N/A	N/A	20	< $0.05	$(15.9)	48	< $0.05	$(40.4)
Cordon Pricing	66	$24.2	$(66.0)	76	$36.1	$(76.3)	92	$39.3	$(97.9)
Congestion Pricing	510	$233.9	$(522.8)	1,021	$349.0	$(792.9)	1,241	$380.3	$(1,033.8)
Intercity Tolls	31	$33.6	$(27.4)	54	$44.7	$(52.1)	105	$58.5	$(107.8)
PAYD	789	$166.0	$(831.2)	1,677	$166.0	$(1,678.0)	2,233	$166.0	$(2,225.8)
VMT fee[d]	280	$166.0	$(252.5)	840	$166.0	$(757.6)	3,361	$166.0	$(3,030.4)
Carbon Pricing (VMT impact)	350	< $0.05	$(316.1)	1,067	< $0.05	$(962.8)	4,744	< $0.05	$(4,246.2)
Carbon Pricing (Fuel economy impact)	1,181	< $0.05	$(236.7)	3,343	< $0.05	$(671.7)	10,442	< $0.05	$(2,121.1)
Land Use and Smart Growth Strategies									
Combined Land Use	160	$1.5	$(118.0)	865	$1.5	$(655.5)	1,445	$1.5	$(1,098.5)
Nonmotorized Transportation Strategies									
Combined Pedestrian	74	$15.2	$(64.4)	171	$30.4	$(148.4)	227	$42.2	$(197.2)
Combined Bicycle	59	$4.6	$(47.6)	117	$20.6	$(95.2)	176	$37.7	$(142.9)
Public Transportation Strategies									
Transit Fare Measures	19	< $0.05	$(17.8)	34	< $0.05	$(31.3)	78	< $0.05	$(72.2)
Transit Frequency/LOS/Extent	45	$52.5	$(47.0)	72	$102.6	$(99.3)	168	$243.8	$(265.5)
Urban Transit Expansion	144	$255.0	$(135.5)	281	$503.0	$(281.7)	575	$1,197.3	$(611.6)
Intercity Passenger Rail	46	$19.3	$(46.5)	47	$35.6	$(49.6)	50	$76.1	$(58.0)
High-Speed Passenger Rail[e]	73	$99.6	$(24.7)	97	$108.2	$(29.5)	143	$144.2	$(40.2)
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	48	$171.8	$(10.2)	64	$231.9	$(13.4)	141	$569.1	$(31.0)
HOV Lanes (24-hour applicability)	1	< $0.05	$(0.2)	1	< $0.05	$(0.3)	2	< $0.05	$(0.4)
Car-Sharing	37	$0.2	$(31.9)	77	$0.3	$(67.5)	163	$0.3	$(147.6)
Employer-Based Commute Strategies	252	$106.0	$(217.4)	486	$120.8	$(419.9)	1,165	$135.6	$(1,013.4)
Regulatory Measures									
Nonmotorized Zones	2	$1.4	$(1.3)	4	$4.2	$(3.2)	6	$8.5	$(4.9)
Urban Parking Restrictions	80	< $0.05	$(55.5)	189	< $0.05	$(135.6)	359	< $0.05	$(276.1)
Speed Limit Reductions	1,236	$4.1	$(389.8)	2,320	$6.5	$(753.6)	2,428	$7.5	$(805.1)
System Operations and Management Strategies									
Eco-Driving	727	< $0.05	$(134.9)	1,170	< $0.05	$(221.8)	1,815	< $0.05	$(366.9)
Ramp Metering	27	$1.3	$(4.5)	78	$3.1	$(12.3)	83	$7.5	$(13.2)
Variable Message Signs	2	$0.8	$(0.3)	2	$2.0	$(0.4)	3	$4.8	$(0.4)
Active Traffic Management	N/A	N/A	N/A	46	$10.8	$(7.7)	80	$25.9	$(13.0)
Integrated Corridor Management	N/A	N/A	N/A	46	$10.8	$(7.7)	80	$26.0	$(13.0)
Incident Management	58	$2.2	$(9.4)	72	$5.4	$(11.8)	80	$12.9	$(13.2)
Road Weather Management	1	$2.0	$(0.1)	1	$4.9	$(0.2)	2	$11.8	$(0.4)
Signal Control Management	3	$2.5	$(0.5)	18	$6.1	$(3.0)	37	$16.9	$(6.1)
Traveler Information	4	$2.0	$(0.7)	30	$4.9	$(4.8)	31	$11.8	$(5.0)
Vehicle Infrastructure Integration	65	$42.6	$(9.9)	16	$42.6	$(2.2)	8	$42.6	$(1.0)
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief[f]	(3)	$29.0	$124.7	(5)	$71.4	$218.7	(11)	$142.7	$481.1
Capacity Expansion[f]	(4)	$333.2	$175.3	(7)	$617.0	$324.6	(15)	$1,234.0	$650.5
Multimodal Freight Strategies									
Rail Capacity Improvements	44	$19.9	$(18.5)	66	$32.6	$(27.7)	131	$48.5	$(55.5)
Marine System Improvements	5	$4.0	$(1.0)	8	$8.0	$(1.4)	12	$17.7	$(2.1)
Shipping Container Permits	8	< $0.05	$(1.6)	8	< $0.05	$(1.7)	9	< $0.05	$(1.9)
LCV Permits	8	< $0.05	$(9.6)	12	< $0.05	$(15.8)	15	< $0.05	$(17.2)
WIM Screening	1	< $0.05	$(0.1)	1	< $0.05	$(0.1)	1	$0.1	$(0.1)
Weigh Station Bypass	1	< $0.05	$(0.2)	1	< $0.05	$(0.2)	2	$0.1	$(0.2)
Truck Stop Electrification	11	$0.6	$(2.9)	25	$1.3	$(6.2)	46	$2.2	$(10.5)
Truck APUs	133	$0.3	$(28.8)	148	$0.3	$(32.6)	162	$0.4	$(36.5)
Truck-Only Toll Lanes	24	$17.1	$(4.6)	59	$42.7	$(11.5)	107	$71.6	$(20.7)
Urban Consolidation Centers	6	$0.4	$(1.6)	8	$0.4	$(2.3)	9	$0.4	$(3.1)

Note: This table summarizes how well each strategy is expected to help reduce GHGs by 2050, as well as the direct implementation costs and vehicle costs and savings of implementing these strategies. It is important to note that the results shown in this table for the individual strategies cannot simply be added together to estimate the impacts of combining strategies; the synergistic impacts of bundling the strategies are discussed in Section 4.2. LOS = level of service.

[a] mmt = million metric tonnes greenhouse gases.

[b] Implementation cost is the estimated cumulative cost to implement each strategy, including capital, maintenance, operations, and administrative costs.

[c] Vehicle cost is the estimated cumulative reduction in the cost of owning and operating vehicles from a societal perspective, which would result with reductions in VMT and fuel consumption experienced with implementation of each bundle. Vehicle costs **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

[d] An equivalent national VMT fee could accomplish the same VMT reductions, but not the fuel efficiency reductions of carbon pricing. The deployment costs of VMT based fees could be shared with required vehicle technology or odometer audits for PAYD if both of these strategies were implemented using consistent approaches.

[e] The evaluation of high-speed rail only takes into account the GHG emissions reduction associated with effects on surface transportation (and does not include air travel effects).

[f] GHG emission reductions use the FHWA methodology, as used for the Conditions and Performance (C&P) reports, to project the effect of capacity expansion on future VMT. This methodology addresses induced demand and diverted travel and also assumes that increased user fees will pay for capacity expansions. If the C&P methodology were to be applied absent the user fee assumption, the estimated GHG produced by these strategies would increase to between 440-560 mmt (which is less than 1 percent of the *Moving Cooler* baseline). This result underscores the importance of pricing strategies.

2050. At maximum deployment, the annual GHG reduction from the baseline because of integrated land use strategies is 4.4 percent in the year 2050. Outside of the economy-wide pricing measures, this reduction is the largest one in 2050 of any strategy. At aggressive deployment, the annual reduction in 2050 is also comparitively high, at 2.7 percent. Implementation of this strategy has one of the highest ratios of vehicle cost savings to implementation costs.

- Combined **pedestrian and bicycle infrastructure and policies** applied nationally would result in a cumulative 0.2 percent to 0.5 percent reduction in baseline emissions, but can be achieved at a relatively low implementation cost, and with positive public health benefits.
- **Transit capital investments**, such as urban transit expansion and intercity and high-speed rail, could produce cumulative GHG reductions ranging up to 1.1 percent of baseline emissions. This expansion of service requires investment over and above current investment trends. Less capital-intensive service expansion (e.g., increased frequency and level of service) would achieve more modest GHG reductions, at a relatively lower cost of implementation. Transit investments may be particularly critical if significant pricing strategies are in place, to provide travelers a viable, lower cost alternative to driving.
- **Car-sharing and employer-based commute strategies** (e.g., vanpool, carpools, employee parking pricing, and telecommuting policies) can contribute to emission savings. In particular, **employer-based commute strategies** could achieve cumulative reductions up to 1.7 percent of the baseline, depending on the level of implementation.
- Lower and strictly enforced **speed limits** have the potential to generate cumulative reductions in GHGs through fuel economy benefits that would range from 2.0 percent to 3.6 percent lower than cumulative baseline emissions. It is also one of the strategies that can be implemented and have positive GHG impacts in the short run. For example, at maximum deployment, the GHG reduction from the baseline because of speed limit reductions is 3.0 percent in the year 2020. Outside of the economy-wide pricing measures, this amount is the largest annual reduction in 2020 of any strategy. The implementation costs of a change in speed limits is low, and would result in vehicle cost savings larger than many other strategies. Lower speed limits would also result in reductions in fatalities. However, the impact of lower speeds would not be all positive, given the increase in travel times that would be experienced.
- **Eco-driving strategies** can achieve cumulative GHG reductions by changing the efficiency of individual driving behavior, if widely embraced and practiced. Cumulative GHG reductions between 1.1 and 2.7 percent from the baseline through 2050 are possible. Though yet to be implemented in the U.S., eco-driving programs are underway in such countries as Belgium, United Kingdom, Spain, Norway, and Iceland through voluntary training programs. These programs focus on techniques that have been shown to achieve reductions of up to 340 lb of CO_2 emissions per driver each year. This strategy, like reduced speed limits, can be implemented and generate results in the near term. It would also have one of the highest positive effects on vehicle costs.

What is the difference between annual and cumulative results?

Moving Cooler **GHG emissions reduction estimates are reported both as annual and cumulative reductions.**

Annual reductions (i.e., 100 mmt in 2050) reflect the magnitude of GHG reductions achieved within a single specified year. Annual reductions by strategy are presented in Table 4.2 for three “snapshot” years: 2020, 2030, and 2050. Annual reductions are helpful in comparing GHG emission reductions from individual strategy and bundle reductions to baseline and 1990 or 2005 GHG emissions, which are the usual basis for proposed GHG reduction goals.

Cumulative reductions (i.e., 100 mmt from 2010 to 2050) reflect the total of all GHG reductions during the 40-year study period. To help interpret what cumulative results mean, as a reference point, the U.S. on-road transportation sector is estimated to generate some 67,657 mmt (67.6 Gt) during the next 40 years, 2010 through 2050. Cumulative reductions are helpful in understanding how individual strategies and bundle reductions through 2050 will influence the total stock of carbon in the atmosphere into the next century, which is generally considered the best basis for the total effect on climate change.

- **Transportation system changes** that improve the flow of traffic generally provide cumulative GHG reductions of about 0.1 percent reduction compared to the baseline. Many of these strategies would not be implemented individually, as a major benefit of ITS is the ability of different systems to effectively communicate with each other. Together, these system operations improvements can result in cumulative reductions as high as 0.6% from the baseline. These strategies also enable more effective implementation of a variety of pricing strategies.

  Given the technology investments assumed for these improvements, implementation costs for most tend to be higher than the anticipated vehicle cost savings. Recall though, that vehicle cost savings evaluated through *Moving Cooler* do not include costs associated with travel time and safety benefits, which are the most substantial benefits of these strategies.
- **Highway capacity expansion and bottleneck relief** are the only two strategies examined by *Moving Cooler* that result in an increase in GHG emissions during the 40-year period, 2010 to 2050. This increase does not happen immediately however; in the short term, improved roadway conditions will decrease congestion and delay and, as a consequence, fuel consumption. It is only as induced demand begins to consume the roadway capacity after 2030 that VMT and GHG emissions are projected to increase. At the same time, the impact to growth in GHG emissions is very small—at its highest, less than 0.02 percent increase in the maximum deployment scenario.
- As compared to other strategies, **multimodal freight improvements** achieve modest GHG reductions from a national perspective. Within this group, the most effective strategies are truck APUs and rail capacity improvements, which together reduce cumulative GHG emissions through less idling and mode shift from truck to rail by up to 0.4 percent from the baseline.

To understand how these reductions and costs might vary over time, Table 4.2 provides results for each strategy at three points in time: 2020, 2030, and 2050. These annual "snapshots" of results show that some strategies achieve fairly constant annual reductions over time. Other strategies—such as land use, transit expansion, and eco-driving programs—show increasing effectiveness in later years. The annual reductions achieved by a few strategies marginally decline over time, as a result of improved vehicle efficiency.

4.2 Evaluating Strategy Bundles for Reducing Greenhouse Gas Emissions

Six illustrative bundles that represent different potential combinations of strategies were assembled for analysis. As discussed in Section 2.0, each set is designed to bring together strategies that focus on similar issues—emphasizing common themes or comprehensive approaches for reducing transportation sector impact on GHG emissions.

While the bundles used for this study represent logical combinations of strategies, any number of other combinations could also be designed and tested. The purpose of this exercise is to provide example analyses that demonstrate the potential that can be achieved by combining multiple strategies.

The bundles were assessed assuming two different scenarios: one in which bundle strategies are implemented at an aggressive level of deployment, and a second in which strategies are implemented at the highest, or maximum level of deployment. Bundles at the lower level of deployment, the "expanded current practice level," were not assessed directly, but can be expected to generate lower reductions of GHG than the aggressive level deployment. Detailed information about the components of each bundle at each deployment level is provided in the study appendices, available at www.movingcooler.info.

The analysis assessed the potential GHG reduction of each bundle as a whole, and also calculated the direct costs of implementation and the change in vehicle costs. Each of the bundles is assessed with and without an economy-wide market strategy—such as nationwide carbon pricing—so that the impact of each bundle can be understood on its own, as well as with economy-wide pricing measures introduced. The results of overlaying economy-wide pricing on each of the bundles is described in Section 4.12.

The results point to nationwide strategies that could help to reduce the carbon footprint of U.S. transportation. At the state and regional level, the results provide insight into the strategies transportation planners might consider as part of a specific context and other program goals.

4.3 How Were Co-Benefits, Externalities, and Equity Considered?

Moving Cooler quantifies information on GHG emission reductions, implementation costs, and vehicle cost savings for the individual and bundled strategies. But these results tell only part of the story.

Table 4.2 ***Moving Cooler*** **Yearly GHG Reduction in 2020, 2030, and 2050 by Strategy (at Expanded Current Practice, Aggressive, and Maximum Deployment Levels)**

	Expanded Current Practice Deployment GHG Reduction in Year (mmt)[a]			Aggressive Deployment GHG Reduction in Year (mmt)[a]			Maximum Deployment GHG Reduction in Year (mmt)[a]		
Strategy Description	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
Pricing Strategies									
CBD/Activity Center on-street parking	< .5	1	1	1	1	1	1	1	1
Tax/higher tax on free private parking	N/A	N/A	N/A	< .5	1	1	1	1	1
Residential parking permits	N/A	N/A	N/A	< .5	1	1	1	2	1
Cordon Pricing	1	1	3	1	2	3	1	3	3
Congestion Pricing	5	18	18	11	35	35	18	43	39
Intercity Tolls	< .5	1	1	2	2	2	3	3	2
PAYD	20	19	19	39	47	44	56	63	59
VMT fee	8	8	7	25	24	22	101	97	90
Carbon Pricing (VMT impact)[b]	11	10	10	32	31	28	136	138	132
Carbon Pricing (Fuel economy impact)	24	37	38	70	103	106	236	325	325
Land Use and Smart Growth Strategies/Nonmotorized Strategies									
Combined Land Use	1	3	10	7	22	45	12	38	73
Combined Pedestrian	2	2	2	5	5	5	6	7	6
Combined Bicycle	1	2	2	1	2	2	2	6	6
Public Transportation Strategies									
Transit Fare Measures	1	1	1	1	1	1	2	2	2
Transit Frequency/LOS/Extent	1	2	2	1	2	3	2	4	9
Urban Transit Expansion	2	4	7	4	7	12	8	14	26
Intercity Passenger Rail	1	1	1	1	1	1	2	2	2
High-Speed Passenger Rail	1	2	3	1	3	4	2	4	6
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	1	1	1	2	2	2	4	4	4
HOV Lanes (24-hour applicability)	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Car-Sharing	1	1	1	2	2	2	5	4	4
Employer-Based Commute Strategies	7	7	7	15	14	13	35	34	31
Regulatory Measures									
Nonmotorized Zones	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Urban Parking Restrictions	< .5	1	7	1	4	13	3	9	18
Speed Limit Reductions	12	44	41	40	75	71	51	76	72

There are other costs and benefits associated with implementing GHG emission reduction strategies that go beyond the scope of this study. These include changes in travel time, mobility, safety, user fees, economic development, environmental protection, and public health—all considerations that are not explicitly accounted for in the *Moving Cooler* results, but are important nonetheless.

For this reason, simply arraying the strategies or bundles by any single measure quantified by *Moving Cooler* will provide an important but not a complete picture. For example, higher cost strategies that improve the transportation network while achieving GHG benefits may offer win-win approaches that improve transportation services while reducing GHGs. Similarly, some strategies may achieve GHG reductions, but may harm business productivity. When designing a bundle of GHG strategies for implementation in a particular region or urban area, transportation planners will need to consider the best way to achieve meaningful GHG reductions while meeting multiple other transportation, environmental, economic development, and equity goals. Therefore, considering the "co-benefits" and potential downsides of GHG reduction strategies—that is, what else a strategy accomplishes—is critical to selecting which strategies make sense in a given context.

Table 4.2 (continued)

	Expanded Current Practice Deployment GHG Reduction in Year (mmt)[a]			Aggressive Deployment GHG Reduction in Year (mmt)[a]			Maximum Deployment GHG Reduction in Year (mmt)[a]		
Strategy Description	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
System Operations and Management Strategies									
Eco-Driving	8	18	36	15	29	54	38	50	65
Ramp Metering	< .5	< .5	2	< .5	< .5	6	< .5	< .5	7
Variable Message Signs	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Active Traffic Management	N/A	N/A	N/A	< .5	< .5	4	< .5	< .5	7
Integrated Corridor Management	N/A	N/A	N/A	< .5	< .5	4	< .5	< .5	7
Incident Management	< .5	< .5	5	< .5	1	7	< .5	1	8
Road Weather Management	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Signal Control Management	< .5	< .5	< .5	< .5	< .5	1	< .5	< .5	3
Traveler Information	< .5	< .5	< .5	< .5	< .5	2	< .5	< .5	2
Vehicle Infrastructure Integration	< .5	< .5	6	< .5	< .5	2	< .5	< .5	1
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief[c]	1	1	(4)	3	3	(7)	4	4	(10)
Capacity Expansion[c]	1	1	(2)	2	2	(4)	5	6	(13)
Multimodal Freight Strategies									
Rail Capacity Improvements	< .5	2	2	1	2	2	2	4	4
Marine System Improvements	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Shipping Container Permits	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
LCV Permits	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
WIM Screening	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Weigh Station Bypass	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Truck Stop Electrification	< .5	< .5	< .5	1	1	1	1	1	2
Truck APUs	3	5	4	4	5	4	5	5	4
Truck-Only Toll Lanes	< .5	1	1	1	2	2	1	3	5
Urban Consolidation Centers	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5

Note: This table summarizes the level of GHG reduction for each strategy in years 2020, 2030, and 2050. Annual GHG reductions of 16 to 17 mmt represent an annual reduction of 1 percent from the *Moving Cooler* study baseline. The study baseline estimates total national on-road GHG emissions based on VMT and fuel economy assumptions, as identified in Section 3.0. These estimates are: 1,712 mmt in 2020, 1,689 mmt in 2030, and 1,653 mmt in 2050.

[a] mmt = million metric tonnes greenhouse gases.

[b] Or an equivalent national VMT fee.

[c] Refer to Footnote e in Table 4.1 for additional explanation.

Behavioral approaches to reduce GHG emissions from transportation raise the prices travelers pay and change the options users have for travel. These changes prompt travelers to make different choices about how they travel in ways that reduce GHG emissions. As a result, some people or businesses may be better off and some may be worse off with specific actions that contribute to GHG reductions. It is important to understand and address the equity implications of these differential effects.

Equity is normally addressed through the transportation planning and programming processes. This is known as "process" equity, and there are rules in place to encourage participation by all affected groups. In practice, however, this does not consistently occur, and decision makers will need to identify the "winners and losers" under any given strategy to understand the magnitude of effect and how the effect can be mitigated through other strategies.

While it is possible to identify the equity implications of individual strategies to reduce GHG emissions, the usefulness of such an approach is limited, because any individual action to reduce GHG emissions reveals little about overall equity. Metropolitan Planning Organizations (MPO) and other transportation agencies analyze equity or "environmental justice" on a systemwide basis, looking at their entire regional investment plans and not at each individual action. A parallel premise is used for this study—because GHG emission reduction strategies will likely be carried out in combinations that will have both synergistic and offsetting effects, and it makes sense to consider equity in terms of bundles rather than by individual strategy.

The anticipated co-benefits of each bundle are presented in the sections that follow. A more detailed examination of potential equity issues and mitigation actions is provided in Section 4.13.

4.4 Analysis for Bundle 1: Near-Term/Early Results

What Strategies Are Included?

This bundle focuses on strategies that can be implemented relatively quickly to help obtain reductions in GHG emissions in the near-term. While these strategies might face tough political or financial hurdles, once the decision has been made to undertake them, they would not require much time to put in place, compared to other strategies that would necessarily take longer to implement (such as those that involve intensive construction or require fundamental changes in land use policies and patterns). Strategies are listed in Table 4.3.

How Would It Be Implemented?

All strategies within this bundle are assumed to be implemented at an accelerated pace compared to other bundles. The majority of strategies would be initiated by 2012 and would be fully implemented before 2020. Pricing strategies take somewhat longer to implement and would be phased in over time, starting with the largest cities and moving on to other urbanized areas. While logistically these strategies are relatively simple to implement, they would require careful planning to assure that the strategies are implemented efficiently to achieve the predicted GHG reductions.

Bundle 1: Near-Term/Early Results

	2050[a]
GHG Reductions	7.1-9.3 Gt
Implementation Costs	$676-$945 billion
Vehicle Cost Savings	$3,211-$4,779 billion

[a] Estimated Cumulative Effect at Aggressive and Maximum Deployment Levels.

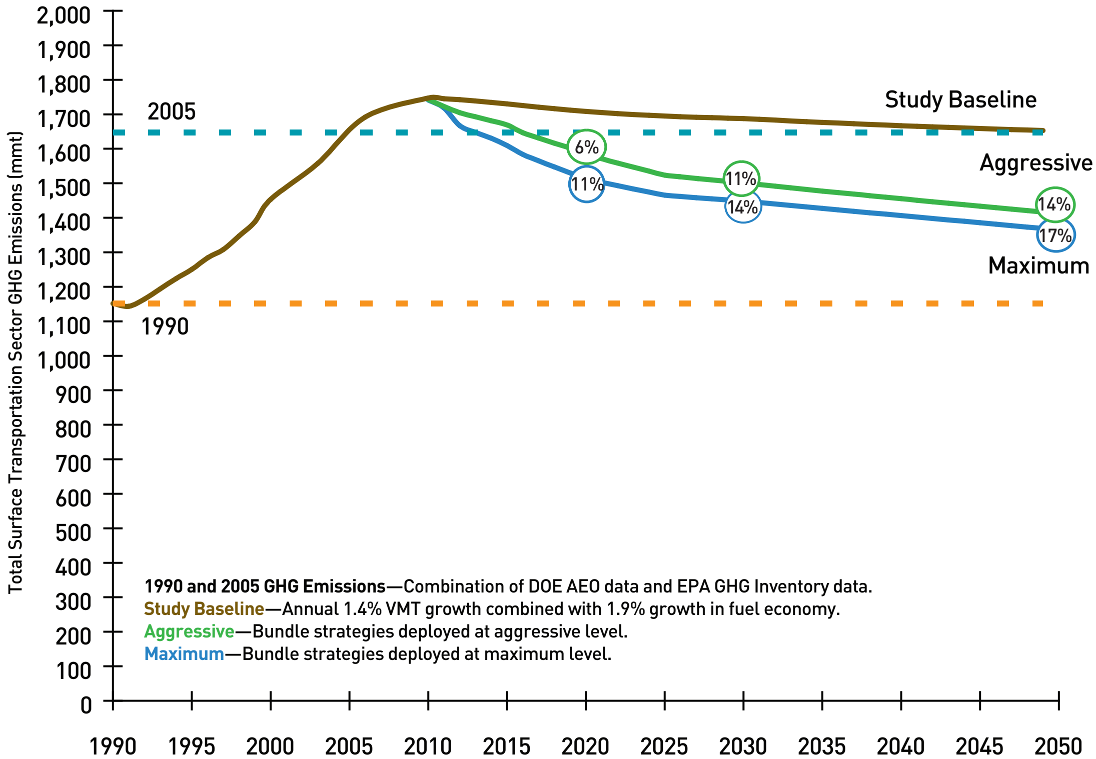
Table 4.3 **Bundle 1: Near-Term/Early Results**

GHG Reduction Strategies
Pricing Strategies
CBD/Activity Center On-street Parking Pricing
New Tax/Higher Tax on Free Private Parking
Residential Parking Permits
Congestion Pricing
Public Transportation Strategies
Transit Fare Measures
Increased Transit Frequency and LOS
HOV/Carpool/Vanpool/Commute Strategies
Car-Sharing
Employer-Based Commute Measures
Regulatory Strategies
Urban Parking Restrictions
Speed Limit Reductions
Systems Operations and Management Strategies
Eco-Driving
Incident Management
Road Weather Management
Signal Control Management
Traveler Information
Multimodal Freight Strategies
Shipping Container Permits
LCV Permits
Truck Stop Electrification

Implementation of congestion pricing requires coordination across public and private sector interests, and a program to install in-vehicle "smart" technology, as well as billing systems. Enforcement requirements will require additional efforts as well. Other strategies within the bundle require some level of new investment from local businesses, as well as coordination by regional planning agencies and transportation management agencies to oversee the implementation of these actions.

The overall picture of this bundle is a combination of congestion pricing, CBD, and activity center parking pricing and parking restrictions, to be deployed in most large urban areas (essentially the largest 50 areas in population, including from New York to New Orleans) before 2020 and the second tier of 50 cities (from roughly Tucson to Portland, Maine) by 2030. At the same time, urban-focused strategies enhancing alternatives such as transit level of service, car-sharing, employer-based commute strategies (such as vanpools and parking cash-out), and roadway systems operations strate-

Figure 4.1 **GHG Reduction for Near-Term/Early Results Bundle**
2010 to 2050



Note: This figure displays the GHG Reduction for Near-Term/Early Reductions Bundle at Aggressive and Maximum Deployment for the 2010 to 2050 time period without economy-wide pricing. Percent reductions are on an annual basis from the study baseline.

gies would be deployed. Combined with eco-driving and speed limit reductions, the bundle achieves early GHG reductions with minimal investment in transportation infrastructure.

GHG Reductions

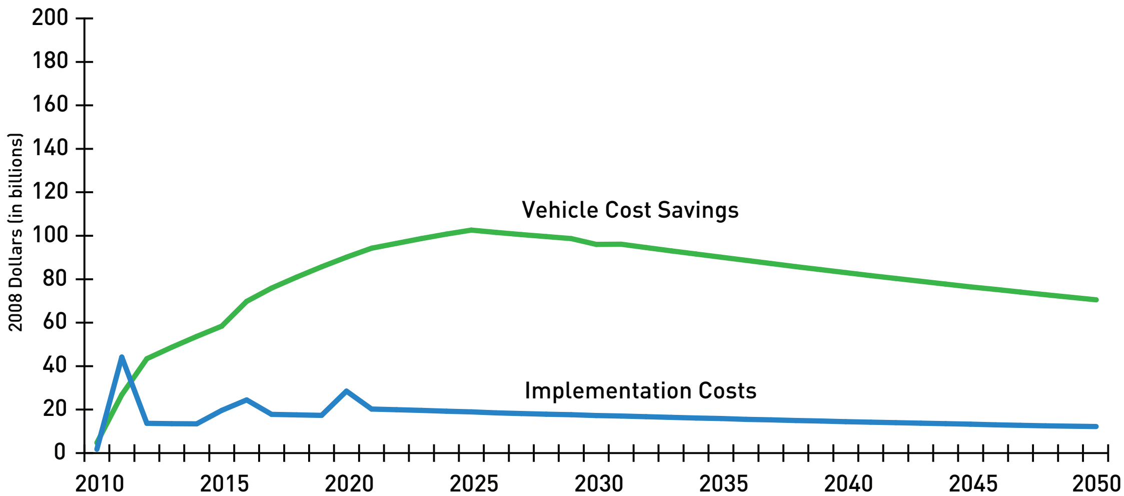
This bundle was assembled based on its anticipated ability to generate results in the near term, thus the analysis focuses on how soon the results would begin to accrue. As anticipated, the bundle achieves GHG reductions in the near term, as shown in Figure 4.1 and Table 4.4. Looking at annual results, baseline GHG emissions in 2020 are reduced by 6 percent (aggressive deployment) and 11 percent (maximum deployment). This percent cumulative reduction in 2020 is the largest of all bundles tested, demonstrating that this bundle can make important contributions in the near term.

These annual reductions result in cumulative emission reductions from the baseline through

Table 4.4 **Bundle 1: Near-Term/Early Results—Summary of Annual GHG Reductions in Target Years**

Bundle	Change from Base or Year		2020	2030	2050
Near-Term/Early Results	Aggressive	Baseline	-6%	-11%	-14%
		2005	-2%	-9%	-14%
		1990	39%	31%	23%
	Maximum	Baseline	-11%	-14%	-17%
		2005	-8%	-12%	-17%
		1990	33%	26%	19%

Figure 4.2 **Implementation Costs and Vehicle Cost Savings for Near-Term/Early Results Bundle at Aggressive Deployment**



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings (reduction in the cost of owning and operating a vehicle from reduced VMT and delay). Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

the year 2050 of 7.1 to 9.3 Gt, equivalent to an 11 to 14 percent reduction of baseline GHG emissions through 2050.

Major individual contributors to these results are congestion pricing, eco-driving, and speed limit reductions. Again, while this bundle and its component strategies can make important contributions, there also are implementation challenges that would need to be addressed. Congestion pricing has been introduced in only a few U.S. locations, and U.S. eco-driving programs do not yet exist. Likewise, there will be resistance to lowered speed limits, particularly as the U.S. focuses on efforts to revitalize the economy.

Implementation Costs and Vehicle Cost Savings

While the benefits of these near-term actions are significant, they come at a relatively high price. Through the year 2050, the estimated cumulative costs of constructing, operating, and maintaining this set of strategies nationwide ranges from $676 billion (aggressive deployment) to $945 billion (maximum deployment) in 2008 dollars (Figure 4.2). The initial deployment costs for congestion pricing are the most significant expenditure in this bundle. Costs include up-front installation of new "smart" technology within vehicles, expanded enforcement requirements, and the development of billing systems.

The cost savings associated with driving less (buying less fuel and less wear and tear on vehicles) are higher than the implementation costs early in the implementation period—earlier in this bundle (by 2012) than all other *Moving Cooler* bundles (Figure 4.2). This savings then results in cumulative vehicle cost savings totaling $3.2 to $4.8 trillion between 2010 and 2050.

The average annual net included cost (i.e., implementation costs less vehicle cost savings) is -$64 billion for aggressive deployment and -$96 billion for maximum deployment (note: minus signs indicate net savings).

Average annual net included costs per tonne range from -$360 (aggressive) to -$410 (maximum) per tonne. This savings means that each tonne of GHG reduced annually results in greater vehicle cost savings than implementation costs.

Other Key Benefits and Impacts

This bundle focuses on achieving GHG reductions as soon as possible, with less emphasis on how the strategies might be combined over the long term to yield an increased level of benefits. Notably, unlike most other bundles, the near-term bundle does not include land use strategies combined with increased levels of public transportation that offer strong synergies, as described later for the Land Use/Transit/Nonmotorized Transportation bundle.

In this bundle, speed limit reductions, eco-driving, improved transit operations, and system operations strategies (including freight strategies) all help smooth traffic flow, minimize idling, and reduce congestion—leading to air quality benefits as well as improved system reliability.

Congestion pricing has by far the most severe equity implications of the strategies in this bundle, requiring offsetting actions for lower-income groups. With a focus on short-term GHG reductions, there is a danger of ignoring longer-term issues. Since this bundle does not include broad expansion to alternative modes such as transit, offsetting strategies are lacking and equity implications would need to be addressed through other means. Other pricing strategies such as parking pricing have some equity impacts that are offset by the combined focus on car-sharing and employer-based commute strategies. This combination also has air quality benefits and improves access to employment.

4.5 Analysis of Bundle 2: Long-Term/Maximum Results

What Strategies Are Included?

This bundle envisions an all-out effort to achieve maximum GHG reductions by pursuing all non-duplicative strategies. It presumes that all issues regarding cost or feasibility have been resolved. This assumption is no small matter, because implementing strategies at this level would certainly require a major shift in national attitudes and political will. Nonetheless, it is useful to consider what the country could accomplish with a major national commitment to reduce GHG emissions from transportation. It is assumed that there are no technical barriers to implementing strategies at this level of intensity. (Note: Consistent with other bundle analyses, economy-wide pricing is

Bundle 2: Long-Term/Maximum Results

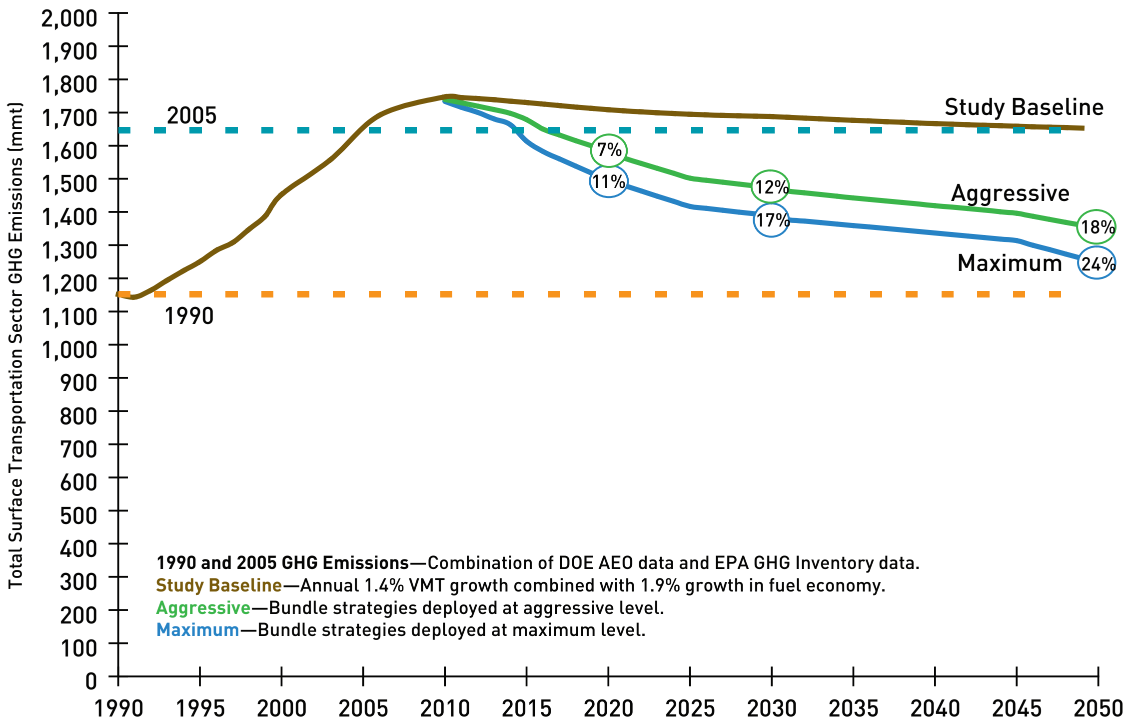
	2050[a]
GHG Reductions	7.6-10.8 Gt
Implementation Costs	$2,611-$5,104 billion
Vehicle Cost Savings	$4,846-$7,667 billion

[a] Estimated Cumulative Effect at Aggressive and Maximum Deployment Levels

Table 4.5 **Bundle 2: Long-Term/Maximum Results**

GHG Reduction Strategies
Pricing Strategies
CBD/Activity Center On-street Parking Pricing
New Tax/Higher Tax on Free Private Parking
Residential Parking Permits
Congestion Pricing
Intercity Tolls
Land Use and Smart Growth Strategies/Nonmotorized Strategies
Combined Land Use
Combined Pedestrian
Combined Bicycling
Public Transportation Strategies
Transit Fare Measures
Increased Frequency, LOS, and Extent
Urban Transit Expansion
Intercity Passenger Rail Expansion
High-Speed Passenger Rail
HOV/Carpool/Vanpool/Commuting Strategies
HOV Lanes
HOV Lanes (24-hour applicability)
Car-Sharing
Employer-Based Commute Measures
Regulatory Strategies
Urban Nonmotorized Zones
Urban Parking Restrictions
Speed Limit Reductions
Systems Operations and Management Strategies
Eco-driving
Freeway Management: Ramp Metering, VMS, Active Traffic Management, and Integrated Corridor Management
Incident Management
Road Weather Management
Signal Management
Traveler Information
Vehicle Infrastructure Integration (VII)
Bottleneck Relief
Highway Capacity Expansion
Multimodal Freight Strategies
Rail Capacity Improvements
Marine System Improvements
Shipping Container Permits
LCV Permits
WIM Screening
Weigh Station Bypass
Truck Stop Electrification
Truck-Only Toll Lanes
Urban Consolidation Centers

Figure 4.3 **GHG Reduction for Long-Term/Maximum Results Bundle**
2010 to 2050



Note: This figure displays the GHG Reduction for Long-Term/Maximum Results Bundle at Aggressive and Maximum Deployment for the 2010 to 2050 time period without economy-wide pricing. Percent reductions are on an annual basis from the study baseline.

not included in this bundle. The effects of including economy-wide pricing in each bundle are discussed in section 4.12.)

As shown in Table 4.5, almost every strategy is incorporated into this bundle, at two deployment levels, aggressive and maximum.

How Would It Be Implemented?

With the all inclusive nature of this bundle, implementation occurs as early and widespread as possible—starting for most strategies before the year 2015. An ongoing program of annual capital investments in appropriate transportation projects—including urban transit expansion, bottleneck relief, and highway capacity expansion projects—is assumed through the year 2050. All urbanized areas would see expansion of all modes of transit, particularly fixed guideway rail services in the most populous 50 urbanized areas; widespread deployment of ITS on all roadway facilities; and focused development in dense, transit-oriented, and bicycle- and pedestrian-friendly environments. These strategies are combined with the deployment of travel demand management and pricing strategies in employment and activity centers, plus targeted improvements to highway bottlenecks, freight infrastructure, and the development of high-speed rail. Essentially this is a multimodal, "do-everything" scenario, including local pricing and regulatory mechanisms; although as noted earlier, it does not include economy-wide pricing.

This bundle is constructed presuming that new policies and significant investment would be in place to support maximum GHG reductions. Substantial annual investments will be required to achieve the ambitious plans envisioned; the resources that would be required far exceed current funding forecasts. If a nationwide pricing strategy were added to this bundle (discussed later in this section), sufficient funds could be made available by directing the revenues generated by higher VMT fees, motor fuel taxes, or carbon pricing to these strategies. Another significant barrier to implementing this bundle likely would be the major planning, organization, and political will required to undertake all of these strategies.

Table 4.6 **Bundle 2: Long-Term/Maximum Results—Summary of Annual GHG Reductions in Target Years**

Bundle	Change from Base or Year		2020	2030	2050
Long-Term/ Maximum Results	Aggressive	Baseline	-7%	-12%	-18%
		2005	-3%	-11%	-18%
		1990	39%	28%	18%
	Maximum	Baseline	-11%	-17%	-24%
		2005	-9%	-16%	-24%
		1990	32%	21%	9%

GHG Reductions

This bundle is designed to achieve sustained, long-term GHG reductions through deployment of a expansive range of strategies at a consistently high level of deployment. At maximum deployment, a 24 percent annual reduction (393 mmt) from baseline emissions is achieved in 2050. This reduction in 2050 is the largest of all bundles evaluated, both for the maximum and aggressive deployment levels (Figure 4.3 and Table 4.6). Annual percent reductions from the baseline also are the highest of all bundles in 2030 (12 percent for the aggressive level of deployment, and 17 percent for maximum deployment). The GHG reductions from this bundle are immediate and remain higher, compared to all other strategy bundles, consistently beyond 2020 (the near-term bundle is approximately the same before 2020).

The high annual reductions discussed above result in cumulative GHG emission reductions of 7.6 to 10.8 Gt, equivalent to an 11 to 16 percent reduction of national on-road GHG emissions through 2050 as compared to baseline levels.

Congestion pricing, land use, speed limits, and eco-driving strategies play the predominant role in delivering these results, with other strategies providing support; or in the case of capacity expansion and bottleneck relief, generating GHG reductions in the short term, but then offsetting with increases over the long term. While this bundle assumes that all barriers to the implementation of strategies are overcome; in reality, substantial political commitment and policy changes would be needed to achieve these results.

Implementation Costs and Vehicle Cost Savings

Achieving this level of reductions would require substantial upfront investments and very strong policy actions at all levels of government. Implementation costs are phased in at a high rate immediately and continually through 2050. Between 2010 and 2016, average annual implementation costs for aggressive deployment are $84 billion; average annual costs through 2050 (in 2008 dollars) are $65 billion. The cumulative implementation cost in 2008 dollars through 2050 ranges from $2.6 (aggressive deployment) to $5.1 trillion (maximum deployment).

Given these high costs, implementation costs through 2017 are higher than the estimated vehicle cost savings (Figure 4.4). However, over the longer run, the savings associated with driving less (buying less fuel and lesser wear and tear on vehicles) exceeds the implementation costs. This savings then results in cumulative vehicle cost savings totaling $4.8 to $7.7 trillion between 2010 and 2050.

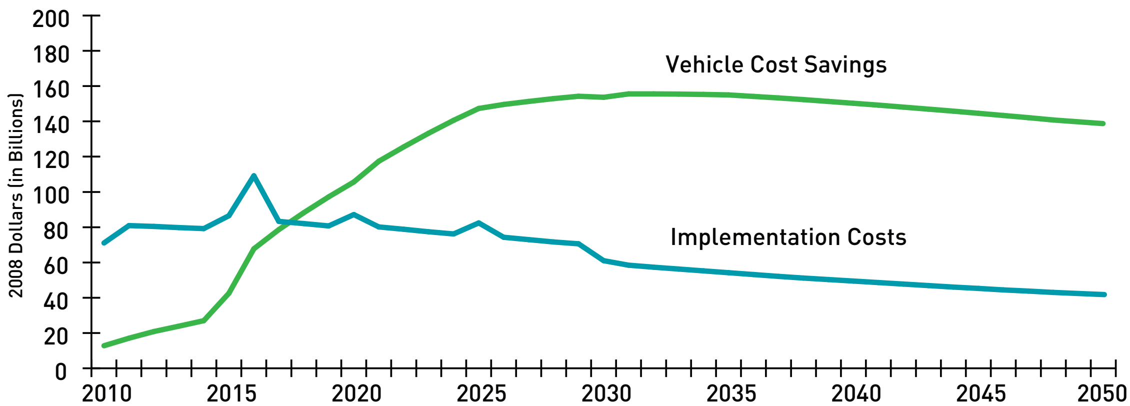
The relationship between implementation costs and vehicle cost savings results in costs exceeding savings through 2017. On average, from 2010 to 2050 the annual net included costs (i.e., implementation costs less vehicle cost savings) range from -$56 billion for aggressive deployment to -$64 billion for maximum deployment (note that minus signs indicate net savings).

When compared to GHG reductions, the average annual net included costs per tonne range from -$290 (aggressive) to -$240 (maximum) per tonne.

Other Key Benefits and Impacts

This bundle is characterized by a comprehensive approach across all strategies for reducing GHG emissions at a high level of effectiveness immediately and over the long term. This bundle requires a substantial outlay of resources to implement and as a result of its comprehensive approach, it will result in a number of large scale effects, with both benefits and negative effects. Pricing measures will smooth traffic flow by providing incentives to drivers to shift to off-peak travel, carpooling, and transit. Operations strategies and highway expansion also will smooth traffic flow and reduce

Figure 4.4 **Implementation Costs and Vehicle Cost Savings for Long-Term/Maximum Results Bundle at Aggressive Deployment**



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings (reduction in the costs of owning and operating a vehicle from reduced VMT and delay). Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

congestion. In addition, HOV lanes may—if not congested or if implemented in a managed lane format—increase travel time reliability for drivers and some transit riders.

The combined effect of more compact land use, improved transit service, and improved bicycle and pedestrian conditions would be to improve mobility by non-automobile modes—leading to more travel options and increased accessibility for those who cannot drive or who would prefer not to rely on a car for their daily travels. Bicycle and pedestrian strategies (particularly as enabled by land use strategies) will also generate health benefits from increased exercise and activity levels.

Speed limits, bottleneck relief, and capacity expansion all will have significant safety benefits. Employer-based commute strategies, car-sharing, and parking pricing strategies encourage alternative choices to driving alone, resulting in air quality benefits, employee commuting travel cost savings, and, according to some studies, increased productivity. Intercity and high-speed rail, as well as freight and maritime strategies, are likely to have positive regional and state economic development impacts.

Pricing measures lead to concerns regarding the equity implications of the strategies in this bundle, and would require other actions to offset the effects for lower-income groups. Transit fare reductions and service improvements and expansion will provide benefits to lower-income residents. Such residents would save money and have greater mobility and access to employment opportunities, health care, education, and retail services. Improved freight efficiency could lower prices for consumer goods, although only very slightly.

4.6 Analysis of Bundle 3: Land Use/Transit/Nonmotorized Transportation

What Strategies Are Included?

Bundle 3 focuses on changes in land use that both facilitate and encourage transportation options that are less GHG intensive. It assumes redeveloped urban areas that support the use of transit and of nonmotorized travel (biking and walking). These changes would reduce the number and length of trips taken by single-occupancy vehicles,

Bundle 3: Land Use/Transit/Nonmotorized Transportation

	2050[a]
GHG Reductions	3.8-6.3 Gt
Implementation Costs	$1,439-$2,390 billion
Vehicle Cost Savings	$3,270-$5,740 billion

[a] Estimated Cumulative Effect at Aggressive and Maximum Deployment Levels.

and provide expanded levels of transportation services. In combination, these strategies would be expected to reduce the average length of trips that a traveler needs to make, whether between home and work or school, to shop, to participate in recreational or cultural activities, or for a variety of other reasons. Strategies included in this bundle are listed in Table 4.7 below.

How Would It Be Implemented?

This bundle focuses on changes in development patterns in urbanized areas, and might require strong *regional* land use planning and oversight agencies. These organizations, made up of local governments in a particular region, would lead the development and implementation of aggressive regional transportation and land use plans that would promote effective, mutually reinforcing, compact land development and transit services. An early priority would be the development of incentive programs for compact development and transit-oriented development at the state and local levels. Other strategies within the bundle—such as employer-based commute strategies, supporting carpools, vanpools, and telecommuting—would require added investment from local businesses, in addition to coordination by regional planning agencies and transportation management agencies. Parking pricing and parking restriction strategies, as well as fully implemented congested pricing, would be put in place early, by 2020 in all urban areas and by 2025 in the first and second tier of cities, totaling 120 metropolitan areas.[1]

In total, the framework for future development and transportation investment within this bundle for all urban areas in the U.S. would be boldly different. The overwhelming majority of employment and residential growth would focus on central cities and adjacent areas, and these cities would have expanded and more robust transit- and bicycle-friendly commuter corridors. Broad parking and congestion pricing, combined with aggressive travel demand management programs, would shift more travel to carpools, vanpools, and transit, and reduce traffic congestion during peak periods.

GHG Reductions

The focus of the bundle design on the interaction of land use with nonmotorized and transit modes results in GHG reductions that are slow to accrue, especially before 2020. The GHG reduction in 2020 is relatively low, ranging from approximately 52 mmt GHGs (aggressive) to 92 mmt GHGs (maximum). These reductions represent a 3 to 5 percent reduction of baseline on-road GHG emissions for aggressive and maximum scenarios, respectively. Approximately 91 percent of total reductions from this bundle occur after 2020, the largest proportion of any bundle. By 2050, the GHG reduction from the baseline has tripled to 9 percent (aggressive) and 15 percent (maximum) (Figure 4.5 and Table 4.8).

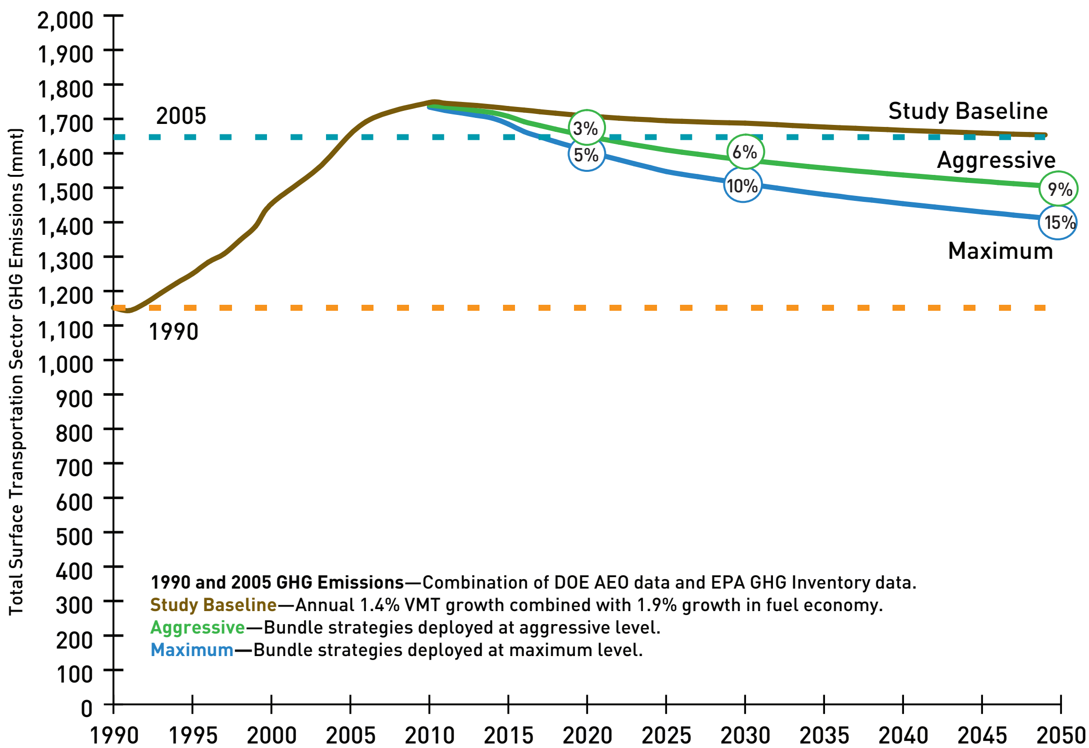
Annual reductions result in cumulative GHG emission reductions through 2050 of 3.8 (aggressive deployment) to 6.3 Gt (maximum deployment), equivalent to a 6 to 9 percent reduction of cumulative baseline GHG emissions.

The predominant strategy supporting this bundle is an increased share of compact development in dense census tracts. For the aggressive

Table 4.7 **Bundle 3: Land Use/Transit/ Nonmotorized Transportation**

GHG Reduction Strategies
Pricing Strategies
CBD/Activity Center On-Street Parking Pricing
New Tax/Higher Tax on Free Private Parking
Residential Parking Permits
Congestion Pricing
Land Use and Smart Growth Strategies/Nonmotorized Strategies
Combined Land Use
Combined Pedestrian
Combined Bicycling
Public Transportation Strategies
Transit Fare Measures
Increased Frequency, LOS, and Extent
Urban Transit Expansion
Intercity Passenger Rail Expansion
High-Speed Passenger Rail
HOV/Carpool/Vanpool/Commuting Strategies
HOV Lanes
HOV Lanes (24-hour applicability)
Car-Sharing
Employer-Based Commute Measures
Regulatory Strategies
Urban Nonmotorized Zones
Urban Parking Restrictions
Systems Operations and Management Strategies
Signal Management
Traveler Information
Multimodal Freight Strategies
Urban Consolidation Centers

Figure 4.5 **GHG Reduction for Land Use/Transit/Nonmotorized Transportation Bundle**
2010 to 2050



Note: This figure displays the GHG Reduction for Land Use/Transit/Nonmotorized Transportation Bundle at Aggressive and Maximum Deployment for the 2010 to 2050 time period without economy-wide pricing. Percent reductions are on an annual basis from the study baseline.

level of deployment, it is assumed that 64 percent of net new development anticipated by 2050 occurs in compact neighborhoods, defined as five or more units to an acre (compared to 34 percent between 1990 and 2000). Under maximum deployment, the assumption is 90 percent. VMT reductions as a result of this strategy increase gradually over time, with the most notable reductions occurring after 2030. Similarly, growth in the use of nonmotorized travel modes and transit also takes time to achieve, as the new land use patterns are put in place.

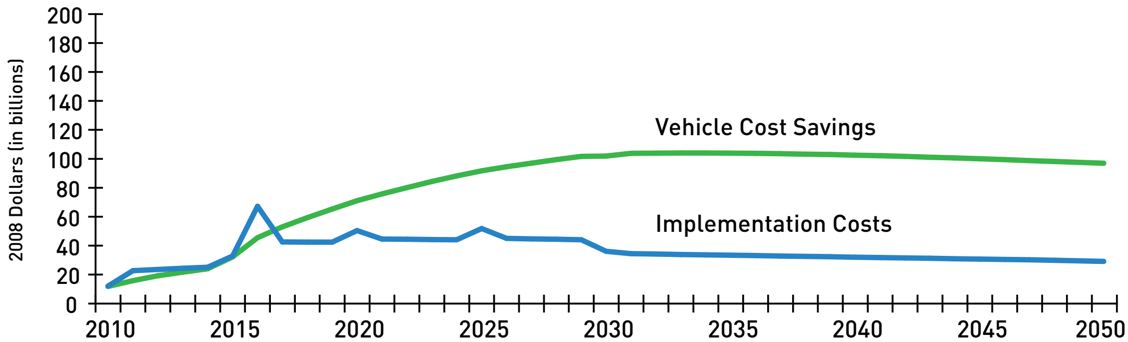
Implementation Costs and Vehicle Cost Savings

Cumulative implementation costs through 2050 for this bundle range from $1.4 trillion (aggressive deployment) to $2.4 trillion (maximum deployment). Annual implementation costs change over time,

Table 4.8 **Bundle 3: Land Use/Transit/Nonmotorized Transportation—Summary of Annual GHG Reductions in Target Years**

	Change from Base or Year		**2020**	**2030**	**2050**
Land Use/Transit/ Nonmotorized Transportation	Aggressive	Baseline	-3%	-6%	-9%
		2005	1%	-4%	-9%
		1990	44%	38%	31%
	Maximum	Baseline	-5%	-10%	-15%
		2005	-2%	-8%	-14%
		1990	41%	32%	23%

Figure 4.6 **Implementation Costs and Vehicle Cost Savings for Land Use/Transit/ Nonmotorized Transportation Bundle at Aggressive Deployment**



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings (reduction in the cost of owning and operating a vehicle from reduced VMT and delay). Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

averaging $36 to $60 billion per year, with a peak investment of $95 billion in 2016.

Cumulative vehicle cost savings total $3.3 to $5.7 trillion between 2010 and 2050. The benefits of coordinated land use, bike and pedestrian, and transit strategies take longer to realize, and are highest in the later decades beyond 2030 (Figure 4.6). Through 2050, average annual vehicle cost savings total $82 to $143 billion.

Implementation costs and vehicle cost savings are approximately the same through 2015, with a blip in costs in 2016, associated with deployment of congestion pricing. Beyond 2016, vehicle cost savings exceed implementation costs. Average annual net included cost (i.e., implementation costs less vehicle cost savings) through 2050 range from $46 billion for aggressive deployment to $84 billion for maximum deployment (note that minus signs indicate net savings).

When net included costs are compared to GHG reductions, the result is average annual net included costs per tonne ranging from -$480 to -$530 per tonne. This annual net included cost per tonne shows the greatest net savings for each tonne of GHGs reduced of any bundle.

Other Key Benefits and Costs

This bundle represents a set of strategies that, over time, will lead to a significant transformation in how Americans live and travel—leading to a number of co-benefits, although it could lead to some possible detractions as well. The combined effect of more compact land use, improved transit service, and improved bicycle and pedestrian conditions would be to improve mobility by non-automobile modes—leading to more travel options for those who cannot drive or who would prefer not to rely on a car for their daily travels. Low-income people, children, the elderly, and others with mobility impairments should especially benefit. Furthermore, increased opportunities for walking and bicycling will lead to improvements in public health, as exercise and activity levels increase. Finally, denser development can lead to energy and GHG savings through decreased building energy use, in addition to transportation efficiencies.

Some of the measures in this bundle may have detractions for some population groups. The pricing measures, particularly congestion pricing and parking fees, would especially affect lower-income travelers, without offsetting actions (such as improved transit service) to address equity concerns. Land use measures may result in higher housing prices, which would negatively affect lower-income residents. But denser urban areas would also decrease their transportation costs and improve their access to employment. To the extent that land use policy changes *support* current market trends (such as a return to urban living), they would provide benefits by providing people with expanded choices. But if land use policies for compact development are set beyond what the market would demand, some people might need to live in smaller homes or on smaller lots than they would prefer.

4.7 Analysis of Bundle 4: System and Driver Efficiency

What Strategies Are Included?

Bundle 4 is designed to enhance the efficiency of transportation networks—making the most of existing roads, rail, and transit and targeting system expansion to highly congested areas. These strategies improve travel speeds, reduce the frequency of acceleration, deceleration, and idling associated with congested systems, and create viable alternatives to driving alone. Strategies are listed in Table 4.9.

How Would It Be Implemented?

Bundle 4 implements a package of key roadway infrastructure investments, combined with operations and management strategies, congestion pricing, and commuting programs. The goal of all of these strategies is more efficient use and operation of the transportation system. Therefore, the critical first step is to identify the current deficiencies and investment needs of the system, so that investments are targeted to changes that will generate the most significant improvements in how the network functions. Minimal changes are required in policy or in regulatory frameworks to move forward on this set of strategies, making the bundle relatively more feasible to implement. The key requirements for success are sufficient capital funding and the availability of technology.

In the near term, priority is given to the implementation of operational improvements, coupled with the deployment of advanced technologies. Operational improvement strategies are steadily implemented each year, starting in 2010, at a higher investment level than currently is practiced. Ensuring efficient links among all the monitoring technology within this bundle requires good planning, technical expertise, and continuous system management, but the costs are low, compared to other strategies. Targeted bottleneck relief and capacity additions connected to these intelligent transportation systems are the most expensive elements of the bundle. Such capital improvement strategies—including upgrades to freight rail and marine infrastructure as well as highway investments—will require significant funding, advanced planning and engineering, and strong political support.

Implementation of this bundle portrays a very efficiently operated and reliable transportation system, where mobility is maintained and delays are reduced. The reductions of GHG are primarily a product of reductions in idling and improvement in traffic flow. Eco-driving and speed limit reductions result in more efficient vehicle operations on

Bundle 4: System and Driver Efficiency

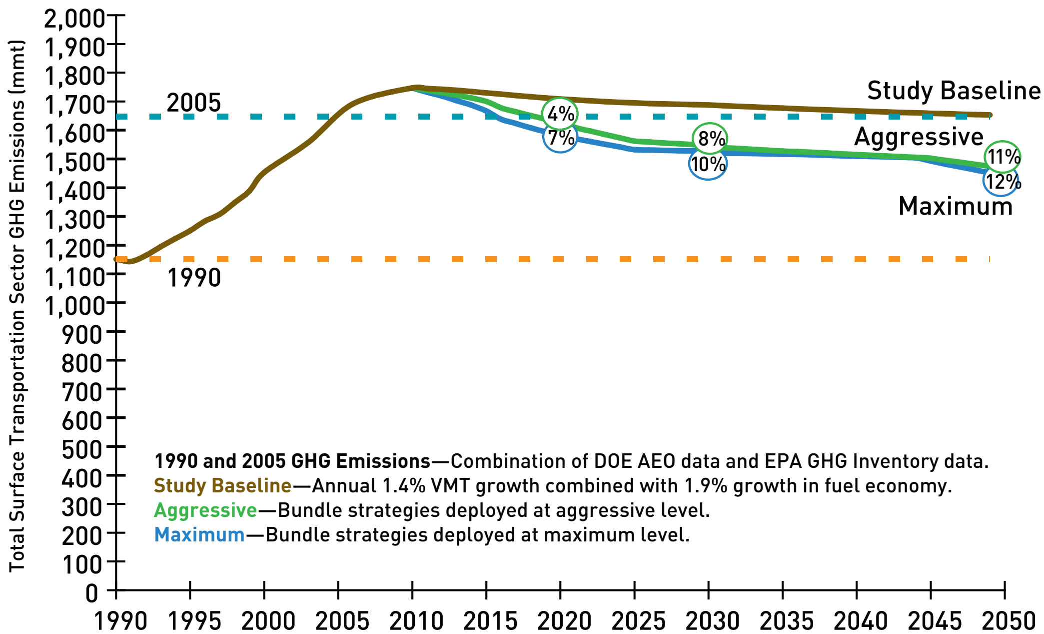
	2050[a]
GHG Reductions	5.0-6.0 Gt
Implementation Costs	$1,870-$3,338 billion
Vehicle Cost Savings	$2,214-$2,737 billion

[a] Estimated Cumulative Effect at Aggressive and Maximum Deployment Levels.

Table 4.9 **Bundle 4: System and Driver Efficiency**

GHG Reduction Strategies
Pricing Strategies
Congestion Pricing
Public Transportation Strategies
Increased Frequency and LOS
HOV/Carpool/Vanpool/Commute Strategies
HOV Lanes
HOV Lanes (24-hour applicability)
Car-Sharing
Employer-Based Commute Measures
Regulatory Strategies
Speed Limit Reductions
Systems Operations and Management Strategies
Eco-driving
Freeway Management: Ramp Metering, VMS, Active Traffic Management, and Integrated Corridor Management
Incident Management
Road Weather Management
Signal Management
Traveler Information
Vehicle Infrastructure Integration (VII)
Capacity Expansion
Bottleneck Relief
Multimodal Freight Strategies
Rail Capacity Improvements
Marine System Improvements
Shipping Container Permits
LCV Permits
WIM Screening
Weigh Station Bypass
Truck Stop Electrification
Truck-Only Toll Lanes
Urban Consolidation Centers

Figure 4.7 **GHG Reduction for System and Driver Efficiency Bundle**
2010 to 2050



Note: This figure displays the GHG Reduction for System and Vehicle Efficiency Bundle at Aggressive and Maximum Deployment for the 2010 to 2050 time period without economy-wide pricing. Percent reductions are on an annual basis from the study baseline.

uncongested and rural transportation systems. Interconnected networks of ITS include broad traveler information systems for all modes, and when combined with telework and other travel demand management strategies, give significant flexibility to travelers regarding time and route of travel. Combined with congestion pricing, this bundle represents a system technology approach for reducing GHG emissions.

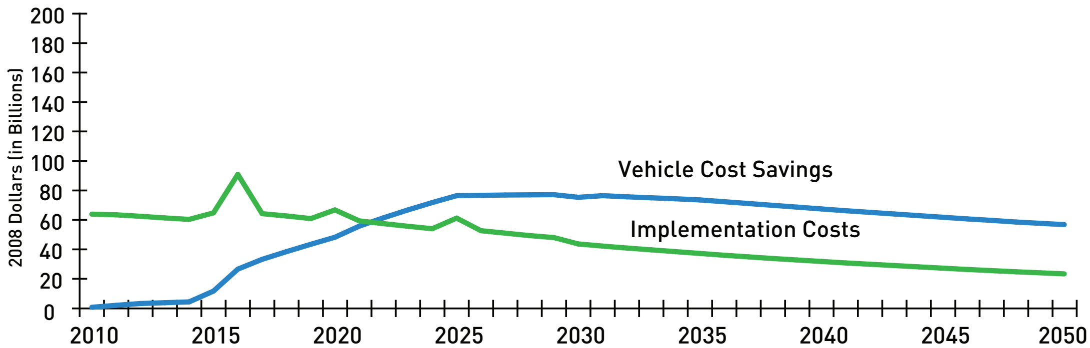
GHG Reductions

A combined focus on roadway infrastructure investments with operations and management strategies results in a mix of short- and long-range benefits at consistent annual implementation costs. The GHG reduction trend in Figure 4.7 shows nearly a linear increase in GHG reductions through 2025. Beyond 2025, the linear increase in GHG reductions stabilizes, as some strategies within the bundle have reached a maximum level of deployment. In other words, while new capacity and bottleneck relief are continually added through 2050, after 2025 there are no additional offsetting GHG reductions that can be achieved by the remaining strategies. The result is an 8 percent (aggressive) and 10 percent (maximum) reduction in 2030 compared to a 11 and 12 percent reduction respectively in 2050 (see Table 4.10).

Table 4.10 **Bundle 4: System and Driver Efficiency—Summary of Annual GHG Reductions in Target Years**

Bundle	Change from Base or Year		2020	2030	2050
System and Driver Efficiency	Aggressive	Baseline	-4%	-8%	-11%
		2005	-1%	-6%	-11%
		1990	42%	35%	28%
	Maximum	Baseline	-7%	-10%	-12%
		2005	-4%	-8%	-12%
		1990	38%	33%	26%

Figure 4.8 **Implementation Costs and Vehicle Cost Savings for System and Driver Efficiency Bundle at Aggressive Deployment**



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings (reduction in the cost of owning and operating a vehicle from reduced VMT and delay). Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

The cumulative reduction through 2050 ranges from 5.0 Gt GHGs (aggressive deployment) to 6.0 Gt GHGs (maximum deployment). This reduction is equivalent to a cumulative 7 to 9 percent reduction of national on-road GHG emissions through 2050, as compared to the baseline.

Major individual contributors to these results are congestion pricing, eco-driving, and speed limit reductions.

Implementation Costs and Vehicle Cost Savings

Highway bottleneck relief and capacity expansion strategies are capital intensive strategies, and rapid deployment of ITS-related strategies also requires early and significant investment. For this analysis, the average annual implementation costs for this bundle are projected to range from $47 billion (aggressive) to $83 billion (maximum) annually. This results in cumulative implementation costs through 2050 ranging from $1.9 trillion to $3.3 trillion. In the initial years of expansion, the GHG benefits of these investments are small and come at high costs.

Vehicle cost savings are slow to occur within this bundle, primarily because of the effect induced demand has on the bundle results. From 2010 to 2020, annual savings average $16.8 billion (aggressive) to $27.8 billion (maximum). During this same period, there is a significant outlay of implementation costs, averaging from $65 billion (aggressive) to $160 billion (maximum) annually.

Over time, as implementation of strategies continue and benefits increase, vehicle cost savings catch up to and then exceed annual implementation costs (Figure 4.8). This transition occurs in 2022 for aggressive deployment. Average annual vehicle cost savings through 2050 range from $55 billion (aggressive) to $68 billion (maximum). This savings results in cumulative vehicle cost savings ranging from $2.2 trillion to $2.7 trillion.

The average annual net included cost (i.e., implementation cost less vehicle cost savings) ranges from -$9 billion for aggressive deployment to $15 billion for maximum deployment (note that minus signs indicate net savings). While annual included savings exceed costs at an aggressive deployment level, costs exceed savings at maximum deployment. This indicates that the added costs of maximum deployment do not accrue comparable savings.

When net included costs are compared to GHG reductions, the result is average annual net included cost per tonne ranging from -$70 to $100 per tonne.

Other Key Benefits and Impacts

The focus on system and vehicle efficiency improvements results in co-benefits associated with improving traffic flow and reducing congestion, such as associated increased capacity, reduced travel time, increased travel time reliability, and air quality benefits. In addition, transit service improvements will provide mobility co-benefits for urban residents and improve transit service reliability. Employer-based commute strategies, combined with managed lane system expansion, will improve access and mode choice to employment, as well as increase commuting time reliability. Speed limits will have significant safety benefits, but will also increase travel times.

A focus on system efficiency that addresses all modes results in relatively few equity impacts. Urban lower-income residents will benefit from improved transit operations, providing them with greater mobility and access to employment opportunities. Improved freight efficiency could lower prices for consumer goods, but this effect will be small.

Congestion pricing has by far the most severe equity implications of the strategies in this bundle. Since the bundle does not include broad expansion to alternative modes, these offsetting actions are not fully addressed. Although operations strategies generally do not have significant equity implications, ramp metering strongly favors commuters from the exurbs and farther out suburbs (who enter the highway before it is metered, and benefit from the improved traffic flow) over those living closer to the center of the metropolitan area.

4.8 Analysis of Bundle 5: Facility Pricing

What Strategies Are Included?

Bundle 5 combines infrastructure improvements with local and regional pricing measures to shape travel choices and generate revenue. The bundle design assumes that the market will drive the need for infrastructure improvements to continue development and economic growth, particularly in urban regions. Strategies included in Bundle 5 are listed in Table 4.11.

How Would It Be Implemented?

The investment focus in this bundle is heavily tied to infrastructure—both transit and highway—in order to support future development and overall regional, state, and national economic growth. These local and regional based pricing strategies act to improve the operating efficiency of the existing and expanded highway infrastructure. Local and regional pricing strategies also serve as the primary mechanism to assist in funding the infrastructure strategies. The timeline for implementation is more variable within this bundle because of the primary focus on infrastructure. A large share of the bundle's overall implementation is tied to both the level of private involvement, as well as the availability of funding provided via revenues from regional congestion pricing and intercity tolls. While some capacity expansion can be accomplished in the near term, the extent of capacity expansion envisioned in this bundle will take many years to complete; building new roads, transit, and rail facilities takes time and major investments. Given the long time frames needed to plan, design, and build new transportation infrastructure, the primary GHG reductions, mobility improvements, and economic benefits from this bundle will occur after the year 2020.

The partial focus on increasing the share of private funding to support transportation infra-

Bundle 5: Facility Pricing

	2050[a]
GHG Reductions	1.4-1.7 Gt
Implementation Costs	$2,371-$4,483 billion
Vehicle Cost Savings	$1,121-$1,656 billion

[a] Estimated Cumulative Effect at Aggressive and Maximum Deployment Levels.

Table 4.11 **Bundle 5: Facility Pricing**

GHG Reduction Strategies
Pricing Strategies
CBD/Activity Center On-Street Parking Pricing
New Tax/Higher Tax on Free Private Parking
Residential Parking Permits
Congestion Pricing
Intercity Tolls
Public Transportation Strategies
Transit Fare Measures
Increased Frequency, LOS, and Extent
Urban Transit Expansion
Intercity Passenger Rail Expansion
High-Speed Passenger Rail
HOV/Carpool/Vanpool/Commuting Strategies
HOV Lanes
HOV Lanes (24-hour applicability)
Systems Operations and Management Strategies
Traveler Information
Capacity Expansion
Bottleneck Relief
Multimodal Freight Strategies
Rail Capacity Improvements
Marine System Improvements
Truck Stop Electrification
Truck-Only Toll Lanes

structure required in this bundle results in investment in large-scale megaprojects, particularly high-capacity toll facilities. Many of these megaprojects would address significant system bottlenecks, and may also include private investment in both freight or passenger rail infrastructure.

GHG Reductions

Because of the primary focus on infrastructure investments (both transit and highways), this bundle shows minor GHG reductions in the short-term with high initial implementation costs. The annual reductions from the baseline in 2020 are 1 to 2 percent; in 2030, the annual reductions have increased only marginally to 3 percent (Figure 4.9, Table 4.12). Annual reductions beyond 2030 track consistently 3 to 4 percent below baseline emissions.

The cumulative reduction through 2050 ranges from 1.4 Gt GHGs (aggressive deployment) to 1.7 Gt GHGs (maximum deployment), equivalent to a 2 to 3 percent reduction of national on-road GHG emissions through 2050.

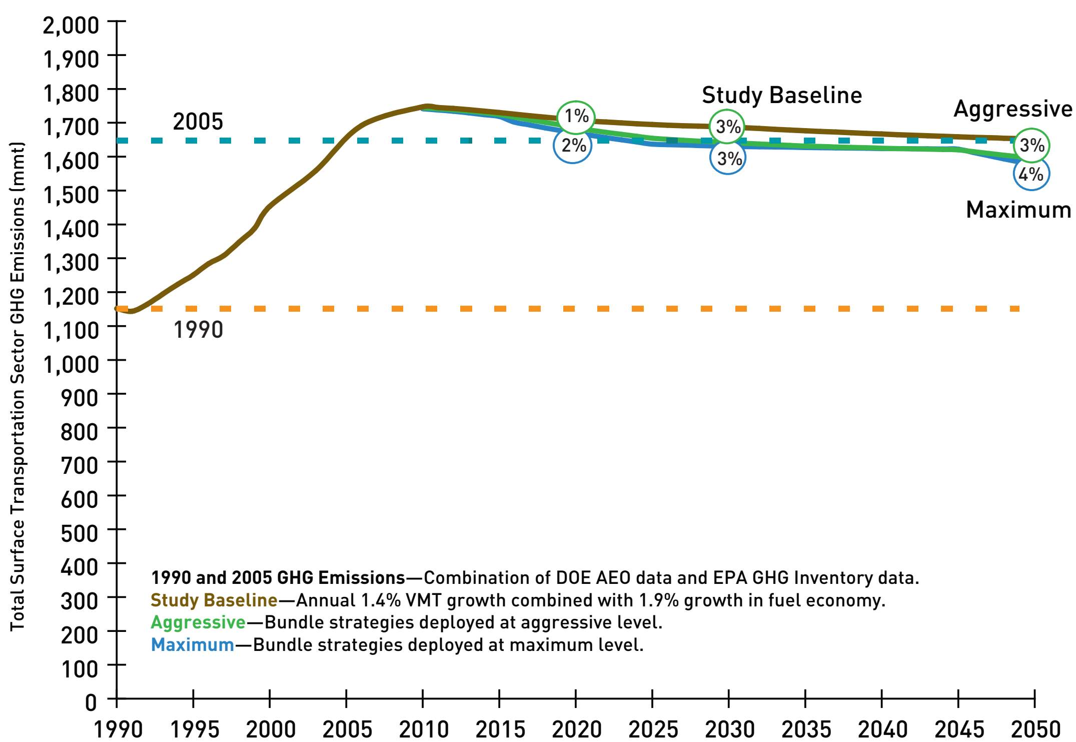
As infrastructure is completed and new services are put in place, GHG benefits from reduced system delay and VMT reduction increase. However, the impact of induced demand, which is applied to a larger share of strategies in this bundle, offsets a portion of total GHG reductions.

Implementation Costs and Vehicle Cost Savings

Urban transit expansion and capacity expansion strategies and highway bottleneck relief show constant, large capital investments through 2050 to meet transit ridership growth goals and highway level of service needs. Cumulative implementation costs through 2050 range from $2.4 trillion to $4.5 trillion. These costs make this bundle the second most expensive, while at the same time showing the lowest cumulative GHG reductions. Average annual implementation costs range from $52 billion (aggressive) to $96 billion (maximum).

Vehicle cost savings are less than the implementation costs through 2030; in the later decades,

Figure 4.9 **GHG Reduction for Facility Pricing Bundle**
2010 to 2050



Note: This figure displays the GHG Reduction for Facility Pricing Bundle at Aggressive and Maximum Deployment for the 2010 to 2050 time period without economy-wide pricing. Percent reductions are on an annual basis from the study baseline.

Table 4.12 **Bundle 5: Facility Pricing—Summary of Annual GHG Reductions in Target Years**

Bundle	Change from Base or Year		2020	2030	2050
Facility Pricing	Aggressive	Baseline	-1%	-3%	-3%
		2005	3%	0%	-3%
		1990	47%	43%	39%
	Maximum	Baseline	-2%	-3%	-4%
		2005	2%	-1%	-4%
		1990	46%	42%	38%

savings and costs track very closely, with savings slightly less than implementation costs from 2030 through 2050 (Figure 4.10). Cumulative vehicle cost savings total $1.1 trillion to $1.7 trillion. Average annual vehicle cost savings range from $28 billion (aggressive) to $41 billion (maximum).

Because vehicle cost savings never exceed implementation costs in this bundle, net included costs per tonne are positive. Net included costs per tonne (i.e., implementation costs less vehicle cost savings) are closest to a negative value in 2050, with a range of $10 to $230 per tonne. The average annual net included costs through 2050 range from $24 billion for aggressive deployment to $54 billion for maximum deployment.

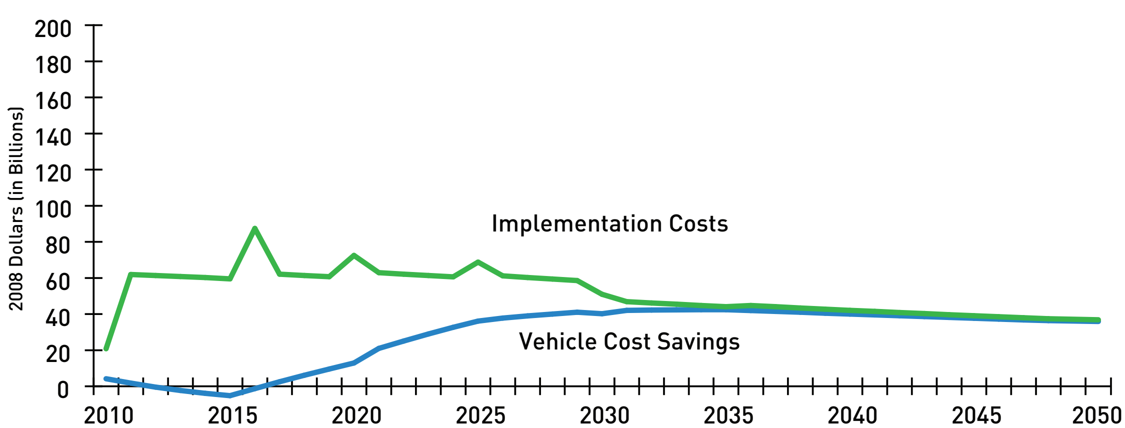
When net included costs are compared to GHG reductions, the average annual net included cost per tonne ranges from $890 to $1,630 per tonne.

Other Key Benefits and Impacts

While the GHG reduction benefits are small, the mobility benefits provided by this bundle through a number of the strategies across all modes are significant. Transit service improvements will provide mobility co-benefits for urban residents and make important contributions to equity for lower-income residents. Intercity and high-speed rail, highway capacity expansion, and freight and marine strategies are likely to have positive regional and state economic development effects. There are potentially more significant surface environmental effects from a bundle with a predominant focus on infrastructure.

As with each bundle that includes facility pricing, pricing measures have significant equity implications and require policies to offset these negative effects. Equity issues can be remedied through investments that improve mobility for lower-income groups, and provide higher benefits to them than the costs they incur. This bundle effectively transfers a portion of revenues collected

Figure 4.10 **Implementation Costs and Vehicle Cost Savings for Facility Pricing Bundle at Aggressive Deployment**



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings (reduction in cost of owning and operating a vehicle from reduced VMT and delay). Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

from automobile drivers to transit riders; however, drivers also benefit from travel time improvements because of capacity expansion and bottleneck relief. Lower-income residents will see both positive and negative equity effects, in part depending on whether they own vehicles. Transit fare reductions and service improvements will provide benefits to urban lower-income residents, who will save money and have greater mobility and access to employment opportunities. Since transit strategies will provide more limited benefits to rural or exurban residents, attention would be needed to ensure that equity issues for these populations are adequately addressed.

4.9 Analysis of Bundle 6: Low Cost

What Strategies Are Included?

Bundle 6 combines the strategies that have the lowest implementation costs. In contrast to the design of other bundles, these strategies are packaged together without regard to whether they might or might not have beneficial synergies. Rather, the bundle simply reflects the best that might be done to implement strategies that are low cost with GHG reductions. The detailed list of strategies included in this bundle is shown in Table 4.13.

How Would It Be Implemented?

This bundle includes a set of strategies that are low cost and that have minimal investment in new infrastructure. This focus means that strategies are quickly implemented and provide GHG benefits early. Thus, the on-the-ground reality of this bundle is very similar to the Near-Term/Early Results bundle, except with the added focus on land use with coordinated bicycle and pedestrian infrastructure.

For example, regulatory strategies—such as urban parking restrictions, speed limits, and eco-driving, as well as parking pricing and employer-based commute strategies—all require planning, organization, and potential legislative efforts. Nonetheless, their direct implementation costs are relatively minimal and benefits can all be realized before the year 2020. The operations and congestion pricing strategies included in this bundle do require moderate investments and will take longer to deploy. However, once in place, much of the technology and system management required can be shared across all of these strategies.

A potential challenge for the deployment of this bundle is that an exclusive focus on strategies that cost the least may disregard the important role more capital-intensive strategies can play in an overall GHG reduction program. For example, advancing smart growth policies to increase

Bundle 6: Low Cost

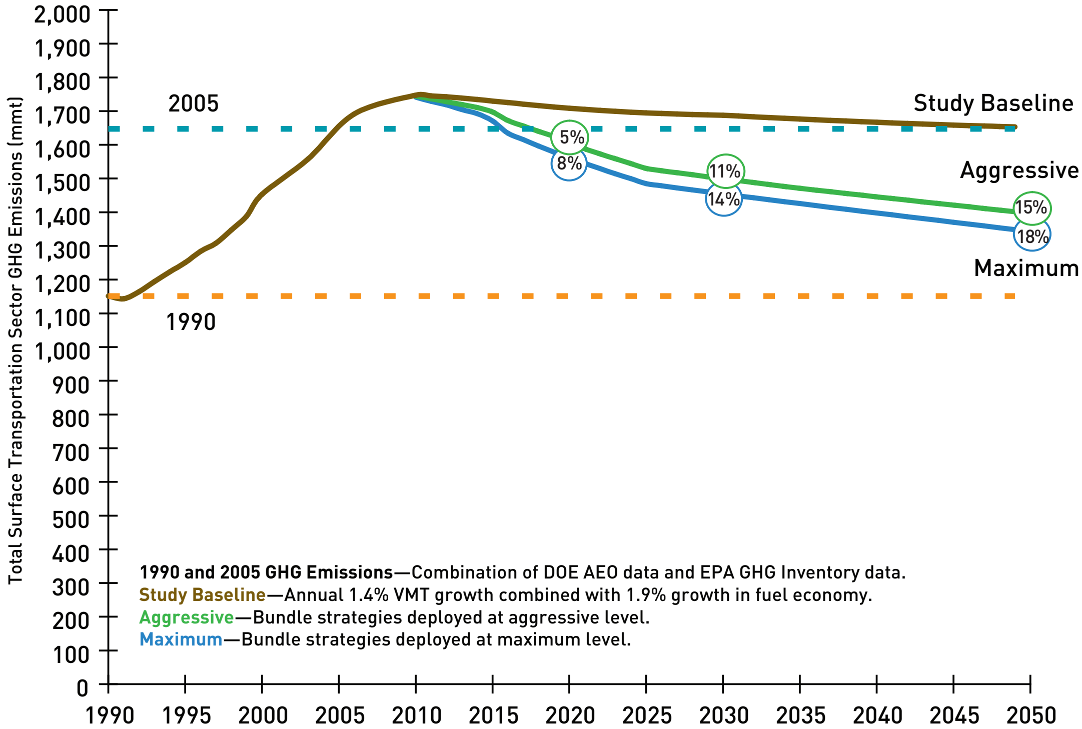
	2050[a]
GHG Reductions	7.5-9.8 Gt
Implementation Costs	$599-$634 billion
Vehicle Cost Savings	$3,499-$5,103 billion

[a] Estimated Cumulative Effect at Aggressive and Maximum Deployment Levels.

Table 4.13 **Bundle 6: Low Cost**

GHG Reduction Strategies
Pricing Strategies
CBD/Activity Center On-Street Parking Pricing
New Tax/Higher Tax on Free Private Parking
Residential Parking Permits
Congestion Pricing
Intercity Tolls
Land Use and Smart Growth Strategies/Nonmotorized Strategies
Combined Land Use
Combined Pedestrian
Combined Bicycling
Public Transportation Strategies
Transit Fare Measures
HOV/Carpool/Vanpool/Commuting Strategies
Car-Sharing
Employer-Based Commute Measures
Regulatory Strategies
Urban Parking Restrictions
Speed Limit Reductions
Systems Operations and Management Strategies
Eco-driving
Freeway Management: Ramp Metering, VMS, Active Traffic Management, and Integrated Corridor Management
Incident Management
Traveler Information
Vehicle Infrastructure Integration (VII)
Multimodal Freight Strategies
Shipping Container Permits
LCV Permits
WIM Screening
Weigh Station Bypass
Truck APUs
Urban Consolidation Centers

Figure 4.11 **GHG Reduction for Low Cost Bundle**
2010 to 2050



Note: This figure displays the GHG Reduction for Low Cost Bundle at Aggressive and Maximum Deployment for the 2010-2050 time period without economy-wide pricing. Percent reductions are on an annual basis from the study baseline.

compact development can achieve significant reductions at relatively low costs; however, without investments in transit expansion and improved highway operations, these policies could result in congestion, reduced mobility, and equity concerns.

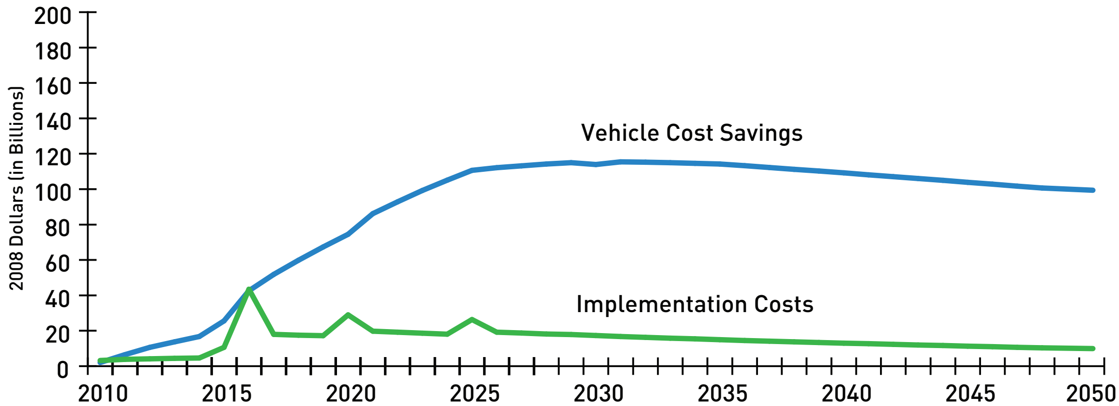
GHG Reductions

Benefits are realized slowly within this bundle, similar to the GHG reduction curves for the land use focused bundle. Over time, with the added effect of land use strategies, GHG reductions increase, hitting a reduction in 2050 from the baseline of 15 to 18 percent, the second highest value of all bundles (Figure 4.11, Table 4.14). The inclusion of other cost-effective strategies, such as speed limit reductions and eco-driving, result in the higher 2050 reductions, compared to the land use bundle (Bundle 3). Notably, these reductions are also achieved at relatively low cost, as compared to the Long-Term/ Maximum Results bundle, while achieving similar magnitude annual GHG reductions.

Table 4.14 **Bundle 6: Low Cost—Summary of Annual GHG Reductions in Target Years**

Bundle	**Change from Base or Year**		**2020**	**2030**	**2050**
Low Cost	Aggressive	Baseline	-5%	-11%	-15%
		2005	-2%	-9%	-15%
		1990	41%	31%	22%
	Maximum	Baseline	-8%	-14%	-18%
		2005	-6%	-12%	-18%
		1990	37%	27%	17%

Figure 4.12 **Implementation Costs and Vehicle Cost Savings for Low Cost Bundle at Aggressive Deployment**



Note: This figure displays estimated annual implementation costs (capital, maintenance, operations, and administrative) and annual vehicle cost savings (reduction in cost of owning and operating a vehicle from reduced VMT and delay). Vehicle cost savings **DO NOT** include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

The resulting cumulative GHG reduction through 2050 ranges from 7.5 Gt GHGs (aggressive deployment level) to 9.8 Gt GHGs (maximum level). These reductions represent a cumulative 11 to 15 percent reduction of national on-road GHG emissions from baseline.

Implementation Costs and Vehicle Cost Savings

By design, the costs of implementation of this bundle are low, ranging on average from $15 billion annually (aggressive) to $17 billion annually (maximum) through 2050, at a relatively steady level of investment. Cumulative implementation costs are the lowest of all the bundles for both aggressive and maximum deployment ($599 billion to $634 billion)

In contrast, cumulative vehicle cost savings total $3.5 trillion to $5.1 trillion through 2050, more than six times the implementation costs. Moreover, after just the first two years (for maximum deployment), implementation costs already are less than vehicle cost savings. The bundle shows that annual vehicle cost savings are higher than implementation costs in every year except 2010 and 2016 at either level of implementation (Figure 4.12). Average annual vehicle cost savings range from $87 billion (aggressive) to $128 billion (maximum).

As a result of the combination of low implementation cost and high vehicle cost savings, net included costs (i.e., implementation costs less vehicle cost savings) are highly negative. In fact, the average annual net included costs are more negative for this bundle than all others (-$72 billion for aggressive and -$112 billion for maximum).

When net included costs are compared to GHG reductions, the result is an average annual net included cost per tonne through 2050 of -$390 to -$460 per tonne.

Other Benefits and Impacts

The strategies within this bundle are low cost with comparatively high GHG reductions, an approach that generally may be viewed as the most politically palatable solution. As a result, government and public support for this approach may be higher than other bundles.

Pricing will reduce downtown congestion and improve traffic flow by providing incentives to drivers to shift to off-peak travel, carpools, and transit. Operations strategies also will improve traffic flow and reduce congestion. Mobility benefits will be provided to some extent by several strategies in this bundle. Land use measures will increase access and mode choice to nearby destinations. However, increased development in densely developed areas without supporting transit expansion will lead to increased congestion and potentially negative air quality effects.

This bundle has more significant equity implications than other bundles. Travel costs are increased for drivers, but limited relief is provided because travel options, such as transit, are not expanded. This problem indicates that urban and lower income travelers would be negatively affected by an approach that focuses solely on low-cost strategies to reduce GHGs.

4.10 Summary of Key Findings of Bundle Analysis

What GHG Reductions Are Achieved?

The analysis of these six bundles illustrates how national and local decision makers may consider various combinations of strategies to achieve GHG reductions from transportation.

On an annual basis, in 2050, the annual reduction from baseline emissions for maximum deployment range from a low of 4.0 percent for the Facility Pricing bundle to a high of 24.0 percent for the Long-Term/Maximum Results bundle. For aggressive deployment, the range overlaps with the maximum deployment range and in 2050 shows a high of 18.0 percent for the Long-Term/Maximum Results bundle. The effect of adding economy-wide pricing strategies to each of these bundles is addressed separately, and is described in Section 4.12.

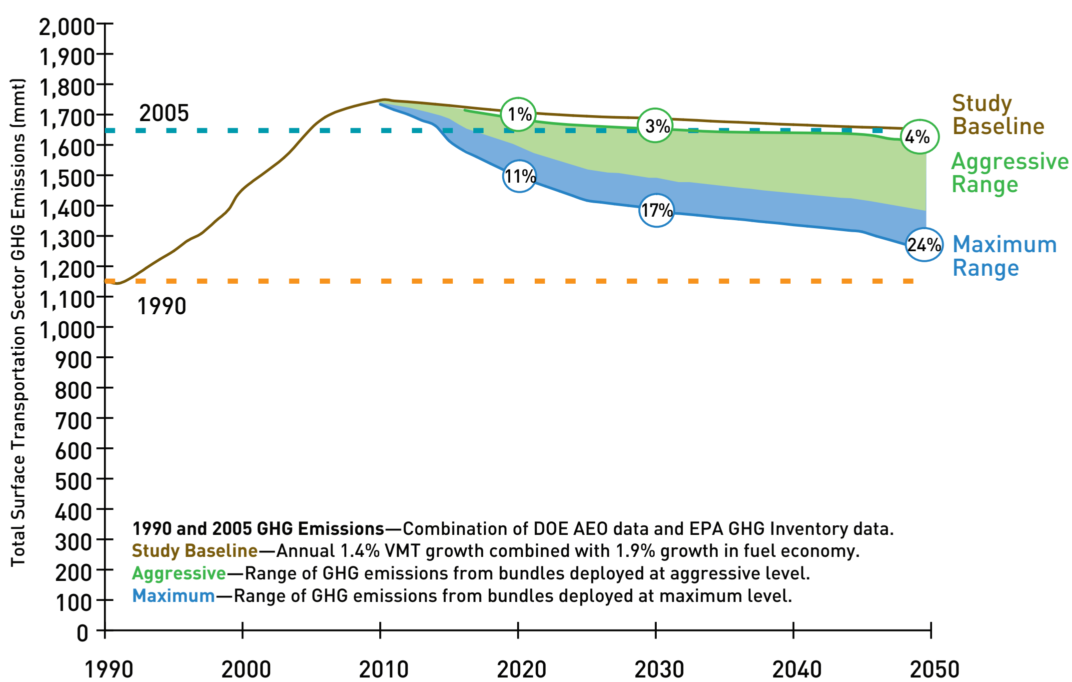
Table 4.15 summarizes the total cumulative GHG reductions through 2050 for each bundle at aggressive and maximum levels. Nationally, cumulative baseline emissions are reduced from 2010 through 2050 from a low of 1.4 Gt (2.1 percent) for the Facility Pricing bundle (at aggressive deployment) to a high of 7.6 Gt (16.0 percent) for the Long-Term/Maximum Results bundle (at maximum deployment). On average, the cumulative GHG reduction from a bundle at maximum deployment is 35 percent greater than the reduction from aggressive deployment.

As with individual strategies, the effectiveness of these bundles needs to be viewed relative to the scale of their potential implementation. Even though their effects on total national reductions are modest, some bundles may be appropriate and more beneficial in helping to meet regional GHG objectives, while enhancing transportation service.

What Are the Costs and Savings?

The national costs to implement the bundles—to build, maintain, operate, and administer each strategy—similarly vary. The cumulative costs to implement the Low Cost and Near-Term/Early Results bundles are relatively modest, while capital

Figure 4.13 **Range of Annual GHG Emission Reductions of Six Strategy Bundles at Aggressive and Maximum Deployment Levels**
2010 to 2050



intensive bundles, such as the Long-Term/Maximum Results bundle are substantial (Table 4.15). These investment costs need to be considered in light of the total GHG reductions that a set of strategies achieves, as well as the array of other objectives that can be simultaneously accomplished. For example, high investment–high return strategy bundles can be designed to contribute to reducing GHGs, while sustaining mobility, supporting economic development, and promoting technology advancements that may help build a stronger 21st-century economy.

Across all bundles, the vehicle costs—the costs of vehicle ownership, maintenance, and fuel—are reduced by the GHG reduction strategies. This effect makes intuitive sense; as VMT decreases and travel becomes more efficient, the savings in fuel and ownership expenses increase. The extent of these savings varies across bundles; the highest vehicle savings are generated in the Long-Term/Maximum Results bundle. In all but one case—the Facility Pricing bundle—the vehicle cost savings exceed the direct costs of implementation.

Table 4.15 also shows the cumulative net included cost and net included cost per tonne of GHG reductions when the vehicle cost savings are subtracted from implementation costs. The Land Use/Transit/Nonmotorized Transportation bundle shows the most negative net included cost per tonne, which results from its promotion of reduced VMT (both amount of travel and travel distance) and the use of alternative modes of transportation (transit, bicycling, and walking) and its relatively low implementation cost.

The Low Cost and Near-Term/Early Results bundles also show negative net included cost per tonne, primarily due to the minimal infrastructure investment and both bundles focus on land use, system operations, and regulatory strategies. On the other hand, the Facility Pricing bundle shows positive included costs per tonne from 2010 to 2050, an indication of high implementation costs combined with lower vehicle cost savings and GHG emission reductions.

How Quickly Are Results Achieved?

While some strategies achieve GHG reductions quickly, others involve significant upfront investments whose effects on GHG reduction are realized over

Table 4.15 **Summary of *Moving Cooler* Bundle Analysis Results: Cumulative GHG Reductions, Implementation Costs, and Change in Vehicle Costs by Strategy (at Aggressive and Maximum Deployment Levels)**
2010 to 2050

	Aggressive Deployment					Maximum Deployment				
		Included Costs					Included Costs			
	GHG Reduction (Gt)	Implementation Costs[a]	Change in Vehicle Costs[b]	Imp. Costs Less Vehicle Costs	Net Cost per Tonne[c]	GHG Reduction (Gt)	Implementation Costs[a]	Change in Vehicle Costs[b]	Imp. Costs Less Vehicle Costs	Net Cost per Tonne[c]
1. Near-Term/Early Results	7.1	$676	-$3,211	-$2,535	-$356	9.3	$945	-$4,779	-$3,834	-$410
2. Long-Term/ Maximum Results	7.6	$2,611	-$4,846	-$2,235	-$293	10.8	$5,105	-$7,668	-$2,563	-$237
3. Land Use/Transit/ Nonmotorized Transportation	3.8	$1,439	-$3,270	-$1,831	-$484	6.3	$2,390	-$5,740	-$3,350	-$531
4. System and Driver Efficiency	5.0	$1,870	-$2,214	-$344	-$69	6.0	$3,338	-$2,737	-$601	$100
5. Facility Pricing	1.4	$2,371	-$1,121	$1,250	$891	1.7	$4,484	-$1,656	$2,828	$1,632
6. Low Cost	7.5	$599	-$3,499	-$2,900	-$387	9.8	$634	-$5,103	-$4,469	-$457

Note: Gt (gigatonne) = one billion metric tonnes.

[a] Implementation cost is the estimated cumulative cost to implement each bundle, including capital, maintenance, operations, and administrative costs.

[b] Vehicle cost is the estimated cumulative reduction in the cost of owning and operating vehicles from a societal perspective, which would result with reductions in VMT and fuel consumption experienced with implementation of each bundle. Vehicle costs DO NOT include other costs and benefits that could be experienced as a consequence of implementing each bundle, such as changes in travel time, safety, user fees, environmental quality, and public health.

[c] Included cost per tonne is simply the estimated cumulative cost of implementation, less the estimated vehicle cost savings divided by the estimated cumulative reduction in GHG emissions for each bundle.

several decades. Figure 4.14 compares the cumulative GHG reductions during four decades. In all bundles, more GHG reductions are achieved in each of the decades after the first one, generally reflecting the challenge in obtaining short-term cumulative reductions from a number of strategies. This observation is particularly true for bundles that have long-term implementation schedules, such as land use and infrastructure-based bundles. The Near-Term/Early Results bundle shows the largest share of cumulative reductions (41 percent) before 2030. Conversely, the Land Use/Transit/Nonmotorized Transportation bundle shows approximately 68 percent of its total reduction after 2030; most benefits are realized in the later decades. Interestingly, the Near-Term/Early Results and Long-Term/Maximum Results bundles both show roughly the same reductions before 2020, because they both share strategies that will yield early results. The higher cumulative reductions achieved by the Long-Term/Maximum Results bundle result from longer-term strategies not included in the Near-Term/Early Results bundle.

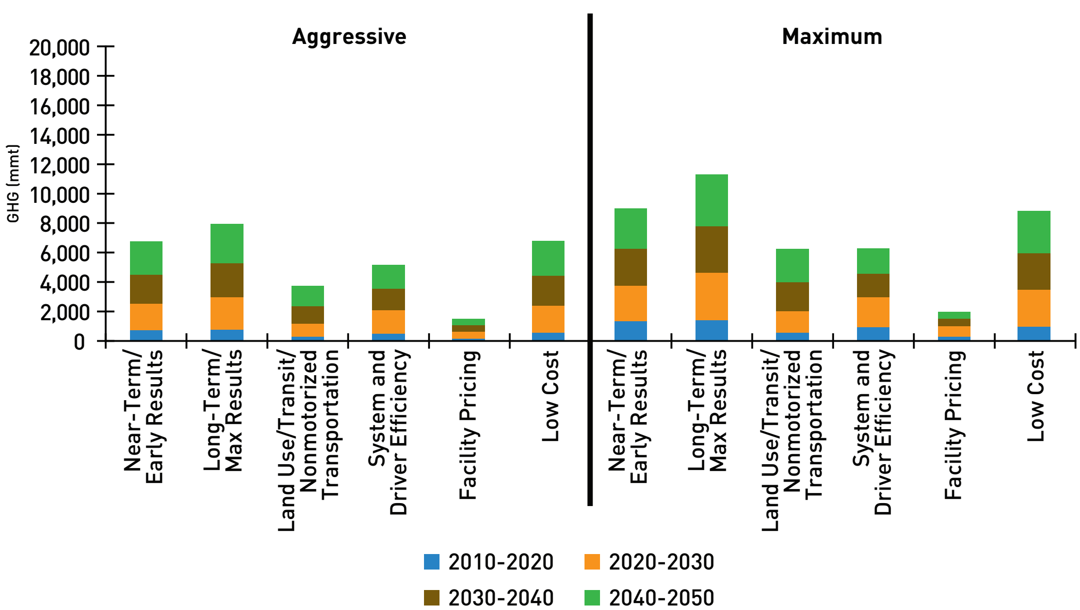
What Are the Fuel Savings?

All strategies to reduce transportation GHG emissions reduce the amount of carbon-based fuel consumed. Figure 4.15 shows the annual gallons of fuel saved by bundle from 2010 to 2050. The resulting cumulative (years 2010 to 2050) gallons of fuel saved by the bundles at an aggressive level of deployment ranges from 2 to 11 percent of total projected on-road fuel consumption. Under maximum deployment, the bundles result in savings in cumulative gallons of fuel consumed from 3 to 15 percent. (Figure 4.16). These decreases are equivalent to a cumulative national fuel savings of 180 billion to 1,120 billion gallons of gasoline and diesel fuel, or 4.3 billion to 26.7 billion barrels of oil during 40 years. The addition of economy-wide pricing strategies would further increase the fuel savings that could be achieved. The potential for transportation GHG reduction strategies to improve the nation's energy security through reduced fuel use is a significant added benefit. Compared to DOE's Annual Energy Outlook 2009 forecasts through 2030,[2] the range of fuel savings from the maximum deployment bundles equates to a reduction from 5 to 21 percent of the total forecasted U.S. oil imports from 2010 to 2030.

Who Pays?

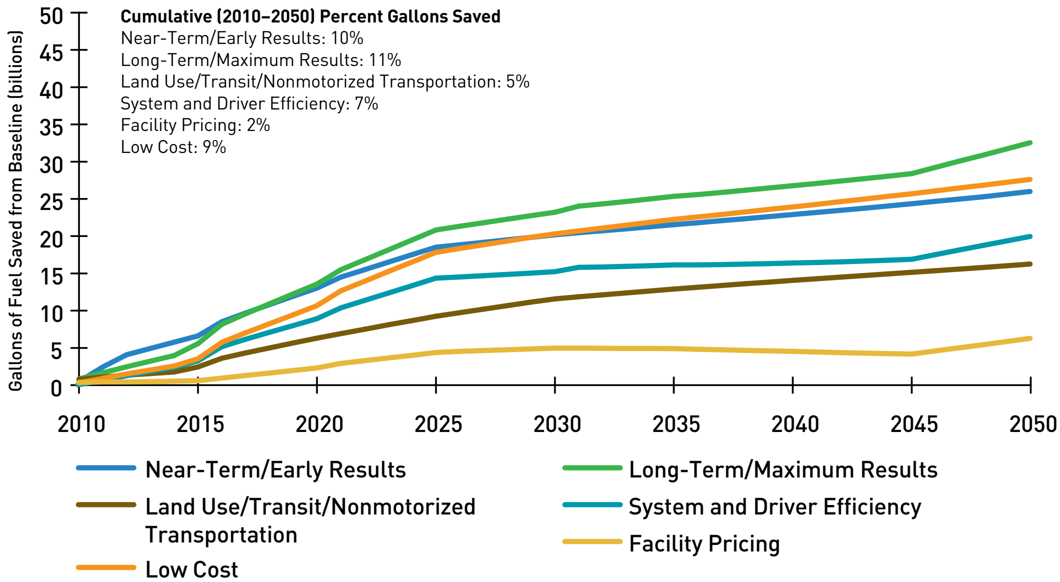
The costs of implementing these strategies are borne by different participants in the national economy. Implementing agencies would pay for

Figure 4.14 **Cumulative GHG Reduction by Bundle over Time at Aggressive and Maximum Deployment Levels**



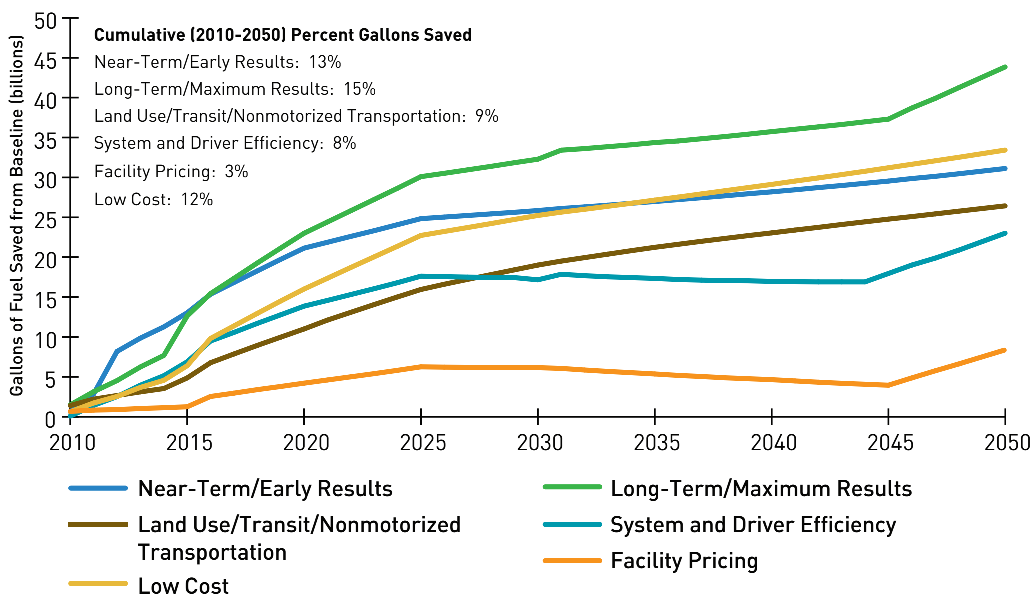
Note: This figure displays the cumulative GHG reduction by bundle (aggressive and maximum deployment levels shown separately) across four 10-year periods from 2010 through 2050. For all bundles, the majority of reductions are achieved after 2030. These reductions do not include economy-wide pricing, such as fuel/carbon pricing.

Figure 4.15 **Gallons of Fuel Saved by Each Bundle at Aggressive Deployment (without Economy-Wide Pricing)**
2010 to 2050



Note: The figure displays the number of gallons of fuel saved from the baseline for each bundle during the 2010 to 2050 time period, assuming an aggressive level of deployment. The cumulative percentage of gallons saved during this time period ranges from a high of 11 percent saved by the Long-Term/Maximum Results bundle to a low of 2 percent saved by the Facility Pricing bundle.

Figure 4.16 **Gallons of Fuel Saved by Each Bundle at Maximum Deployment (without Economy-Wide Pricing)**
2010 to 2050



Note: The figure displays the number of gallons of fuel saved from the baseline for each bundle assuming maximum deployment during the 2010 to 2050 time period. The cumulative percentage of gallons saved during this time period ranges from a high of 15 percent saved from the Long-Term/Max-Results bundle to a low of three percent saved from the Facility Pricing bundle.

putting strategies in place; drivers and businesses incur the costs and savings of changes in fuel prices and other vehicle costs. Travelers also are affected by changes in the travel times, by increases in transportation costs or fees, and by increased or reduced access to transportation options.

As the nation tackles climate change, how all of these costs would be managed and mitigated is a vitally important challenge, to ensure a strong economy and the equitable distribution of burdens across the population.

Strategies to reduce transportation GHG emissions require financial investment. The cumulative direct implementation costs are considerable, even for low-cost strategies: during the four decades studied, the nation would spend $600 to $634 billion to implement the Low Cost bundle and as much as $5.10 trillion to implement the bundles that include infrastructure-intensive strategies. While pricing strategies, including the economy-wide pricing assessed in Section 4.12, can generate revenues to apply to these costs—and indeed revenues received by implementing agencies could exceed the costs to implement, if pricing levels are set sufficiently high—the investments called for would require a major national commitment.

Consumers incur direct costs for many of these scenarios. Economy-wide pricing measures—in the form of carbon pricing, PAYD, or VMT fees—as well as local facility pricing measures net of any subsidies, such as reduced transit fares, would cost travelers and businesses $1.42 trillion to $6.43 trillion between 2010 and 2050. When combined with vehicle cost savings resulting from reductions in VMT fees and delays, the nationwide direct costs to users are negative: users would save on a per capita basis. These average annual savings range from $90 per year to $800 per year.

Many of these savings, of course, result from reduced levels of travel. Some of the reduced travel comes without a loss of economic welfare; for example, when land use changes enable desired travel to occur in shorter trips, resulting in lower total vehicle miles. However, some reductions in vehicle miles may reduce the economic well-being of some groups. Low-income users may have travel reduced or even be priced off the system entirely by higher fees or tolls, and may have to pay higher proportions of their income for fuel or congestion fees. Investments in highway infrastructure and operations, carpools, and transit can alleviate the effects of this lost mobility for low-income groups. Other measures place additional burdens on travelers, particularly by increasing travel times.

Conversely, on a national basis, costs incurred by users may translate to revenue for implementing agencies; these financial transfers provide the revenues to implement improvements to the transportation network, and in that respect, provide significant society-wide benefits in terms of enhanced mobility, as well as GHG reductions. Our society would also benefit significantly from the reductions in resources applied to vehicle operations and fuel consumption.

What Are the Main Co-Benefits and Externalities of the Strategy Bundles?

Strategies designed to achieve GHG reductions often make sense for other reasons as well. Because the strategies focus on improving the efficiency of travel and reducing emissions from fuels, these approaches usually result in better air quality and public health, less congestion on roads, and often more travel options for the traveling public. Investments in transit, highways, and rail improve transportation service, while the efficiency of these better networks can result in safer, less polluting transportation. Lower speed limits produce safety benefits, reducing the number of fatalities and injuries that occur on the nation's highways. Improvements in freight operations improve the efficiency of moving goods across the country and across town, while improving air quality due to lower truck emissions. Programs such as employer commuter benefits and car-sharing can reduce the cost of travel for workers, while easing travel congestion. Thoughtful design of denser mixed-use cities can reduce the distance and time people need to travel, enable residents to safely walk and bicycle to more destinations, preserve open space, improve water, air quality, and public health, and increase social capital as more opportunities for personal interaction are created.

Not all effects are positive, however. Regional and local pricing measures—such as higher parking fees or congestion pricing—increase the costs of travel for all, most notably for lower-income people who can least afford higher transportation costs. Investments focused on urban areas might create perceptions of inequitable investment in rural areas. Some land use changes could result in households buying smaller homes and lots, which could be considered a loss of welfare to some consumers. Reduced speed limits increase travel times.

GHG reduction measures—particularly changes in fees and pricing—also may change the financial capacity and business practices of transportation agencies. In particular, increased implementation of any of the pricing strategies could produce new revenues to support transit, highway, and other improvements. In turn, these revenues can help mitigate potential inequities created by higher prices, as discussed in more detail in Section 4.13.

4.11 Sensitivity Analysis

The starting point for all of the *Moving Cooler* analyses of GHG reductions are referred to as the study "baseline" (see Section 3.2 for details). Three alternative baseline scenarios were developed to investigate the sensitivity of bundle GHG reduction estimates to differing assumptions. These scenarios and their effects on projected GHG emissions relative to the baseline assumptions shown are described and shown graphically in Section 3.0. Table 4.16 below presents the results of the sensitivity tests. In summary:

- **High Price, Low VMT.** Under this scenario, fuel prices increase faster than assumed in the baseline forecast, resulting in lower VMT growth and better fuel economy. This scenario results in GHG emissions that are less than in the baseline case. This scenario means that all bundle strategies, whether they focus on reducing VMT or fuel consumption through reducing delay, will be affecting a smaller base and would therefore result in lower GHG reductions.
- **Low Price, High VMT.** Under the second scenario, fuel prices stay low compared to those assumed in the baseline, resulting in higher VMT growth and lower fuel economy. This scenario results in GHG emissions that are higher than the baseline as a result of more travel and higher emissions per vehicle mile. With most bundles, the composite strategies would therefore be impacting a larger base of both VMT and fuel economy, and would achieve higher GHG reductions than estimated under the baseline case. This effect is not true for all bundles, however. The Near-Term/Early Results and Low Cost bundles show cumulative decreases in GHG emissions. These decreases occur because the reductions from these two bundles are focused primarily on facility pricing strategies and in general, the impact of facility pricing will decrease when the overall cost of travel is lower.
- **High Technology, High VMT.** Under the third scenario, technology (including both fuel economy and low carbon fuels) progresses more rapidly than assumed in the baseline, reducing the cost of driving and resulting in higher VMT growth but with lower GHG emission impacts. The result is that GHG emissions are projected to be lower than the baseline, but not as low as in the first sensitivity test. However, because VMT also increases with technology enhancements, the cost of travel is the least of all the sensitivity tests and thus the impacts of strategies, particularly facility pricing, are less effective.

Table 4.16 illustrates the results of sensitivity tests, assuming different baselines for each bundle at both aggressive and maximum deployment levels.

The sensitivity analysis procedure was applied to the Obama Administration's new proposed national fuel economy standard, extrapolating 2016 guidelines to the year 2050, using the same assumptions as the *Moving Cooler* baseline fuel efficiency forecasts. Figure 3.2, as discussed earlier, shows that the Obama Administration's proposal in the short term roughly follows the high technology, high VMT growth sensitivity test emissions. Beyond 2025, the trend follows more closely to the *Moving Cooler* study baseline. The analysis shows that under this scenario, individual strategy and bundle results in percentage terms would each be reduced by about 10 percent from baseline estimates.

4.12 Impacts of Economy-Wide Pricing

Economy-wide pricing refers to a small set of strategies that would be implemented nationally to send price signals that affect consumer behavior. Economy-wide pricing strategies include PAYD and VMT fees, which only affect the number of miles traveled, motor fuel (gasoline and diesel) taxes, which affect VMT and also encourage the purchase of more fuel-efficient vehicles, and carbon pricing and cap-and-trade mechanisms, which reduce VMT, encourage more fuel-efficient and less GHG-intensive vehicles, and which also have other effects in petroleum and energy consumption across all sectors (not modeled in this analysis).

Moving Cooler separately examined the additional GHG reductions that could be achieved for each bundle, if economy-wide pricing strategies are overlaid on the other strategies that comprise each bundle. This analysis looks at the additional impact on GHG emissions if the costs of driving, fuel, and GHG emissions become more expensive through the application of these strategies.

Table 4.16 **Sensitivity Test Results for Each Bundle at Aggressive and Maximum Deployment: Cumulative GHG Emission Reductions (Gt) (without Economy-Wide Pricing)**

	Near-Term/ Early Results (Gt)	Long-Term/ Maximum Results (Gt)	Land Use/ Transit/ Nonmotorized (Gt)	System and Driver Efficiency (Gt)	Facility Pricing (Gt)	Low Cost (Gt)
Aggressive Deployment						
Bundle Analysis	7.1	7.6	3.8	5.0	1.4	7.5
Sensitivity Tests						
High Price, Low VMT	5.6	6.9	2.9	4.9	1.4	6.1
Low Price, High VMT	6.4	7.8	3.8	5.4	2.0	7.1
High Technology, High VMT	4.9	5.1	2.2	4.2	0.5	5.5
Maximum Deployment						
Bundle Analysis	9.3	10.8	6.3	6.0	1.7	9.8
Sensitivity Tests						
High Price, Low VMT	7.5	9.4	4.6	5.7	1.8	7.9
Low Price, High VMT	8.7	10.9	6.4	6.8	2.4	9.7
High Technology, High VMT	6.8	8.2	3.6	5.0	0.4	7.4

Impact of PAYD Insurance and VMT Fees

While all of the economy-wide pricing strategies affect vehicle travel, as they all affect the cost of travel in some way, reduction in VMT is the primary focus of the PAYD and VMT fee measures. These two strategies involve charging drivers based on their individual VMT, collected through audited odometer readings and advanced electronic, GPS, and other telematics means that can accurately report VMT without violating personal privacy.

PAYD will reduce VMT as users become aware of the insurance costs they are paying on a per-mile basis and are prompted to reduce their costs by traveling less. As explained in Section 3.0, while this same signal exists today in terms of the cost of a gallon of gasoline or travel time costs, PAYD shifts an additional portion of overall vehicle costs from a fixed payment basis to a basis that can be controlled simply by driving less. The price signal from PAYD (6.6 cents per mile) was estimated to phase in by 2025, reaching 75 percent of drivers in the aggressive implementation scenario and 100 percent of drivers with maximum implementation. Because the cost of PAYD is tied to a driver's level of individual travel, the financial impact on drivers will vary, with those driving more paying the highest costs annually, and those driving less paying lower annual costs.

Table 4.17 shows the results of adding the VMT-related effects of PAYD onto each of the bundles, at both the aggressive and maximum level. For the aggressive level, the result is an added 1.7 Gt cumulative reduction (e.g., 3.1 Gt – 1.4 Gt for the Facility Pricing bundle). For the maximum level, the result is an added 2.2 Gt cumulative reduction.

A VMT-based fee would work in much the same way as PAYD, providing a travel-based signal to drivers that would result in reduced VMT. This strategy includes a $0.03 per mile fee at aggressive deployment and 12 cents per mile at maximum deployment. The effect of VMT fees alone range from a 0.8 Gt increase in cumulative reductions for the bundles at the aggressive level, and a 3.4 Gt increase in cumulative reductions for the bundles at the maximum level.

Through 2050, the cumulative combined effect of these two strategies range from an additional reduction of 2.5 Gt at the aggressive level, to 5.6 Gt at the maximum level. In total, these cumulative reductions range from a 4 to 8 percent reduction of cumulative baseline GHG emissions through 2050. The annual reductions from these strategies are available in the Technical Appendix located at www.movingcooler.info.

Table 4.17 **Summary of Bundles Cumulative (2010 to 2050) GHG Reductions with PAYD Insurance and VMT Fees (VMT Effect Only)**

Cumulative 2010-2050 GHG (Gt) Reduction (Aggressive Deployment)	Near-Term/ Early Results	Long-Term/ Maximum Results	Land Use/ Transit/ Nonmotorized Transportation	System and Vehicle Efficiency	Facility Pricing	Low Cost
Aggressive Deployment						
Bundle	7.1	7.6	3.8	5.0	1.4	7.5
Bundle + PAYD Insurance	8.8	9.3	5.5	6.7	3.1	9.2
Bundle + PAYD Insurance + VMT fees	9.6	10.1	6.3	7.5	3.9	10.0
Maximum Deployment						
Bundle	9.3	10.8	6.3	6.0	1.7	9.8
Bundle + PAYD Insurance	11.5	13.0	8.5	8.2	3.9	12.0
Bundle + PAYD Insurance + VMT fees	14.9	16.4	11.9	11.6	7.3	15.4

Motor Fuel and Gasoline Taxes

Motor fuel and gasoline taxes are one potential alternative to VMT fees, and were considered in this study as a replacement for, rather than an addition to, such fees. These taxes affect both VMT and fuel economy by providing an economic incentive to reduce costs, as do carbon pricing and cap-and-trade pricing (discussed below). However, unlike carbon pricing and cap-and-trade strategies, these taxes do not account for the expected increasing shift to electric or alternative fuel vehicles. Therefore, for the purpose of analysis in this study, carbon pricing and cap-and-trade mechanisms are used to allow for the full range of potential fuel and technology adoption pathways.

Carbon Pricing and Cap-and-Trade Mechanisms

Nationwide carbon pricing and cap-and-trade mechanisms are equivalent in their effects on the transportation sector, given an equivalent carbon price.[3] Both increase the cost of travel per mile (due to the increased cost of fuel) and change the cost of fuel per mile (due to changes in fuel costs based on their carbon content. The effects are modeled using both of these components.[4]

The two measures were converted to costs per VMT, based on the analysis of vehicle average fuel economy that has been previously presented. This cost per mile, which was calculated annually, is sensitive to the changing fuel efficiency of the vehicle fleet. This approach was used as a basis for estimating the VMT effect of these strategies, using the same methodology as PAYD insurance and VMT fees.

To place the VMT fee in context: A VMT fee of $0.03 per mile (aggressive level of deployment) would represent a 5 percent increase in the Internal Revenue Service's assumption of vehicle costs per mile ($0.58.5 per mile for 2008). In terms of per gallon costs, the $0.03 per mile VMT fee would be equivalent to $0.63 per gallon in the early years; as fuel economy increases, the cost per gallon would rise to maintain the same cost per mile. The maximum deployment level VMT fee is substantially greater.

Once the VMT fee was established, the effects were calculated for the change in MPG (or GHG/mile) that would occur because consumers would be purchasing more fuel-efficient and lower GHG-emitting vehicles, because of the increased cost of fuel (or relative cost of more carbon-intensive fuel). This improvement in MPG/GHG emissions per mile was used to calculate an additional GHG savings from reduced emissions per mile. Finally, feedback (or rebound) effects were accounted for by incorporating the effects that the purchase of more fuel-efficient vehicles would lower travel costs and thus create a partially offsetting effect in VMT. This rebound effect was reflected in both VMT and GHG emission results.

Impact of VMT and MPG Effects of Carbon Pricing

Table 4.18 shows the combined effects of adding both the VMT and fuel efficiency-related impacts of carbon pricing to each bundle. These effects range from a 4.4 Gt increase in cumulative reductions for

Table 4.18 **Summary of Bundles Cumulative (2010 to 2050) GHG Reductions with Carbon Pricing (VMT and MPG Effect)**

Cumulative 2010-2050 GHG Reduction (in Gt)	Near-Term/ Early Results	Long-Term/ Maximum Results	Land Use/Transit/ Nonmotorized Transportation	System and Driver Efficiency	Facility Pricing	Low Cost
Aggressive Deployment						
Bundle	7.1	7.6	3.8	5.0	1.4	7.5
Bundle + VMT effect of Carbon Price	8.2	8.7	4.9	6.1	2.5	8.6
Bundle + VMT + MPG effect of Carbon Price	11.5	12.0	8.2	9.4	5.8	11.9
Maximum Deployment						
Bundle	9.3	10.8	6.3	6.0	1.7	9.8
Bundle + VMT effect of Carbon Price	14.1	15.6	11.1	10.8	6.5	14.6
Bundle + VMT + MPG effect of Carbon Price	24.7	26.2	21.7	21.4	17.1	25.2

the aggressively deployed bundles and a 15.4 Gt increase in cumulative reductions for the bundles at maximum deployment. The very large difference between results at the aggressive and maximum levels of deployment is because of the difference in cost per mile or cost per gallon increases (see Table 2.1). These results demonstrate the very powerful additive effects that pricing can have in reducing GHG emissions.

Fuel Efficiency-Related Impacts of Carbon Pricing

The overlay of fuel efficiency effects of carbon pricing measures on each bundle will have a stronger potential impact on each bundle than the VMT impacts of both PAYD and VMT fees. When the fuel efficiency-related aspects of carbon pricing are introduced to any bundle, the cumulative GHG reductions through 2050 increase by 3.3 Gt for the aggressive level of deployment and by 10.6 Gt for the maximum level. These increases compare to cumulative increases of 2.2 Gt and 5.6 Gt for the aggressive and maximum levels of deployment with the combined VMT impacts of PAYD and VMT fees.

Across both aggressive and maximum deployment, the fuel economy effect of carbon pricing is two to three times greater than the VMT effect of carbon pricing.

4.13 Equity Implications of GHG Reduction Strategies

It is clear from this analysis that there are many reasons, other than reductions in GHGs, to implement the strategies examined in this study. The distribution among different groups of the monetary and other transportation and non-transportation costs and the benefits of implementing these strategies illustrate that implementation of GHG reduction strategies poses serious equity issues. Interestingly, the characteristics of these strategies can work together to both generate a variety of benefits to the society overall, while also addressing the potential adverse equity effects of implementing the strategies.

Potential Equity Issues

The potential equity issues that might occur with the implementation of differing types of *Moving Cooler* strategies and opportunities to address them are summarized below.

- **Pricing strategies.** All pricing strategies, unless mitigated, would adversely impact lower-income groups more than those with higher incomes. The poorest users get fewer benefits from congestion pricing, VMT fees, or other fees, because they spend a higher proportion of their income on transportation, are less able to afford to pay higher fees, and may be priced off these services altogether. Rural or exurban users, because of lower incomes and fewer transit and carpool options, will have equity issues from pricing that may be even harder to remedy. To mitigate these adverse equity effects, the revenues generated by the pricing strategies could be used to invest in other transportation services, as noted in the following paragraphs, or to fund income transfers among those affected by the strategies.

- **Land Use and Smart Growth.** Land use and smart growth can improve accessibility and mobility for those without access to autos, and enable individuals in all income groups to avoid the increased costs of travel that would occur with other GHG reduction strategies, thereby providing an option to mitigate the adverse effects of those strategies. While there are potential concerns with the effects on property values, these may be offset by decreased transportation costs. Gains and losses to property owners in more or less centrally located areas from the changes in land use regulation are a secondary concern, but should be noted.
- **Nonmotorized.** Investment in nonmotorized modes can have substantial positive equity effects by increasing mobility for lower-income groups and all those without significant access to vehicles (youth, the elderly, disabled persons, or others unwilling or unable to obtain a driver's permit).[5] These new modes would enhance their access to jobs, medical care, education, retail services, and other needed services.
- **Public Transportation.** Public transportation services provide access to employment opportunities, health care, education, retail services, and other services. Because lower-income people rely more on public transportation than other groups, public transportation improvements can potentially channel higher percentages of benefits to lower-income people and those without other mode choices, such as people who reside in rural areas. As with nonmotorized transportation, these benefits also should apply to many in the driving-age population without daily access to an automobile. Public transportation improvements can thus remedy part of any mobility loss due to pricing measures. Reduced fares also can make transit more affordable for lower-income groups.
- **Commuter, HOV, Carpool, and Vanpool.** Commuter, HOV, carpool, and vanpool measures can improve equity by providing low-cost mobility and access to jobs, medical care, education, retail, and other needed services for lower-income, disabled, and other users who are most in need of sharing the costs or tasks of travel. These strategies, along with investments in public transportation services, may be particularly helpful in rural settings to mitigate other inequities. These equity benefits would also apply to many others who are unable to drive a vehicle.
- **Regulatory.** Lower speed limits will impose significant travel time penalties on all groups, and perhaps more on rural users. Lower speeds improve safety, by reducing fatalities and injury incidents.
- **System Operations and Management.** System operations measures have no significant equity issues, except for ramp metering, which may have negative effects on drivers who must access the metered roadway from locations closer to urban centers than other drivers.
- **Capacity Expansion and Bottleneck Relief.** Highway improvements provide significant mobility and accessibility benefits to all highway users. Economy-wide pricing, by providing a source of funding to make investments in capacity expansion and bottleneck relief, can mitigate the equity issues caused by higher per mile costs from the pricing measures. These strategies can thus provide improved access to employment opportunities, health care, education, retail services, and other services for highway users.
- **Multimodal Freight Strategies.** Freight strategies, while potentially having some redistributive effects across freight modes, should have no negative equity implications for other users and may decrease congestion. They can enhance delivery of various goods and services to businesses and consumers.

All of these factors will influence the design of national and local strategies to reduce GHGs from transportation. There are significant opportunities to build win-win solutions through integrated approaches that improve the nation's transportation network and enhance mobility, in addition to creating the benefits of the reductions in GHG emissions. However, the investment costs of some of these strategies are considerable and the potential for negative equity effects from some of the pricing strategies are high, absent strong policy intervention.

Many negative effects—any mobility losses and particularly the potential burdens placed on lower-income and rural travelers—could be addressed by using the revenues from fees and taxes to provide substantial benefits; for example, through highway, ride-share, transit, or other improvements or through financial reimbursements to lower-income and other low-mobility groups. These reinvestment strategies could help ensure that lower-income and other low-mobility groups do not have their travel restricted as a result of increased costs because of pricing or other measures.

Pricing Strategies and Equity

The analysis presented in this section shows that pricing strategies have the potential to generate reductions in GHG emissions greater than those of many other individual strategies. By the same token, pricing strategies also present the most significant equity issues for lower-income groups and rural residents. According to the U.S. Bureau of Labor Statistics data, the lowest-income group spends four times the percentage of their income on motor fuel, when compared to the highest-income group. Given this fact, any strategy that increases the price of travel will have a disproportionate effect on lower-income populations.

Table 4.19 shows the incomes, transportation expenditures, motor fuel expenditures, and the percentages of income paid by income quintiles for 2007. Each income quintile represents the average of one-fifth of the households in the U.S., ranked by income level from the lowest one-fifth of households to the highest one-fifth of households.

The last row of the table shows how much each income group now spends on motor fuel and oil, in comparison to its income. Virtually all these expenditures are on motor fuel itself. While the lowest-income group spent nearly 10 percent of its after-tax income on motor fuel in 2007, the highest-income quintile spent about 2.5 percent of income.

Approaches for addressing potential equity effects of higher prices need to first identify how those prices affect different populations. Planning organizations are increasingly analyzing overall equity effects as part of their planning processes. For example, the analyses performed by such MPOs as the San Francisco Metropolitan Transportation Commission explicitly estimate how planned transportation expenditures are allocated to lower-income households, as compared to all other households. This type of analysis will be central to first understanding and then mitigating equity effects of pricing strategies to reduce GHGs.

The revenues generated by the pricing strategies can be a significant part of the response to mitigate inequities through the reinvestment of those revenues in other transportation services. There can be three basic ways of mitigating equity effects with these revenues. First, revenues created by the pricing strategies could be transferred to affected groups. Second, these revenues could be reinvested in the transportation system to benefit all groups. Third, transportation investments could be further focused on those portions of the transportation system, such as public transportation, that are used more extensively by lower-income populations.

Addressing Equity through Rebates

As one example of how revenue transfers might be used to address inequities, an MIT study evaluated the economic consequences—that is the gain or loss of income—of GHG and energy tax proposals. In its examination of a carbon tax equivalent to a $27 per ton CO_2 price or a $0.26 increase in the price of regular gasoline, MIT estimated that the revenues generated would total from 3 to 21 percent of federal rev-

Table 4.19 **Equity Analysis by Quintile of Income: Motor Fuel Expenses as a Percentage of Income of U.S. Households**
2007

Parameters	Lowest One-Fifth	Second One-Fifth	Middle One-Fifth	Fourth One-Fifth	Highest One-Fifth	Average
Income After Tax	$10,534	$27,419	$45,179	$70,050	$150,927	$60,858
Transportation Expenditures	$3,242	$5,717	$7,926	$11,058	$15,831	$8,758
Air and Public Transportation	$171	$242	$362	$506	$1,406	$538
Private Transportation	$3,071	$5,475	$7,564	$10,552	$14,425	$8,220
Percent Spent on Private Transportation	29.2%	20.0%	16.7%	15.1%	9.6%	13.5%
Gas and Oil Expenditures	$1,046	$1,768	$2,418	$2,988	$3,696	$2,384
Percent Spent on Gas and Oil	9.9%	6.5%	5.4%	4.3%	2.5%	3.9%

Source: U.S. Department of Labor, "2007 Bureau of Labor Statistics Consumer Expenditure Survey," 2008, http://www.bls.gov/cex/home.htm.

enues in 2050. The carbon pricing revenues evaluated by MIT would apply to all sectors of the economy, not just to transportation. MIT also estimated that the monetary impacts of a carbon tax on households—constituting an income loss—ranged from 3.7 percent of the income for the lowest 10 percent to only 0.8 percent of the income for the highest 10 percent of households. To address this inequitable effect, MIT estimated the effects of a "lump sum" rebate of all carbon revenues to all households. Rebating all revenues as a common lump sum would result in a 5.6 percent income gain for the lowest 10 percent of households to a 0.6 percent gain for the highest 10 percent of households. The net equity results generated by MIT are shown in Table 4.20.

It is conceivable that rebates of general carbon taxes might use just a portion of the total revenues generated, rather than reimburse households the full amounts that are generated. This allocation would allow some proceeds to be used for transportation investments that could provide benefits to all income groups.

Addressing Equity through Highway Reinvestment

Revenue reinvestment is widely acknowledged by economists and policy makers to be an effective response to inequitable income effects of user fees, by redistributing benefits through transit, highway, or other investments. Using pricing revenues to reinvest in the transportation system is therefore another way to address potential inequities. A highway investment analysis conducted for AASHTO's Bottom Line report[6] estimated the net user cost savings of higher levels of investment that would be economically justified, compared to current investment levels. The analysis showed that the increased user benefits were two times greater than the increased investments needed. All of the projects implemented in this analysis return benefits that are greater than their costs. These net benefits are proportional for each income group's use of the roads, as are the motor fuel taxes paid by each group. Given this positive return, investments will provide a benefit to all groups, which will help offset the higher price of travel. Operations improvements have been shown to have even higher net returns on investments than the average for other types of highway investments.

Table 4.20 **Distributional Impacts of Carbon Tax and Lump Sum Rebate**

Income Decile	Carbon Tax as Percent of Income (Income Loss) (percent)	Lump Sum Rebate as Percent of Income (Income Gain) (percent)	Net Impact (percent)
1	-3.7	5.6	1.9
2	-3.0	4.0	1.0
3	-2.3	3.1	0.8
4	-2.0	2.4	0.4
5	-1.7	2.1	0.4
6	-1.5	1.6	0.1
7	-1.3	1.3	0.0
8	-1.2	1.2	0.0
9	-1.0	0.9	-0.1
10	-0.8	0.6	-0.2

Source: Gilbert E. Metcalf, Sergey Paltsev, John M. Reilly, Henry D. Jacoby and Jennifer Holak, *Analysis of U.S. Greenhouse Gas Tax Proposals*, Report No.160, (Boston: MIT Joint Program on the Science and Policy of Global Climate Change, Massachusetts Institute of Technology, April 2008).

Addressing Equity through Targeted Public Transportation Investments

Focusing reinvestment of the pricing revenues on public transportation improvements is another way to address equity. And, like the highway investment above, it also returns significant economic benefits. Because public transportation is used disproportionately by lower-income users, by other disadvantaged groups such as the disabled, and by those too young or too old to drive, providing more services would benefit those groups and offset the effect of higher prices of travel by automobile.

A Cambridge Systematics report for APTA, *Public Transportation and the Economy* (2000, and 2009 Update),[7] found returns on investment of three to one or more for public transportation capital improvements. The average returns for the largest urban areas is six to one. These returns on investment were calculated using a much broader measure of benefits than in the highway benefit calculations, so the results of these studies do not directly compare the return on investment for public transportation and for highway investments.

Summary of All Findings of the Equity Analysis

The most important findings of the *Moving Cooler* equity analysis are:

- Pricing strategies, including congestion pricing, VMT fees, motor fuel taxes, carbon taxes, parking pricing, and other fees, would have equity implications and would require consideration of offsetting measures to remedy equity concerns. Lower-income groups pay four times as high a percentage of their income for motor fuels as the highest-income groups, and would receive even more inequitable effects from pricing strategies that increase their traveling costs.

- Equity issues for lower-income or other disadvantaged groups created by pricing strategies could be addressed through reinvestment in highways, public transportation, nonmotorized transportation, system operations, commuter and ridesharing programs, and other *Moving Cooler* suggested actions. However, equitable reinvestment is a key policy decision and will not happen automatically.
- Equity-based reinvestment is economically justified. Analyses of highway and public transportation strategies in *Moving Cooler* and the results of the cost-benefit studies cited above conclude that these investments provide economic returns on these investments ranging from two to one or three to one or more, in terms of their benefits in relation to costs.
- Carbon taxes on all fuels or the effects of cap-and-trade on the prices of all fuels also will increase other nontransportation fuel costs for lower-income groups.

The highway and transit investments evaluated in *Moving Cooler* could remedy negative equity effects of higher fees on lower-income groups. Although all groups would receive net benefits after paying the increased fees, the incidence of added motor fuel user fees on the household budgets of lower-income groups is still of concern. Additional equity repayments suggested by MIT and other researchers for lower-income groups also could be used.

The bottom line is that—with sufficient political will and careful program design—the equity concerns about any particular strategy or group of strategies to reduce GHG emissions can be addressed through bundling with other strategies and the reinvestment or redistribution of revenues generated by GHG reduction strategies.

Notes

1 Cities with populations greater than 500,000.

2 Energy Information Administration, *Annual Energy Outlook 2009*, Table 7—Transportation Sector Key Indicators and Delivered Energy Consumption. Annual Energy Outlook 2009, Table 11—Liquid Fuels Supply and Disposition. (Washington, DC: EIA, U.S. Department of Energy, 2009). Available at http://www.eia.doe.gov/oiaf/aeo/index.htm.

3 The difference is that carbon pricing provides a fixed carbon price (albeit subject to governmental changes to meet societal and climate change goals) while a cap-and-trade system results in a carbon price that varies, depending on emissions across multiple sectors to meet governmental carbon emission goals through market forces.

4 Both of these measures are likely to be implemented across all sectors if they are implemented at all. This implementation would have additional feedback effects on petroleum and energy demand at the national level that would include some feedback on this analysis. However, these effects were estimated to be insignificant for this analysis as well as far beyond its scope, and so thus were not estimated.

5 According to U.S. Census 2007 estimates, 15 percent of the age-eligible U.S. population does not hold a driver's license. When accounting for the elderly, those unable to afford a car, and multi-driver and single-vehicle (or similar) households, a significantly larger portion of the U.S. population does not have daily access to a personal vehicle.

6 American Association of State Highway and Transportation Officials, *Transportation: Are We There Yet?: Bottom Line Report*, (Washington, DC: AASHTO, 2009).

7 American Public Transportation Association, *Public Transportation and the Economy* (Washington, DC: APTA, 2000, and updated 2009).

5.0 Conclusions

THE DEBATE ON HOW TO MEET the nation's climate change challenge is well underway, and ambitious goals for GHG reductions are likely to be established. Proposals under discussion would set national targets for up to an 83 percent reduction from 2005 levels of emissions by 2050—equivalent to an economy-wide reduction of more than 5,900 million metric tonnes (mmt) of GHGs. To meet these substantial reduction goals, all sectors of the economy—including transportation—are challenged to identify strategies that can contribute to major reductions in GHGs. Currently, roughly 28 percent of the United States' GHG emissions are produced by transportation, and transportation emissions have been growing faster than those of other sectors.

Previous research has focused on the potential contributions of new vehicle technologies and fuels to achieve GHG reductions from transportation—and advancements in these strategies will be critical. To expand this research, *Moving Cooler* was commissioned by a wide range of agencies and interest groups seeking objective information about the potential contributions of transportation strategies to meet GHG reduction goals. Through its focus on transportation activity strategies, *Moving Cooler* adds to the body of knowledge about how to reduce GHG emissions from the transportation sector.

Moving Cooler Baseline

The baseline projections developed by the authors of *Moving Cooler* show that innovations in technology will have a substantial effect on GHGs, but that these gains will largely be offset by increases in travel, along with growth in the U.S. population. The baseline is based on an annual rate of vehicle and fuel technological changes, consistent with forecasts of the U.S. Department of Energy in its "Annual Energy Outlook" and the U.S. Department of Transportation's examination of alternative Corporate Average Fuel Economy (CAFE). Both these analyses forecast substantial increases in the fuel efficiency of autos and light trucks during the next 20 or 30 years. The *Moving Cooler* baseline extrapolated these projections further to 2050, resulting in a potential doubling or greater of fleet fuel efficiency. These efficiency gains, however, are largely offset by an equally large increase in vehicle-miles traveled (VMT)—projected to grow by 82 percent during this period of time. The net result in 2050 is a less than 1 percent increase from 2005 in GHG emissions from transportation, as the U.S. population grows and travel increases.

Given this, a broad range of other strategies may be considered to reduce the GHG impact of transportation services. *Moving Cooler* has examined the effectiveness of strategies that transportation agencies and policy makers can consider to complement and reinforce the improvements that technology can achieve.

Combining Strategies to Reduce GHGs

An integrated, multistrategy approach—combining travel activity, local and regional pricing, operational, and efficiency strategies—can contribute to significant GHG reductions. Such reductions would, however, involve considerable changes to current transportation systems and operations, travel behavior, land use patterns, and public policy and regulations. How strategy bundles are designed will be key to reducing GHGs.

The six bundles analyzed by *Moving Cooler* illustrate that different combinations of strategies—implemented at different levels of intensity—vary considerably in how much GHG reduction they achieve, as shown in Figure 4.13. The reductions projected from these bundles range from 4 percent to 18 percent, assuming Aggressive Deployment. At the high end, the Maximum Effort Deployment of a complete portfolio of *Moving Cooler* strategies (excluding economy-wide pricing strategies)—as demonstrated by the Long-Term/Maximum Results bundle—could achieve annual GHG reductions of up to 24 percent by 2050 from the baseline.

Within these illustrative bundles, the strategies that contribute the most to GHG reductions are local and regional pricing and regulatory strategies that increase the costs of single-occupancy vehicle travel, regulatory strategies that reduce and enforce speed limits, educational strategies to encourage eco-driving behavior that achieves better fuel efficiency, land use and smart growth strategies that reduce travel distances, and multimodal strategies that expand travel options. Well-designed bundles could provide both GHG reductions and improved transportation service, including changes in the travel choices available.

The analysis also shows that some combinations of strategies could create synergies that enhance the potential reductions of individual measures. In particular, land use changes combined with expanded transit services achieve stronger GHG reductions than when only one option is implemented.

These results demonstrate that transportation agencies and other decision makers could create effective combinations of transportation strategies that provide high-quality transportation services, while achieving meaningful GHG reductions. In practice, most *Moving Cooler* strategies would typically be implemented as part of a long-range transportation plan or prioritized in a state climate action plan designed to meet multiple objectives; achieving GHG emission reductions adds an important objective to the planning process that can inform future transportation decisions.

Implementation Costs and Vehicle Cost Savings

While the costs of implementing many of the *Moving Cooler* strategies are substantial, so too are the benefits and savings realized nationally through improved mobility and reduced fuel consumption. The costs of implementing bundles of GHG reduction strategies vary, driven by the types of strategies included. Not surprisingly, bundles that involve capital investments—in infrastructure, technology, or vehicle stock—cost significantly more than bundles focused on changes in services, pricing, or regulatory approaches.

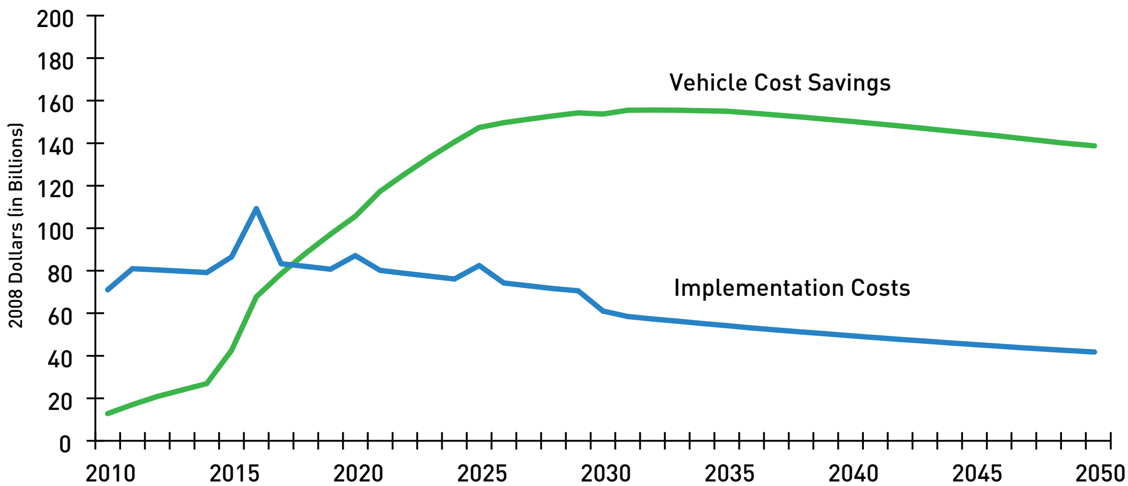
However, for five of the six bundles examined (the facility pricing bundle being the exception), the average annual savings in direct vehicle costs exceeds the projected implementation costs—by up to $72 billion for an aggressive level of deployment, as illustrated in Figure 5.1, and up to $112 billion for a maximum level of deployment during a 40-year time frame. At a national level, the reduced fuel consumption achieved through these strategies translates to an average annual savings of 85 to 470 million barrels at aggressive deployment, and to a savings of as much as 110 to 660 million barrels a year at maximum deployment.

It is important to note that this comparison of implementation costs to vehicle cost savings is not a full assessment of costs and benefits, because the *Moving Cooler* analysis did not address other important benefits and costs such as changes in mobility, travel time, safety, user fees, environmental quality, economic development, and public health.

Pricing Measures

Strong economy-wide pricing measures, beyond the local and regional pricing strategies included in some of the bundles, can generate substantial additional GHG reductions. For example, an additional fee (in current dollars) starting at the equivalent of $0.60 per gallon in 2015 and increasing to $1.25 per gallon in 2050 (aggressive deployment) could result in an additional 17 percent reduction in GHG emissions in 2050. A much higher fee, similar to current European fuel taxes, starting at $2.40 a gallon in 2015 and increasing to $5.00 a gallon in 2050 (maximum effort deployment) could result in an additional reduction

Figure 5.1 **Implementation Costs and Vehicle Cost Savings for the Long-Term/Maximum Results Bundle at Aggressive Deployment**
2010 to 2050



Note: This figure illustrates the effect of economy-wide pricing measures, as applied to the Long-Term/Maximum Results bundle at an aggressive deployment level for the 2010 to 2050 time period.

of 28 percent in GHG emissions. Figure 5.2 illustrates the effect of adding economy-wide pricing to one bundle at aggressive deployment.

Two factors would drive this increased reduction in GHG as a result of different pricing signals: reductions in vehicle-miles traveled (VMT), and more rapid technology advances. Implementation of both Pay as You Drive insurance (PAYD) and/or a direct VMT fee would increase consumers' cost per mile of travel, resulting in a national reduction in VMT. Pricing of carbon-based fuel leads to higher fuel costs that depress VMT, and also creates market conditions that encourage the purchase of more fuel efficient vehicles and spurs more rapid advancements in vehicle technology. As the number of more fuel efficient vehicles on the road increases, compared to the *Moving Cooler* forecasted emissions per vehicle mile baseline trend, GHG reductions increase two to three times over the VMT reduction effect alone.

Individual *Moving Cooler* Strategies

When evaluated individually, almost all of the strategies could achieve some GHG reductions. In particular, measures that reinforce efficient driving—either through regulation (speed limit reductions) or education (eco-driving)—could achieve a cumulative (from 2010 to 2050) 1.1 to 3.6 percent reduction from the baseline GHG emissions, depending on the level of deployment. Strategies that aim to reduce the distances people travel in cars and trucks by raising the cost of travel—PAYD and VMT fees—could have a comparable effect: a 1.2 to 7.1 percent reduction from cumulative baseline GHG emissions, depending on the level of deployment assumed.

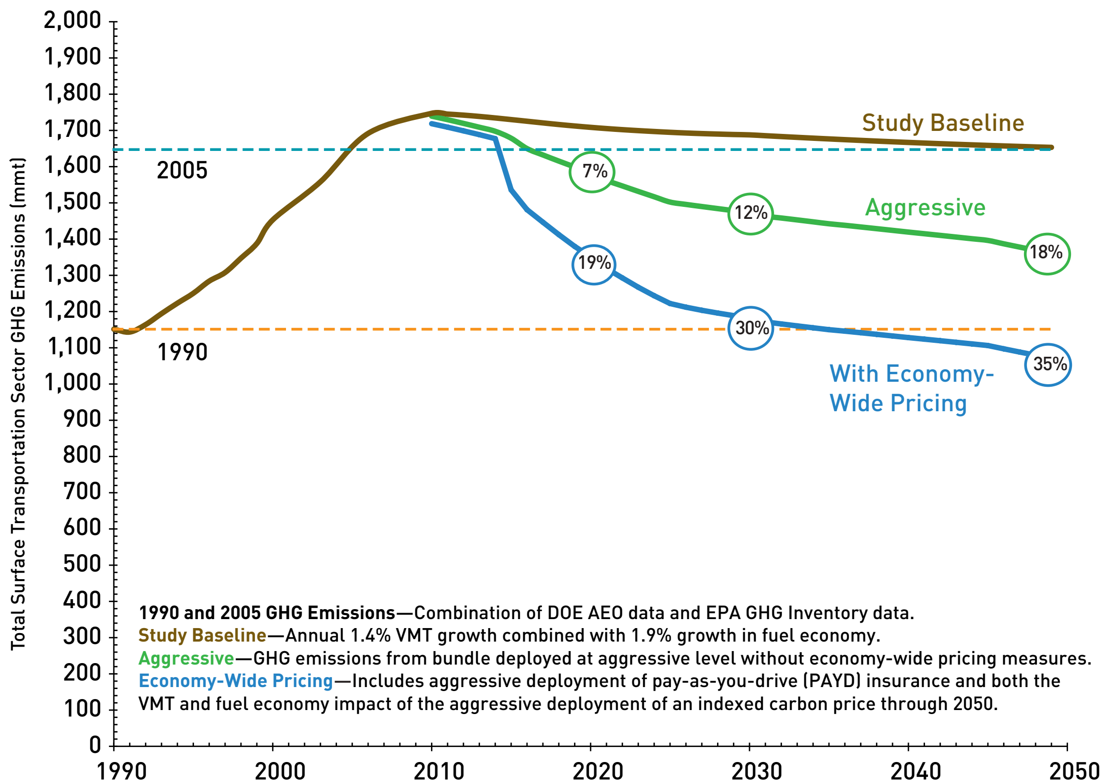
An integrated set of land use strategies achieves cumulative GHG reductions from 0.3 to 2.1 percent improvement over the baseline. Because these strategies take many years to implement and will involve the participation and acceptance of many parties to achieve, the benefits accrue quite slowly in the short term, before beginning to escalate significantly in later years.

Transit capital investments, such as urban transit expansion and intercity and high-speed rail, could produce cumulative GHG reductions ranging from 0.4 to 1.1 percent of baseline emissions. This expansion of service requires sustained investment over and above the current levels of investment.

Implementation of a full set of operational and ITS improvements could achieve 0.3 to 0.6 percent cumulative GHG reductions.

If implemented individually, many of the strategies are estimated to achieve cumulative national reductions of less than 0.5 percent from the *Moving Cooler* baseline by 2050, even at maximum levels

Figure 5.2 **Effect of Combined Economy-Wide Pricing Measures on GHG Reductions for the Long-Term/Maximum Results Bundle at Aggressive Deployment**
1990 to 2050



of deployment. However, the effectiveness of these strategies needs to be viewed relative to the scale of their potential deployment. While *Moving Cooler* measures GHG reductions against a national baseline, many strategies are only appropriate within selected urban areas, and therefore only address one "slice" of the total transportation GHG challenge. At the local and regional scale, many *Moving Cooler* strategies can be useful techniques to help meet regional GHG objectives, while enhancing transportation service.

Other Social, Economic, and Environmental Goals

The fact that many individual strategies will likely make only small contributions to national GHG reductions does not indicate that they should be discarded. In addition to making a contribution to reducing GHGs, many strategies achieve other important objectives, such as expanded travel options, reduced congestion, greater accessibility, improvements in the livability of urban areas, improved equity, improved environmental quality, enhanced public health, and improved safety. The analysis shows, for example, that additional investment in highway capacity and bottleneck relief could result in GHG reductions through 2030 and a no net cumulative change in GHG through 2050. Review of other cost-benefit studies demonstrates that higher levels of investment in public transportation and highways have returns of two or three times to one, in terms of benefits in relation to the costs of these strategies.

This analysis shows that many transportation improvements can be implemented while achieving some reduction in GHG emissions. Further, many strategies have very low costs of implementation—for example, land use and parking strategies, speed limits, and eco-driving can be implemented at direct costs of $5 to $10 per tonne of GHG reduction, even before consideration of vehicle cost savings.

Near-Term Reductions

Many of the strategies analyzed in *Moving Cooler* could be implemented within a few years and begin generating reductions in GHG emissions before

2020. For example, near-term strategies, such as lower speed limits, congestion pricing, eco-driving, operational improvements, and increased transit frequencies and speeds, if implemented, are among the strategies that would achieve GHG reductions relatively quickly. Achieving early results would reduce the cumulative GHG reduction challenge in later decades. In contrast, technology improvements—while vital—take time to engineer and deploy, and the combined fuel efficiency of the actual cars and trucks on the road improves only gradually as consumers purchase new vehicles. Near-term actions can give the sector a strong start in reducing GHGs, while creating the impetus for more aggressive innovation in technology.

Land Use and Improved Travel Options

While some *Moving Cooler* strategies could be implemented quickly, others would require many years to put in place. This observation is particularly true for bundles that involve changes in development patterns to increase density and reduce the distance of or need for vehicle travel. The analysis demonstrates that over time, land use changes and investments in improved transit and transportation options can improve the efficiency and quality of all travel, reduce vehicle trip lengths or completely replace vehicle trips and thereby reduce GHG emissions. The notable reductions for these strategies are realized in the outer decades of this analysis, in 2030 and beyond. These strategies would require changes in policies and significant funding because of the capital costs of expanded transit services, but these actions could achieve meaningful GHG reductions by 2050, ranging from 9 to 15 percent, without economy-wide pricing.

Equity Effects

The direct costs of implementing these strategy bundles will vary, with different costs incurred by government, consumers, and businesses. If properly designed, highway, public transportation, ride-sharing, and operations investments could be implemented to benefit all income groups and all user groups.

Without mitigating policies, the pricing strategies would potentially create serious equity issues because of their disproportionate effects on lower-income groups and on those with limited mobility options. Lower income groups spend as much as four times more of their income (than higher income groups) on transportation; implementation of pricing strategies would exacerbate this inequity.

One solution to this problem could involve taking the revenues from pricing strategies and reinvesting them in additional strategies that address equity concerns, particularly through investments in public transportation and highway investments that benefit lower income and disadvantaged communities, to reduce the effects of higher fees. The equity analysis shows that highway investments using revenues from pricing measures, if appropriately designed, could create benefits for lower-income groups greater than what they would pay in added fees, and that investments in public transportation can have strong benefits for lower-income groups, who are less likely to have private vehicles. Other income transfer approaches also could be used to address the effects on lower-income groups; the increase in incomes that could result from these transfers would give households more purchasing power to pay for transportation as well as other needs, but would not necessarily result in improved transportation services.

Future Research

Ongoing research is needed in several areas, including further evaluations of the effectiveness of GHG measures in specific contexts, and research and evaluation of effective means to develop and deploy new strategies and technologies. The interactions of land use, urban form, and transportation are complex, particularly when attempting to project the long-range impacts of investments choices on travel behavior. For example, analysis could be conducted to assess the potential for synergistic effects between expanded intercity rail service and expanded urban transit service. The interactive effects of combinations such as employer-based commute options with travel alternatives, financial incentives, and transit services also merit additional study. Development of more refined modeling tools combining GHG and economic analyses could help decision makers more effectively examine investment and planning scenarios in terms of GHG effects and overall societal benefits and costs. Additional research on these and other topics would help to inform future policy decisions, as our understanding of transportation and climate change continue to evolve.

Glossary

AEO—The U.S. Department of Energy's "Annual Energy Outlook."

Baseline—Projection of future GHG emissions, VMT, fuel economy, and fuel prices for on-road surface transportation to 2050. This baseline is used to compare the effect of GHG reduction strategies for all *Moving Cooler* analyses.

Bundle—A combination of strategies implemented together to achieve GHG reductions from transportation. *Moving Cooler* analyzed six bundles: Near Term/Early Results; Long Term/Maximum Results; Land Use/Transit/Non-motorized Transportation; System and Driver Efficiency; Facility Pricing; and Low Cost.

CAFE—Corporate Average Fuel Economy (federal standards for new passenger and non-passenger automobiles in the United States).

Cap-and-trade—System where emitters can trade allowances to emit GHGs within a specified budget that restricts the total level of national GHGs emissions allowed on an annual basis. Some cap-and-trade systems also allow for purchases of "credits" to emit GHGs through auction.

CBD—Central Business District.

CO_2—Carbon dioxide, the major greenhouse gas from transportation.

CO_2e—Carbon dioxide equivalent. A unit used to standardize the emissions of various greenhouse gases.

Co-benefits—The other benefits that are achieved by the implementation of a strategy that reduces GHG reductions. These benefits may include mobility, environmental, economic development, and equity outcomes.

Congestion pricing—Charging drivers a fee or toll to reduce traffic congestion.

Cost-effectiveness—A measure of the implementation cost per tonne of GHG reduced.

DOE—U.S. Department of Energy.

DOT—U.S. Department of Transportation.

Eco-Driving—Programs to train drivers on behavior that can reduce gas consumption, such as avoiding rapid acceleration and braking, reducing speeds, proper gear changing, and cruise control usage.

Effectiveness—Measure of the extent of GHG reduction achieved by a strategy or bundle.

EIA—U.S. Energy Information Agency.

EPA—U.S. Environmental Protection Agency.

Equity analysis—Assessment of the potential differential effects that pricing measures and other GHG reduction strategies may have on different demographic groups. The *Moving Cooler* equity assessment focused particularly on the specific effects of strategies on lower income consumers and the need to ensure that the transportation decision-making processes consider these affected groups when GHG strategy decisions are made.

ETS—Emissions Trading System.

EWP—Economy-wide pricing. EWP increases the cost of carbon-based fuel or of vehicle travel through national pricing strategies. These may include strategies such as a nationwide fuel tax, carbon tax, PAYD, or cap-and-trade.

Externalities—Positive or negative effects expected to occur through implementation of a GHG reduction strategy. In *Moving Cooler,* some externalities are quantified; others are discussed qualitatively (such as impacts on travel time and mobility costs, safety benefits, and air quality).

FHWA—U.S. Federal Highway Administration.

FTA—U.S. Federal Transit Administration.

GHG—Greenhouse gas. Major GHGs from transportation are: carbon dioxide, methane, nitrous oxide, and certain refrigerants. GHGs are often measured in units of $C0_2$ emission equivalents, $C0_2e$.

Gt—gigatonne = 1 billion metric tonnes.

Heavy-duty vehicles—Primarily freight trucks and non light-duty vehicles.

HERS—Highway Economic Reporting System, a detailed national highway investment, cost, delay, and benefit model used by FHWA.

HOV—High-occupancy vehicle.

HPMS—Highway Performance Monitoring System.

Implementation costs—Includes the direct costs required to construct, operate, and maintain GHG reduction strategies. These costs may include capital expenses, installation of vehicle technologies, and ongoing administrative and program management costs. Implementation costs do not include offsetting revenues resulting from pricing strategies.

Induced demand—The increase in travel that may occur when travel costs or congestion decrease, as travelers take advantage of the lower cost and better level of service (i.e., faster travel times).

IPCC—Intergovernmental Panel on Climate Change.

ITS—Intelligent Transportation Systems.

Light-duty vehicles—Includes passenger cars and light-duty trucks (sport utility vehicles, pickup trucks, and minivans).

LOS—Level of service. A measurement of the frequency and quality of transportation services.

mmt—million metric tonnes.

MPG—Miles per gallon.

MPH—Miles per hour.

MPO—Metropolitan Planning Organization (comprised of local governments in a particular region).

Net costs—Defined as vehicle cost savings minus implementation costs.

PAYD—Pay as You Drive insurance, a system of vehicle insurance that charges users insurance premium costs, based in part on how many miles a vehicle is driven in a given year.

PPM—Parts per million.

Pricing strategies—Economy-wide or regional and local measures designed to reduce GHGs or congestion and generate revenues. Economy-wide pricing strategies include PAYD, VMT fees, and gas or carbon pricing. Regional pricing strategies focus on tolls or fees for use of specific facilities, parking fees, and other facility charges.

RGGI—Regional Greenhouse Gas Initiative, a regional collaborative of 10 northeastern states working to reduce GHGs.

TCRP—Transit Cooperative Research Program, a research program of the Transportation Research Board.

TDM—Transportation Demand Management.

Tg—Teragram = 1 mmt (million metric tonnes).

TMC—Traffic Management Center, a centralized "hub" of a urban or regional transportation system where real-time travel information is collected, monitored, and used to manage the system.

Vehicle Cost/Savings—The fuel and operating cost or savings to a user or owner resulting from changes in the costs of vehicle maintenance and repair, insurance, and fuel, increases or decreases in miles traveled, and congestion or improved traffic flow. This calculation does not include other user costs, such as fees, tolls, and gas taxes, nor does it include travel time, safety, or mobility considerations.

VII—Vehicle Infrastructure Integration. A system of intelligent transportation technologies that provides a communications link between vehicles on the road, and between vehicles and the roadway in order to increase the safety, efficiency, and convenience of the transportation system.

VMS—Variable message signs to provide real-time information to drivers on road conditions, closures, special events, and alternate routes.

VMT—Vehicle-miles traveled.

WIM—Weigh-in-motion systems to minimize delays in freight movement.

MOVING COOLER: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions

Both the public and private sectors are grappling with decisions regarding policies that will lead to reductions in greenhouse gas (GHG) emissions. *Moving Cooler* analyzes and assesses the effectiveness and costs of almost 50 transportation strategies for reducing GHG emissions, as well as evaluates combinations of those strategies. The findings of this study can help decision makers coordinate and shape effective approaches to reducing GHG emissions at all levels—national, regional, and local—while also meeting broader transportation objectives.

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ISBN 978-0-87420-118-5
9 780874 201185 90000