REPORT S2-C09-RR-1

Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process

SHRP2 CAPACITY RESEARCH

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

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The Second
STRATEGIC HIGHWAY RESEARCH PROGRAM

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Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process

PB Americas, Inc.

Cambridge Systematics, Inc.

E. H. Pechan & Associates, Inc.

EuQuant, Inc.

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2013
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The need for SHRP 2 was identified in *TRB Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life,* published in 2001 and based on a study sponsored by Congress through the Transportation Equity Act for the 21st Century (TEA-21). SHRP 2, modeled after the first Strategic Highway Research Program, is a focused, time-constrained, management-driven program designed to complement existing highway research programs. SHRP 2 focuses on applied research in four areas: Safety, to prevent or reduce the severity of highway crashes by understanding driver behavior; Renewal, to address the aging infrastructure through rapid design and construction methods that cause minimal disruptions and produce lasting facilities; Reliability, to reduce congestion through incident reduction, management, response, and mitigation; and Capacity, to integrate mobility, economic, environmental, and community needs in the planning and designing of new transportation capacity.

SHRP 2 was authorized in August 2005 as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The program is managed by the Transportation Research Board (TRB) on behalf of the National Research Council (NRC). SHRP 2 is conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Sciences, parent organization of TRB and NRC. The program provides for competitive, merit-based selection of research contractors; independent research project oversight; and dissemination of research results.

SHRP 2 Report S2-C09-RR-1

ISBN: 978-0-309-12930-5

Library of Congress Control Number: 2012955847

Copyright Information

Note: SHRP 2 report numbers convey the program, focus area, project number, and publication format. Report numbers ending in "w" are published as web documents only.

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ACKNOWLEDGMENTS

This work was sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials. It was conducted in the second Strategic Highway Research Program, which is administered by the Transportation Research Board of the National Academies. The project was managed by Stephen J. Andrle, Deputy Director for SHRP 2.

The research described in this report was performed by PB Americas, Inc., supported by Cambridge Systematics, Inc.; E. H. Pechan & Associates, Inc.; and EuQuant, Inc. Michael Meyer was the Principal Investigator. Other contributors to this report were Cindy Burbank and Lisa Zeimer of PB Americas; Chris Porter and Joanne Potter of Cambridge Systematics, Inc.; and Jim Wilson of E. H. Pechan & Associates.

The research team acknowledges the Colorado Department of Transportation, the Massachusetts Department of Transportation, the Minnesota Department of Transportation, and the Washington State Department of Transportation, which sponsored one-day workshops that assessed the information provided in the *Guide* that accompanies this final report.

FOREWORD

Stephen J. Andrle, *SHRP 2 Deputy Director*

Scientific evidence is mounting that the release of greenhouse gases into the atmosphere is contributing to noticeable changes in the earth's climate. While this assertion is controversial, many public agencies, including transportation agencies, have begun to investigate how to reduce greenhouse gas emissions. This is a new topic for most, and analytical procedures are not well established. This report and the associated *Practitioners Guide* provide a framework and methods for assessing greenhouse gas emissions from transportation projects or programs. The framework is linked to decision points in the larger transportation planning and environmental review process. The report and *Practitioners Guide* will be of interest to transportation professionals charged with analyzing strategies for reducing greenhouse gas emissions from the transportation sector. For those in areas that are not using complex transportation planning and air quality models at the present time, this report will be particularly useful. The findings are also available on the SHRP 2 website Transportation for Communities—Advancing Projects through Partnerships (TCAPP).

It is generally accepted that the transportation sector of the economy contributes about 28% of the United States' greenhouse gas emissions, making transportation a significant target of opportunity for mitigating strategies. Carbon dioxide is the major transportation-generated greenhouse gas, constituting over 80% of U.S. greenhouse gas emissions. Carbon dioxide emissions are directly linked to the amount of fuel consumed and its carbon intensity. Carbon emission reductions can be achieved by increasing the use of low-carbon fuels, improving fuel economy, reducing vehicle miles of travel, and reducing congestion. The job of a transportation analyst is to determine the cost effectiveness of various strategies at their disposal.

This report provides background information to aid in understanding the issues, a summary of the state of the practice, a framework for conducting greenhouse gas analysis, a description of tools and data requirements, and an overview of the cost-effectiveness of various strategies. Eight short case studies are included to demonstrate the state of the practice by state departments of transportation, metropolitan planning organizations, and other units of government. Workshops were conducted in four states to vet the framework and the methods.

The *Practitioners Guide* identifies steps in the transportation planning and environmental review process where greenhouse gas emissions could be considered and at what scale. The *Practitioners Guide* uses the decision points in the transportation planning and environmental review process from TCAPP to structure the information and link the scale of greenhouse gas analysis to stages in planning and environmental review. Finally the appendices to the *Practitioners Guide* contain data useful for conducting greenhouse gas emissions analysis, a compendium of tools, references to carbon calculators, life cycle fuel and emissions estimates and other resources.

The report and *Practitioners Guide* provide a structure to aid transportation professionals in coping with the greenhouse gas emissions issue, clarify the types of mitigating actions available to a transportation agency, and provide methods and data for analysts.

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Online version of this report: www.trb.org/Main/Blurbs/166936.aspx.

Executive Summary

This report presents the findings of research completed for the second Strategic Highway Research Program (SHRP 2) Capacity Project C09, Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process. The collaborative decision-making process (now called Transportation for Communities: Advancing Projects Through Partnerships, or TCAPP) developed by Capacity Project C01 served as the major conceptual decision-making framework for this research, including the identification of key decision points that comprise such decision making. This report identifies where and how greenhouse gas (GHG) emissions and energy consumption fit into this conceptual framework. This report is accompanied by the *Practitioners Guide to Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process* (*Practitioners Guide*) (PB Americas et al. forthcoming), which provides a useful guide on how GHG emissions and energy factors can be considered in different planning and decision-making contexts. In addition to describing the technical approaches and data needs that accompany GHG emissions and energy analyses, this report presents case studies that illustrate how state transportation agencies, transit agencies, and metropolitan planning organizations have been incorporating such factors into transportation planning.

This report provides background research on GHG emissions and energy consumption, information that is important for understanding how the transportation sector fits into an overall policy or program for reducing GHG emissions. Up-to-date information on the types of transportation-related strategies that can be considered as part of a GHG emissions reduction program is also presented. A technical framework is described that can be used for considering GHG emissions in different transportation planning and decision-making contexts. The framework is organized around questions that guide analysts to the tools and data necessary to conduct a GHG analysis. Case studies are used to illustrate GHG analyses that have been undertaken for highway and transit projects.

The examined GHG-reducing strategies that are most directly under the influence of transportation agencies include

- Infrastructure provision, including the design, construction, and maintenance of highway, transit, and other transportation facilities and networks;
- Management and operation of the transportation system, such as transportation system pricing policies or technologies and operational practices to improve traffic flow; and
- Provision of transportation services and demand management measures to encourage the use of less carbon-intensive modes, such as transit service improvements, rideshare and vanpool programs, and worksite trip reduction.

Other strategies that may be influenced by transportation agencies include

- Land use planning, for which transportation agencies may provide regional coordination, funding, and/or technical assistance to support state and local efforts to develop more efficient land use patterns;
- Pricing strategies, such as tax and insurance policies, mileage-based pricing, or registration fees, for which transportation agencies may provide analysis support and encourage state-level policy changes; and
- Provision of alternative fuels infrastructure, as well as direct purchase of alternative fuel vehicles for agency fleets.

The largest absolute GHG benefits in the transportation sector are likely to come from advancements in vehicle and fuel technologies. Particularly promising technologies in the short- to midterm include advancements in conventional gasoline engines, truck engine improvements and drag reduction, and hybrid electric vehicles. In the longer term, ethanol from cellulosic sources, battery-powered electric vehicles, plug-in hybrid electric vehicles, and hydrogen fuel cell vehicles all show great promise for reducing GHG emissions, but only if the technologies can be advanced to the point of being marketable and cost-competitive. Most of these strategies show the potential for net cost savings to consumers.

The impacts of any single transportation system strategy (system efficiency and travel activity) are generally modest, with most strategies showing impacts of less than, and usually considerably less than, 1% of total transportation GHG emissions in 2030. A few strategies show larger impacts (greater than 1%), including reduced speed limits, compact development, various pricing measures, and eco-driving (driving behavior that minimizes GHG emissions); but the ability to implement these strategies at sufficiently aggressive levels is uncertain due to institutional and/or political barriers. Despite the modest individual strategy impacts, the combined effects of all transportation system strategies may be significant: on the order of 5% to 20% of transportation GHG emissions.

Transportation infrastructure investment. Both highway and transit investment are generally high cost, with cost-effectiveness estimates of $500 to $1,000 per metric ton (tonne) or more. One study has suggested that cumulative GHG benefits of highway expansion strategies may actually be negative over the 2010 to 2050 time frame when induced travel effects are considered. Based on limited evidence, bicycle and pedestrian improvements may be relatively lower cost (in the range of $200 per tonne), although the magnitude of impacts is likely to be modest. Although major infrastructure investments are not among the most cost-effective GHG reduction strategies, they may be worthwhile for other purposes, such as mobility, safety, or livability, or as part of a package of strategies that is collectively more cost-effective (e.g., transit with land use, bottleneck relief with congestion pricing).

Infrastructure maintenance. Virtually all studies assume that the existing system remains in a state of good repair and that lane closures, bridge postings, and major diversions and increased congestion do not occur. Unfortunately, current expenditures do not support this assumption, and it may be that the most cost-effective thing a department of transportation (DOT) can do is to keep the existing system intact.

- Although *rail and marine freight* are considerably more energy efficient than truck travel on average, the absolute magnitude of reductions from freight mode shifting is limited because only certain types of goods (particularly long-haul, non-time-sensitive goods) can be competitively moved by rail. One estimate of the cost-effectiveness of rail freight infrastructure improvements falls in the range of $200 per tonne, but this is based on highly optimistic estimates of truck-to-rail mode shifts. Improved estimates are needed to assess the GHG reduction and cost-effectiveness of rail and marine freight investments to encourage freight mode shift.

- *Transportation system management strategies* that reduce congestion and improve traffic flow may provide modest GHG reductions at lower cost than capacity or system expansion (typically between $50 and $500 per tonne, with lower costs if operating cost savings to drivers are included). As with highway capacity strategies, however, there is considerable uncertainty in the GHG reduction estimates for these strategies because of uncertainty regarding the magnitude and treatment of induced demand. However, the synergies needed for effective reductions should be kept in mind; any effective pricing system will need a companion intelligent transportation system component to be viable, for example, and traveler advisories can increase transit use.
- Like transit infrastructure improvements, *urban and intercity transit service improvements* have high direct (public sector) costs, generally over $1,000 per tonne, although they provide similar nonmonetary (mobility) benefits and in some circumstances they may yield net savings to travelers as a result of personal vehicle operating cost savings. The GHG benefits of any particular transit project will vary depending on ridership levels, and they could be negative if ridership is insufficient. Among other imponderables, improved transit and novel modes such as shared electric vehicles may eventually change travel behavior over the very long term.
- *Truck operations strategies,* in particular idle reduction, can provide modest total benefits with a low public investment cost while yielding net cost savings to truckers. The most effective strategy is to require on-board idle reduction technology, which would require harmonization of state regulations.
- *Speed limit reductions* can provide significant benefits at modest cost, although they have mobility disadvantages, are not likely to be popular, and require strong enforcement to achieve GHG benefits.
- *Land use strategies* can potentially provide significant GHG reductions over the long term at very low public sector cost. Modest to moderate changes in land use patterns can probably be accomplished without significant loss of consumer welfare, but more far-reaching changes may not be popular and may be very difficult to achieve in the current political and economic environment.
- *Pricing strategies,* especially those that affect all or a large portion of vehicle miles traveled (VMT), such as VMT-based fees or congestion pricing, can provide significant GHG reductions, but only by pricing at levels that may be unacceptable to the public. A 2- to 5-cent per mile fee, for example, is equivalent to a gas tax increase of $0.40 to $1.00 per gallon at today's fuel efficiency levels. The technology and administrative requirements for VMT monitoring make implementation costs moderate (less than $100 per tonne to $300 per tonne or more) for most mechanisms. (Cost-effectiveness improves with higher fee levels, since the same monitoring and administration infrastructure is required regardless of the amount of the fee.) Pricing strategies will also have significant equity impacts unless revenues are redistributed or reinvested in such a way as to benefit lower-income travelers. A gas tax increase or carbon tax could be implemented at much lower administrative cost, but these strategies are not currently politically acceptable at a national level or in most states.
- Although *transportation demand management strategies* have modest GHG reduction potential at moderate public cost (typically in the range of $100 to $300 per tonne), they require widespread outreach efforts combined with financial incentives. Furthermore, the public sector has so far demonstrated little ability to influence strategies such as telecommuting and compressed work weeks, and adoption of these strategies has primarily been driven by private initiative.
- Studies have suggested that *eco-driving* may have significant GHG reduction potential while providing a net savings to travelers. However, these results are based on limited European experience and may not be transferable in a widespread fashion to the United States.

The technical framework for conducting GHG emissions analysis presented in this report is organized around 13 key questions grouped into five basic steps of analysis, as shown in Table ES.1.

Table ES.1. GHG Analysis Framework

Analysis Step	Key Questions
I. Determine information needs	1. What stakeholders should be included in GHG strategy development and evaluation?
	2. What is the scope of GHG emissions analysis?
II. Define goals, measures, and resources	3. What goals, objectives, and policies relate to GHG reduction?
	4. What GHG-related evaluation criteria and metrics will be used?
	5. What are the baseline emissions for the region or study area?
	6. What is the goal or target for GHG reduction?
	7. How will GHG considerations affect funding availability and needs?
III. Define range of strategies for consideration	8. What GHG reduction strategies should be considered?
	9. Are strategies and alternatives consistent with a long-range plan and/or other relevant plans that meets GHG reduction objectives?
IV. Evaluate GHG benefits and impacts of candidate strategies	10. What calculation methods and data sources will be used to evaluate the GHG impacts of projects and strategies?
	11. What are the emissions and other impacts of a particular project, strategy, or design feature?
V. Select strategies and document overall GHG benefits and impacts of alternatives	12. What GHG-reducing strategies should be part of the plan, program, or project?
	13. What are the net emissions impacts for the overall plan, program, corridor, or project alternatives considered and the selected alternative?

These analysis steps and key questions are, for the most part, common across all four decision-making contexts of the TCAPP framework; that is, they can be used for long-range planning, programming, corridor planning, and environmental review and permitting. However, they might be addressed at different decision points in each context and require somewhat different analysis methods. This report describes the different methods and models that are available for these different decision points.

The 13-question process is presented as an idealized process. Iterations among the various questions might be necessary, and local agencies may consider issues in a different sequence than presented here. Case studies are presented that illustrate the application of this process. Readers are referred to the *Practitioners Guide* for more detailed information on how these questions relate specifically to TCAPP.

Some of the key knowledge gaps identified by the research team during this project include data and methodological limitations for the development of inventories and baseline forecasts, limitations on basic knowledge regarding strategy effectiveness, and limitations in tools and methods for analyzing strategy effectiveness.

CHAPTER 1

Introduction

Background

This report presents the findings of research completed for the second Strategic Highway Research Program (SHRP 2) Capacity Project C09, Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process. The collaborative decision-making process developed by Capacity Project C01 served as the major conceptual decision-making framework for this research, including the identification of key decision points that comprise such decision making. The collaborative decision-making process is now called Transportation for Communities: Advancing Projects Through Partnerships (TCAPP). The research identifies where and how greenhouse gas (GHG) emissions and energy consumption fit into this conceptual framework. In addition to describing the technical approaches and data needs that accompany GHG emissions and energy analyses, this report presents case studies that illustrate how state transportation agencies, transit agencies, and metropolitan planning organizations (MPOs) have incorporated such factors into transportation planning.

Motivation and Objectives

Most climate scientists agree that humans are accelerating a change in Earth's climate through the emission of GHGs. In response, governments and organizations in the United States at local, state, and regional levels have been enacting policies aimed at reducing energy consumption and GHG emissions. These policies typically include an overall emissions reduction target for a city, a state, or an agency. To meet reduction targets, some agencies and organizations have developed plans and strategies that are often broken down by emissions sources. Transportation, particularly surface transportation, is one of the most significant sources of GHG emissions: about 29% of all U.S. GHG emissions, and growing at a faster rate than most other sectors.

Thus far, the most common transportation-related response to reduce GHG emissions and promote energy security through reduced energy consumption has focused on four core strategies: reduce vehicle miles traveled (VMT), reduce carbon intensity of fuels, improve vehicle efficiency, and improve overall operational efficiency of the surface transportation system. Ultimately, several of these strategies will require federal policy changes, namely advancements in vehicle technology and further regulation of fuel sources. However, transportation agencies at the state and local levels have more control over reducing VMT and improving the operational efficiency of the surface transportation system since they own, operate, and regulate much of the nation's transportation system. Consequently, these agencies will be heavily involved in efforts to mitigate GHG emissions from surface transportation sources. Successful strategies and plans will result from incorporating GHG emissions into their transportation planning and decision making.

This research had three major objectives:

- Developing strategies for incorporating GHG emissions at key points in transportation planning and decision making using an analysis framework as a point of departure;
- Identifying relevant information and materials that exist for GHG emissions analysis and areas in which more information is needed; and
- Preparing materials and methods that guide GHG emissions and energy analyses, including the *Practitioners Guide.*

Intended Audience

This research will be useful for those involved in transportation planning and decision making who wish to consider GHG emissions in a systematic and thoughtful manner. Thus, the primary audience includes transportation agencies, especially state transportation agencies and MPOs that lead and manage the decision-making processes found in TCAPP. The information produced by this research will be incorporated into the web-based TCAPP to enable users to identify where GHG emissions should be considered and the tools and data necessary to undertake meaningful GHG emissions analysis. The information is presented so that both agency managers and analysts can find useful information for the types of decisions they are likely to face.

Given that GHG emissions analysis is a process that could include a variety of interests, this research could be useful to many organizations and stakeholders that participate in various decision-making processes. For example, environmental resource agencies, advocacy groups, elected officials, and the business community might be very interested in the results of GHG emissions analysis from a variety of perspectives. Such interest could include both the specifics of how many tons of GHG emissions might be emitted for particular strategies and the cost-effectiveness of different strategies to mitigate this impact.

This research project has produced a range of information on GHG emissions analysis that will be useful in different analysis contexts. In particular, this information serves as a

- Background for understanding GHG emissions and their relationship to energy and fuel consumption, as well as other factors;
- Summary of the current state-of-practice in GHG emissions and energy analysis, including case studies illustrating examples of where GHG emissions analysis has occurred for both systems planning and highway and transit projects;
- Framework for conducting GHG emissions analysis;
- Description of the analysis tools and data requirements that exist for conducting GHG analyses; and
- Overview of the cost-effectiveness of the different types of strategies that can be considered to mitigate GHG emissions.

Some of the material produced here in general terms to illustrate the overall approach to GHG emissions analysis is provided in more detail in the *Practitioners Guide,* which presents much more detail on the technical characteristics of GHG emissions analysis, including available models, data requirements, and linkage to decisions and elements of the transportation planning process.

Approach and Organization

This research examined current efforts to conduct GHG emissions analysis and the key steps for conducting such analyses in a credible and substantive way. The research began with an examination of the background conditions and transportation strategies over which state and local governments have some influence that might result in reduced GHG emissions and energy use. This examination depended largely on a targeted literature search of such efforts. The research team next examined the collaborative decision-making framework developed as part of Capacity Project C01, and how GHG emissions analysis could play a role in informing planning and decision-making processes. This effort identified where GHG emissions could be considered in each key decision point within a particular decision-making process (e.g., in the identification of evaluation criteria for long-range planning), as well as how the consideration of GHG emissions in one decision step feeds into other decisions throughout the process and potentially into other decision-making processes. For example, the identification of GHG emissions reduction criteria for corridor planning should be consistent with similar criteria identified for the long-range planning process.

How GHG emissions are considered in planning and decision making will clearly depend on the scale at which a particular planning effort is undertaken (e.g., statewide versus corridor-level planning) and the institutional structure within which such planning occurs. The research identified key participants of GHG emissions analysis efforts and what role each can play. The scale of analysis also has an important influence on the cost-effectiveness of different strategies for reducing GHG emissions, which was examined through a detailed assessment of the different types of strategies that might be considered for different contexts.

The most important research task was developing a technical analysis framework that described the key steps that an analyst would need to take to conduct a GHG emissions analysis. The framework is organized as a set of questions that guide the analyst to appropriate analysis tools and useful data sources. In addition, the framework leads the user to other sources of information that might be appropriate for a particular scale of analysis. The framework is presented in the accompanying *Practitioners Guide,* which serves as a stand-alone technical document for conducting GHG emissions analysis and as a tool for achieving reductions within a specific planning context.

The draft material in the *Practitioners Guide* was presented at one-day workshops in Colorado, Massachusetts, Minnesota, and Washington State. Over 150 individuals representing state transportation agencies, MPOs, transit agencies, natural resource agencies, and advocacy groups attended these workshops. Suggestions and recommendations from workshop participants were incorporated into the final version of the *Practitioners Guide.* The *Practitioners Guide* and its appendix supplement the information presented in this final report on GHG emissions and their relationships to transportation planning and decision making. The final research task was to develop an approach for incorporating the results of this project into TCAPP. To a large extent, the structure and format of this final report and the *Practitioners Guide* were designed to provide for easy transition to TCAPP.

The remainder of this report is organized in the following manner:

- Chapter 2 provides background research on GHG emissions and energy consumption. This background is important for understanding how the transportation sector fits into an overall policy or program for reducing GHG emissions;
- Chapter 3 presents up-to-date information on the types of transportation-related strategies that can be considered as part of a GHG emissions reduction program. In particular, this chapter illustrates the cost-effectiveness of different strategies;
- Chapter 4 describes a technical framework that can be used for considering GHG emissions in different transportation planning and decision-making contexts. The framework is organized around questions that guide analysts to the tools and data that are necessary to conduct a GHG analysis;
- Chapter 5 provides case studies that illustrate GHG analyses that have been undertaken for highway and transit projects; and
- Chapter 6 presents gaps in knowledge and understanding associated with GHG analysis that were found during the course of this research. These gaps are presented as areas of future research.

The research team made sure that the questions (based on the types of decisions that must be made) that guide an analyst to the tools, methods, and data for GHG analysis will be relevant in the future while serving today as a foundation for credible and transparent GHG analysis.

CHAPTER 2

Understanding GHG Emissions and Energy Consumption

Greenhouse Gas Emissions

GHGs include water vapor, ozone, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (SF_6). Of the GHGs, CO_2 is one of the most important human-influenced contributors to climate change, accounting in 2008 for almost 83% of U.S. GHG emissions. Within this broad context, transportation-related GHG emissions can be viewed from different perspectives. This first part of this chapter examines the relative contribution to GHG emissions of different economic sectors, the contribution of the transportation sector by mode, and the contribution over the lifespan of a project. The second part of the chapter describes some of the key factors that will likely influence GHG emissions in the future.

Emissions by Sector

The U.S. Environmental Protection Agency's (EPA) *Inventory of Greenhouse Gas Emissions and Sinks* provides historic data on GHG emissions from transportation and other sectors (U.S. Environmental Protection Agency 2010a). Direct transportation emissions from on-road sources accounted for approximately 23% of total inventoried U.S. GHG emissions in 2008. When considering all transportation sources (including aircraft, marine, rail, and pipeline), this figure increases to about 29%. As shown in Figure 2.1, industry is the only economic sector with higher GHG emissions; however, recent trends show transportation and industry emissions converging to represent an almost equal share of U.S. GHG emissions, with transportation soon to surpass (or already surpassing) industrial emissions. The figures presented in this section reflect only inventoried GHGs with agreed-on 100-year global warming potentials. Recent studies have suggested that other pollutants, such as ozone, black carbon, organic carbon, sulfates, and aerosols, are significant climate change agents. Some of these pollutants contribute to global warming, and some counteract it by reflecting solar radiation or destroying GHGs. However, scientific consensus does not yet support including these gases in national GHG inventories (U.S. Environmental Protection Agency 2010a). As discussed later in this chapter, the industrial sector also is responsible for some transportation-related emissions, including those associated with vehicle manufacture, fuels production, and the production of cement and other materials for transportation facilities.

The growth in transportation GHG emissions between 1990 and 2008 was primarily caused by an increase in person and vehicle miles traveled (VMT) and stagnation of fuel efficiency across the U.S. vehicle fleet. Person miles traveled in light-duty vehicles (LDVs) increased 36% between 1990 and 2008, ton-miles carried by medium- and heavy-duty trucks increased 55% between 1990 and 2007, and passenger miles traveled by aircraft increased 63% between 1990 and 2008 (Bureau of Transportation Statistics 2010a).

Although average fuel economy for the LDV fleet during this period increased slightly because of the retirement of older vehicles, average fuel economy among new vehicles sold actually declined between 1990 and 2004. The decline in new vehicle average fuel economy reflected the increasing market share of light-duty trucks, which grew from about one-fifth of new vehicle sales in the 1970s to slightly over half of the market by 2004.

Both the trends of increasing VMT and declining fuel efficiency have reversed themselves, at least temporarily, in recent years. Average new vehicle fuel economy improved in 2008 and 2009 as the market share of passenger cars increased. Growth in passenger vehicle miles traveled slowed from an annual rate of 2.6% over the period 1990 to 2004 to an average annual rate of 0.7% from 2004 to 2007, and in 2008 it decreased for the first time since 1980 (due primarily to the economic turndown).

The U.S. Department of Energy's *Annual Energy Outlook* (AEO) provides forecasts of carbon dioxide (CO_2) emissions by sector through 2030, referred to as the AEO reference case

Figure 2.1. Historic trends in GHG emissions by sector.

(Energy Information Administration 2009). The AEO reports only CO_2 emissions, but the historic data from the EPA inventory include all GHG emissions. Since CO_2 makes up over 95% of all inventoried transportation GHGs, the data from the two sources can be considered roughly comparable for this sector. The difference is greater in the industrial sector, which is why the AEO forecasts show the transportation sector having higher CO_2 emissions than the industrial sector in both present and future years (Bureau of Transportation Statistics 2010b).

Under the AEO reference case, transportation is forecast to be the economic sector with the largest contribution to total GHG emissions from the present until at least 2035 (Figure 2.2). The AEO forecasts transportation energy usage and GHG emissions based on projections of activity and fuel efficiency for each mode. The 2011 AEO reference case projects that for LDVs between 2009 and 2035, fuel economy gains are almost entirely offset by increases in VMT (Energy Information Administration 2011). LDVs include passenger cars, motorcycles, and light trucks less than an 8,500-pound gross vehicle weight rating, most of which are used primarily for personal travel. Light trucks include almost all four-tire, two-axle vehicles, such as SUVs, minivans, and pickup trucks. The AEO LDV forecasts consider the underlying factors that drive vehicle purchases and use, such as how income per capita, population forecasts, and fuel costs affect the growth of personal travel and VMT. Forecasts for other modes consider different factors, such as how increases in industrial output increase heavy-duty vehicle (truck) activity as well as rail, marine, and air transport.

Emissions by Mode

Figures 2.3 and 2.4 present an inventory of transportation-related GHG emissions sources for both historic trends and forecasted scenarios. LDVs make up the largest portion of GHG emissions, followed by heavy-duty vehicles and aircraft. This is true for both the historic and forecasted inventories. When considering the breakdown of transportation GHG emissions by transportation mode in 2008, passenger modes made up about 71%, with freight modes constituting the remaining 29%.

It is likely that the AEO forecasts overstate future GHG emissions, at least for LDVs. If VMT growth slows below 1.5% annually and vehicle efficiency standards continue to be increased beyond requirements that currently extend through model year 2016, emissions from LDVs will decrease in the future.

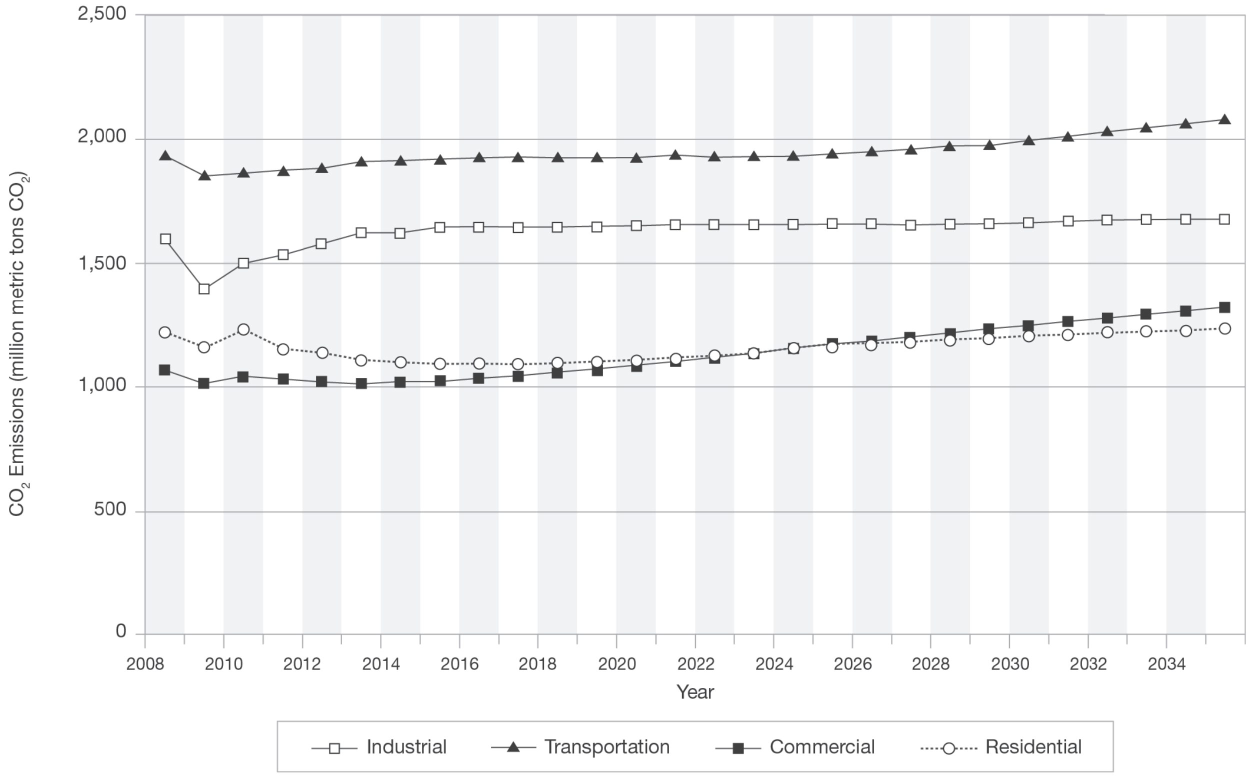

Figure 2.2. Forecasted CO_2 emissions by sector.

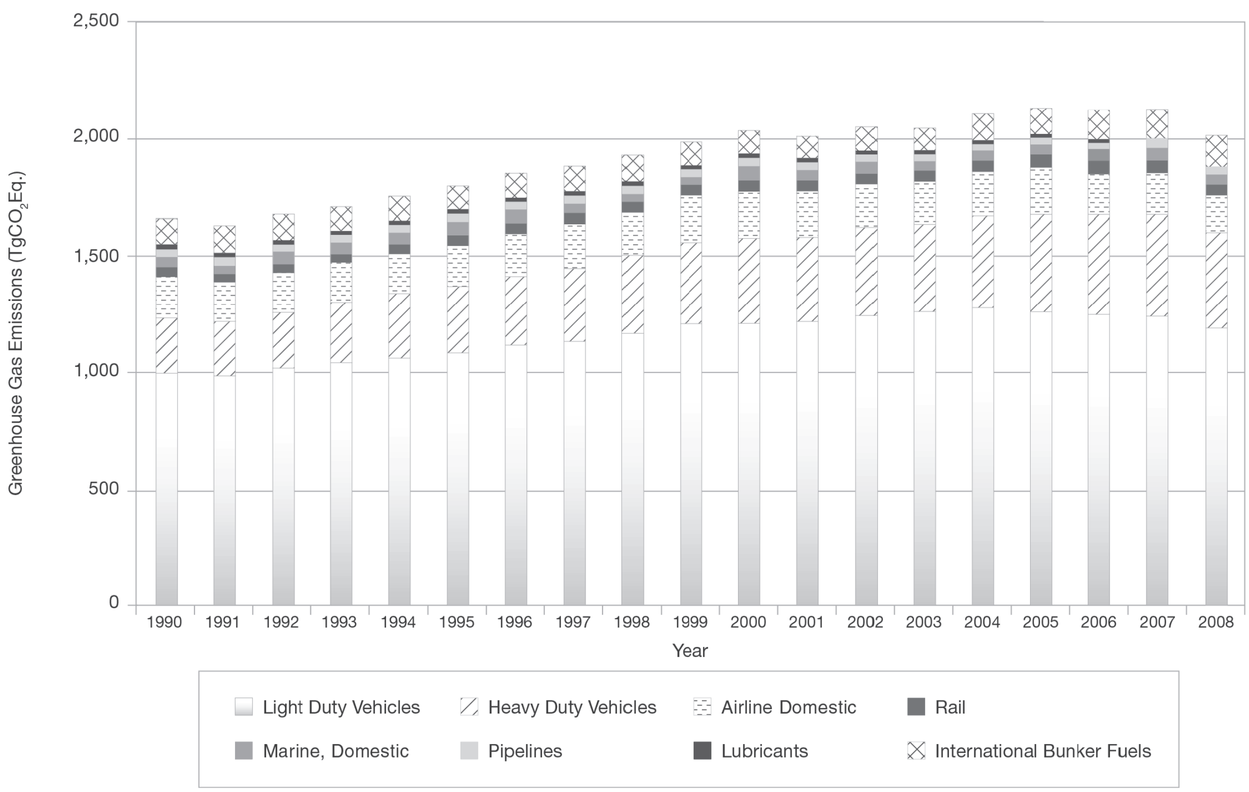

Figure 2.3. Inventory of transportation-related GHG emissions by mode.

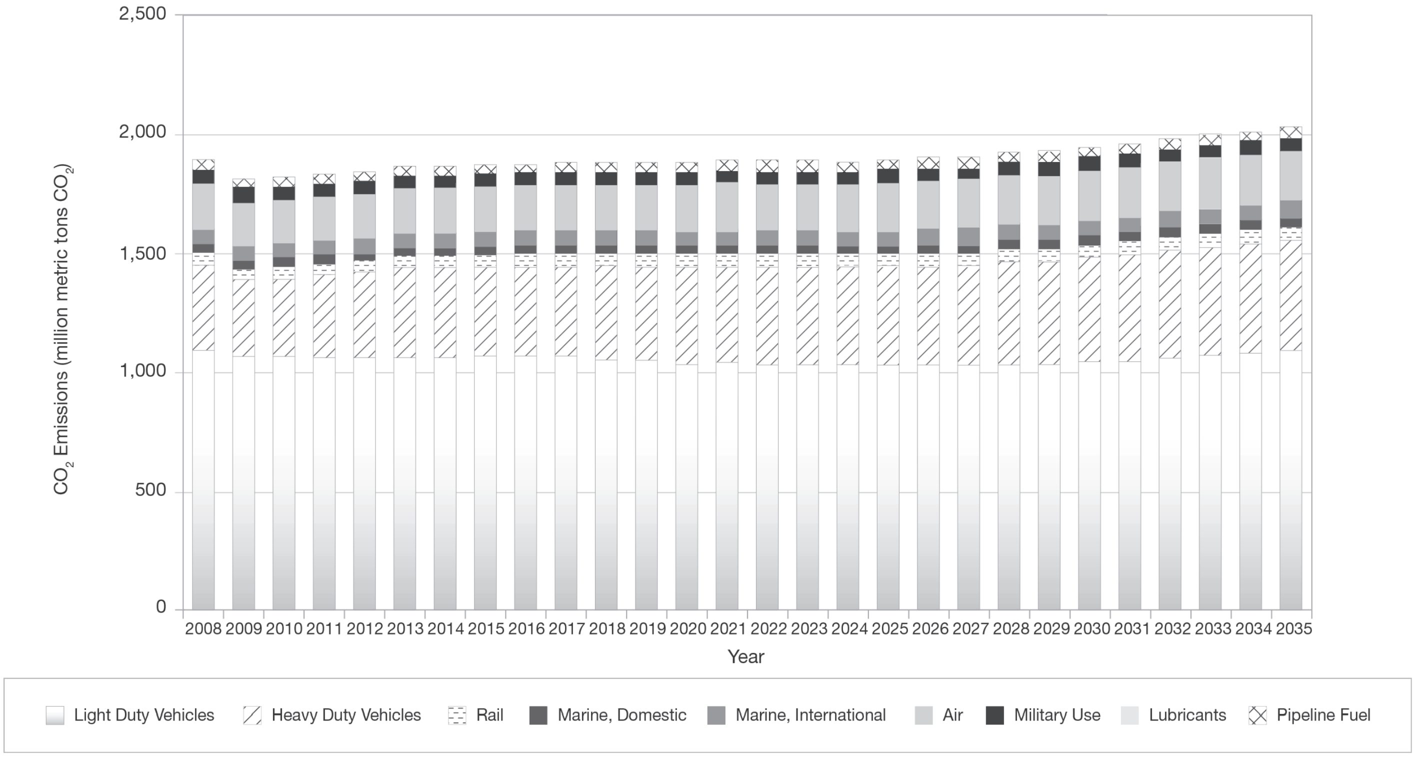

Figure 2.4. Future inventory of transportation-related GHG emissions by mode.

Figures 2.5 and 2.6 show contributions to GHG emissions by both passenger and freight modes. As shown in Figure 2.5, the vast majority of passenger transportation GHG emissions come from LDVs, accounting for 87% of the passenger transportation GHG contribution and 62% of total GHG transportation emissions in 2008. Domestic air travel made up most of the remaining emissions (10% of passenger transportation emissions and 7% of total emissions). Travel by bus, motorcycle, rail, and ship accounted for the very small remaining balance of passenger transportation and total emissions.

Figure 2.6 shows that about three-quarters of freight-related GHG emissions (21% of all transportation GHG emissions) come from trucks. Freight rail accounted for 9%

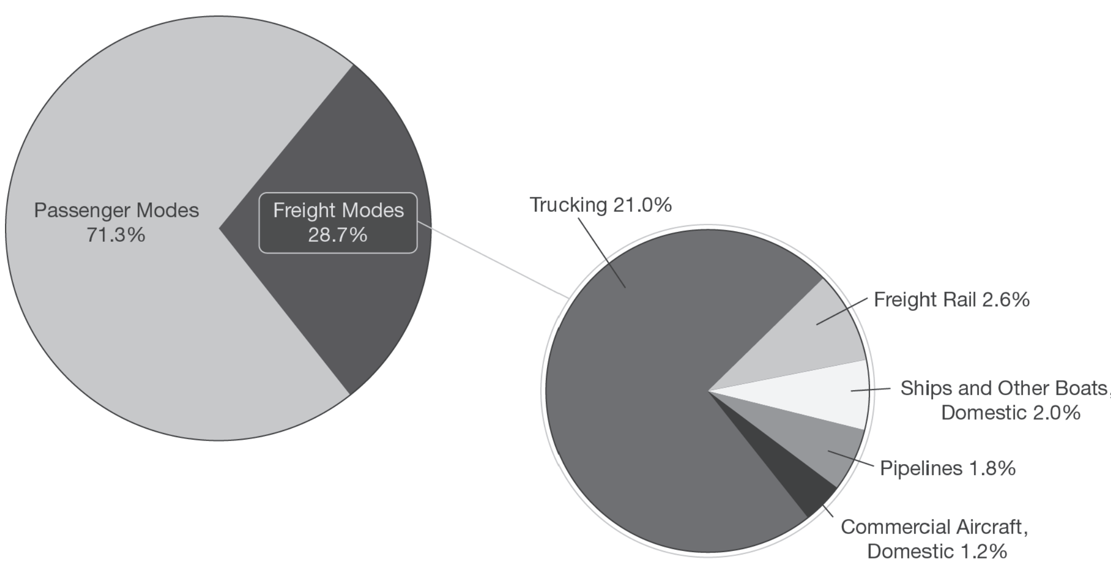

Figure 2.5. Contribution to GHG emissions, passenger modes.

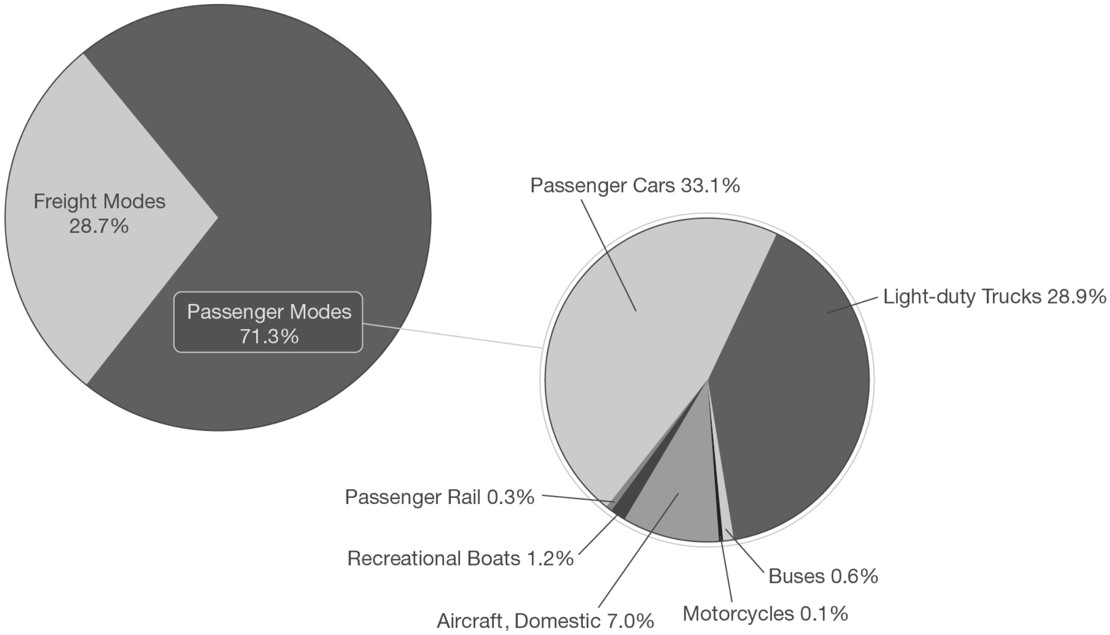

Figure 2.6. Contribution to GHG emissions, freight modes.

of freight-related GHG emissions and 2.6% of total transportation GHG emissions, with GHG emissions from air, marine, and pipeline operations making up less than 2% each of total transportation GHG emissions.

Perhaps of greatest interest in freight-related GHG emissions is that the amount of such emissions from heavy-duty trucks has increased rapidly since 1990, growing at three times the rate of emissions from LDVs. This is the product of decreasing fuel efficiency (as measured per ton-mile carried) and increasing demand for freight movement by trucks. Over the 1990 to 2007 period, CO_2 emissions per ton-mile carried increased almost 12%, while ton-miles carried increased 55%. The changes were driven by an expansion of freight trucking after economic deregulation of the trucking industry in the 1980s, widespread adoption of just-in-time manufacturing and retailing practices by business shippers and receivers, increasing highway congestion, and structural changes in the economy that produced higher-value, lower-weight, and more time-sensitive shipments that were best served by trucking.

Life-Cycle Emissions

Most transportation GHG emissions are the direct result of burning gasoline and diesel fuel to power engines in cars, trucks, locomotives, aircraft, and ships. But GHG emissions are also generated in the process of constructing and maintaining road, rail, port, and airport infrastructure; manufacturing and maintaining vehicles; and extracting and refining transportation fuels; in other words, GHGs are emitted over the life cycle of an asset. A recent study estimated that direct emissions from vehicle operations account for only 60% of the total GHG emissions associated with LDVs (Chester 2008). As shown in Figure 2.7, the extracting and refining of fuels accounts for 10% of emissions, vehicle manufacturing for 12%, and constructing and maintaining roads used by these vehicles for an estimated 17%. Therefore, only 70% of a vehicle's total GHG emissions (including fuel production and vehicle operations) is directly proportional to distance driven (VMT). GHG emissions not directly associated with vehicle operation are not included in the figures for transportation sector GHG emissions provided earlier in this section; therefore, the overall contribution of the transportation sector is actually significantly larger than its direct contribution of 29% of U.S. GHG emissions.

Other transportation modes show different results, but most tend to show a significant increase in GHGs when all components of the vehicle and system's operation are accounted for. In particular, the nonoperational life-cycle components of urban rail transit (i.e., vehicle manufacturing, track and station construction, station operations, and maintenance) account for about 50% of total life-cycle GHG emissions for that mode (Chester 2008).

Context Factors Influencing Transportation GHG Emissions

The AEO reference case presented above is just one potential future scenario for transportation GHG emissions. GHG emissions may be affected by a wide range of factors, some under varying degrees of influence by transportation agencies, such as speed, congestion, infrastructure investment,

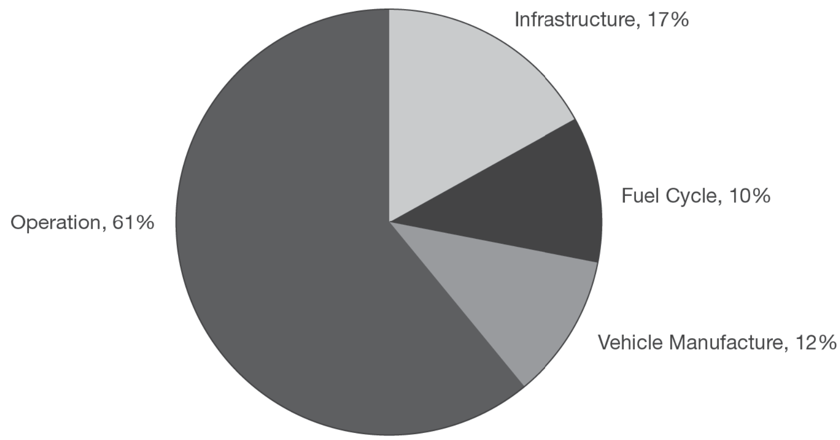

Figure 2.7. GHG emissions sources from a life-cycle perspective.

and pricing; and some over which transportation agencies have little or no influence, such as population growth and vehicle and fuel technologies. As shown in Figure 2.8, GHG emissions from passenger and freight travel are affected by four primary factors: total travel activity, the fuel efficiency of vehicles, the operational efficiency of drivers and the system (e.g., congestion, aggressive driving), and the carbon content of fuels. In addition, energy is consumed in the construction and maintenance of transportation facilities and in transportation agency operations.

Table 2.1 presents an overview of key contextual factors that could influence GHG emissions and surface transportation energy use. Table 2.1 also identifies which of the components of transportation GHG emissions (as identified above) each factor will likely affect. Additional discussion is provided in the following sections on some of the most important factors that are most directly relevant to GHG planning and analysis. These factors include

- Population and economic growth;
- Passenger and truck VMT;
- Vehicle technology and fuel efficiency;
- Trends in the management and operation of transportation infrastructure;
- Future scenarios for energy use, supply, and costs; and
- Potential federal policy initiatives directed at GHG reduction, both economywide (e.g., cap-and-trade, carbon tax) and for the transportation sector in particular (e.g., transportation planning regulations, funding, and vehicle and fuel standards).

Population and Economic Growth Forecasts

The U.S. Bureau of the Census releases national population forecasts every 4 years using the cohort-component method, which is based on assumptions about future births, deaths, and net international migration. A 2008 Census release projects that the U.S. population will increase from 310 million people in 2010 to 374 million people in 2030, a growth of about 20%, or 0.93% per year. Out of this increase of 64 million people, 29 million (46%) are expected to be immigrants (U.S. Census 2008). This is important to travel trends because immigrants are usually already working age and need to travel to work, unlike those born in the United States who will not reach working age until many years after birth. The percentage of the population aged 65 and older will also increase, with people 65 and older making up 19% of the population in 2030 compared with 13% in 2010. This will potentially reduce the demand for personal travel and especially work-related travel.

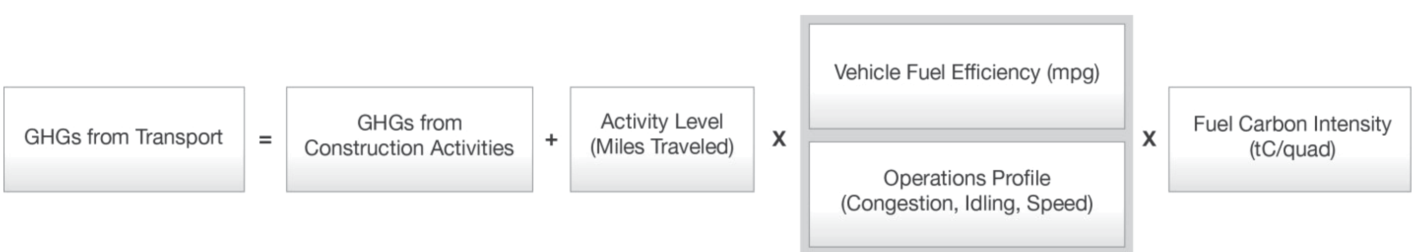

Figure 2.8. Different components of transportation-related GHG emissions.

Table 2.1. Context Factors That Could Influence GHG Emissions and Surface Transportation Energy Use

Factor Category	Factors	Influence
Transportation costs and pricing	• Congestion pricing • Parking pricing • User fees (gas taxes, VMT fees, excise taxes) • Cost of fuel • Vehicle insurance and registration fees	A, E, S, F
Population and economic activity	• Overall population growth, nationally and by region • Aging population • Increasing immigration • Continuing internal (to the U.S.) migration • Changing levels of affluence • Economic growth or stagnation • Service versus industrial economy • Magnitude and patterns of consumption • Tourism and recreational activity patterns • Patterns and variations in values, priorities, and political beliefs of the population • International trade and travel • Fiscal conditions for state DOTs, transit operators, and local transportation agencies	A, E, S
Land use and urban form	• Urban and rural land use patterns • Developing megaregions • Continuing and emerging challenges in rural and nonmetropolitan areas • Quality of schools as it affects locational choices • Crime and security as they affect locational choices • Comparative cost of housing and other services in different land use settings • Comparative fiscal and economic conditions in different local jurisdictions and statewide	A
Operational efficiency of drivers and system managers	• Congestion • Intelligent transportation systems • Eco-driving and other driving behaviors • Speed (speed limits, speed enforcement, design speeds, flow management, traffic signal timing and synchronization, and use of roundabouts) • Freight routing, border-crossing procedures for freight, urban freight consolidation centers, urban goods movement policies, and other freight logistics	S, A
Passenger and truck VMT	• Magnitude and type of costs and pricing for transportation use (e.g., cost of fuel, cost of vehicles, and user fees) • Passenger VMT per capita • Freight and logistics patterns and overall freight demand • Extent of use of telecommuting and alternative work schedules • Potential shifts to pay-as-you-drive insurance • Parking supply management and pricing	A
Policies and regulations	• Emerging national approaches (cap-and-trade, taxation, and conformity) • Statewide and metropolitan surface transportation planning legislation and regulations • National Environmental Policy Act (NEPA)	A, E, S, F, C
Vehicle technology and fuel efficiency	• Fuel economy: CAFE standards and California Pavley standards and consumer purchase decisions • Emerging alternative propulsion systems (hybrid and electric) and characteristics	E, F
Carbon intensity of transportation fuels	• Corn ethanol • Cellulosic fuels • Algae-based fuels • Electricity as a vehicle power source (including differential of carbon intensity of electric power sources over time and across regions and states) • Low-carbon fuel standards and policies	F
Future scenarios for energy use, supply and cost	• Price of energy (especially petroleum) • Conservation incentives and education	A, E, F

(continued on next page)

Table 2.1. Context Factors That Could Influence GHG Emissions and Surface Transportation Energy Use (continued)

Factor Category	Factors	Influence
Construction and maintenance agency operations	• Extent of new construction and type of construction (tunnels versus at-grade) • Energy intensity and carbon intensity of construction equipment and practices • Energy intensity of materials used in construction and maintenance (including extent of use of recycled materials) • Roadway lighting • Vegetation management along right-of-way (including vegetation choices and mowing practices) • Snow-plowing practices • Vehicles and fuels used in agency fleets • Paving frequency, pavement type, paving practices • Work zone management (as it affects traffic tie-ups and idling) • Energy efficiency of agency buildings and facilities • Asset management practices affecting energy and carbon generation • Increasing requirements for energy-efficient construction	S, C

Note: A = influences travel activity; E = influences vehicle fuel efficiency; S = influences system and driver efficiency; F = influences carbon content of fuels; C = influences GHGs from construction, maintenance, and agency operations; DOT = department of transportation; CAFE = corporate average fuel economy.

Economic growth also affects transportation demand, since a growing economy will involve the production of more goods and services, many of which need to be transported. The Congressional Budget Office, which produces 10-year economic forecasts, projects that gross domestic product will grow by about 3.5% annually between 2010 and 2015 (in real terms), and 2.3% annually between 2016 and 2019 (Congressional Budget Office 2009). A recent report for the U.S. Chamber of Commerce notes that international trade has continued to grow faster than the U.S. economy, increasing the volume of freight moving through international gateways, as well as along domestic trade corridors (Cambridge Systematics et al. 2008). All of these economic forecasts assume recovery from the economic downturn that began in 2008.

Passenger and Truck VMT Forecasts

Multiple sources have developed VMT forecasts for passengers and trucks. As noted above, the VMT growth rate assumption used in the AEO reference case works out to be an average of 1.5% per year between now and 2030, which is lower than the previous rate of 1.8%. A recent *Bottom Line* report (Cambridge Systematics and Pisarski 2009) and the *Moving Cooler* study (Cambridge Systematics 2009) of transportation GHG reduction strategies use a growth rate of 1.4% growth in VMT per year. However, some experts have come to view even this rate as too high. They suggest that factors such as rising fuel prices, saturation of the workforce, aging population, and a lower rate of transportation investment will further reduce VMT growth rates in the future. Since 2000, the annual VMT growth rate was only 1.4%, with an absolute decline occurring in 2008.

The early release of the 2011 AEO projects an annual growth in truck VMT averaging 1.9% between 2011 and 2020, moderating to 1.4% through 2035 (Energy Information Administration 2011). The long-term growth rate is in line with the *Bottom Line* report, which forecasts truck VMT growth at the same 1.4% annual rate as LDV VMT (Cambridge Systematics and Pisarski 2009). The forecast is based on the observation that freight VMT has recently been growing at about the same rate as passenger VMT. For example, between 1995 and 2006, passenger car and other two-axle, four-tire vehicle traffic grew by 24.4%, while combination truck traffic grew by 23.6%, and all truck traffic grew by 25.2%. In contrast to light-duty VMT, which is primarily affected by socioeconomic, demographic, and land use factors, truck VMT is closely related to overall economic activity, as well as to the structure of how industries produce and ship goods. At first glance this seems to contradict the earlier observation that GHG emissions have increased more rapidly from trucks than from cars since 1990. This can be explained by two factors: first, the greatest increase in freight volumes occurred in the early part of this period (1990 to 1995); and second, the productivity of freight movement (ton-miles per VMT) has continued to decrease.

Vehicle Technology and Fuel Efficiency Forecasts

Significant increases in fuel economy standards for LDVs, coupled with higher prices and investments in alternative fuels infrastructure, are likely to have a dramatic impact on the development and sales of alternative fuel and advanced technology LDVs. The AEO reference case includes a sharp increase in sales of unconventional vehicle technologies, such as flex-fuel, hybrid, and diesel vehicles. For example, hybrid vehicle sales of all varieties increase from 2% of new LDV sales in 2007 to 40% in 2030; diesel vehicles account for 16%

of new LDV sales, and flex-fuel vehicles for 13%. Dramatic shifts away from spark- and compression-ignited engines are not anticipated in the next 20 years because it is not anticipated that battery-powered electric or fuel cell vehicles will be able to replace the petroleum-based fleet in this time period.

In addition to the shift to unconventional vehicle technologies, the AEO reference case shows a shift in the LDV sales mix between cars and light trucks. Driven by rising fuel prices and the cost of corporate average fuel economy (CAFE) compliance, the market share of new light trucks is expected to decline. In 2007, light-duty truck sales accounted for approximately 50% of new LDV sales. In 2030, their share is estimated to be 36%, mostly as a result of a shift in LDV sales from SUVs to midsize and large cars.

For the first time in 20 years, the 2007 Energy Independence and Security Act (EISA) required a change in federal fuel economy standards. In May 2010, EPA and the National Highway Traffic Safety Administration adopted a set of new light-duty fuel economy standards through 2016 consistent with the GHG emissions standards adopted by California (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration 2010a). In October 2010, the agencies announced their intent to propose more stringent light-duty fuel efficiency standards for the 2017 through 2025 model years (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration 2010b).

One of the uncertainties in future year motor vehicle technology and fuel efficiency forecasts is whether U.S. LDV sales will return to historic levels after the economic recession is over. Recent annual LDV sales have been near 16 million units, but the 2009 AEO forecast for 2030 is for sales near 20 million units per year. Some analysts believe that the most recent historic sales are artificially high, for a number of reasons, and that near-term vehicle sales will be closer to 12 million than 16 million. If this occurs, the penetration of new technologies and more fuel-efficient vehicles will be slower than expected, and baseline GHG emissions will be above expected values. This would make it more difficult to meet GHG emissions reduction targets.

Unlike LDVs, heavy-duty vehicles are not currently subject to fuel efficiency standards. However, the 2007 EISA required that the EPA evaluate fuel efficiency standards for trucks. In October 2010 EPA and NHTSA announced proposed GHG and fuel efficiency standards for heavy-duty trucks (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration 2010c). The proposed standards would reduce energy consumption and GHG emissions by 7% to 20% for combination tractors, heavy-duty pickups and vans, and vocational vehicles by model year 2019 compared with a 2010 baseline. (The reduction compared with the AEO reference case would be somewhat lower since this projection already assumes modest increases in fuel efficiency over this time period.) The proposed standards are less aggressive than light-duty standards (as measured by the percentage improvement in fuel efficiency, as for LDVs), largely because market forces have already fostered more aggressive development and adoption of fuel economy improvements for U.S. trucks compared with LDVs.

Trends in Management and Operation of Transportation Infrastructure

As gas tax revenues fall and the highway trust fund realizes severe shortfalls, state and local agencies are facing significant budget constraints that affect their ability to operate the transportation system. This fiscal stress, along with constrained right-of-way, community impacts, and environmental concerns, limits major expansions of the transportation system as a solution to ease traffic congestion. Many agencies, in particular state departments of transportation (DOTs), have begun to use incident and congestion management strategies (e.g., intelligent transportation systems [ITS], real-time information, managed lanes, and pricing) to maintain an adequate level of service as transportation demand outpaces infrastructure investment. This trend is likely to continue in the future. Given that the United States consumed an additional 2.9 billion gallons of fuel in 2005 due to congestion, a substantial increase from 0.5 billion gallons in 1982 (Schrank and Lomax 2007), the success of such strategies in reducing delay and easing traffic congestion could help reduce GHG emissions as fuel is used more efficiently. Conversely, if VMT continues to increase without corresponding infrastructure or operational improvements, then congestion, delay, and associated emissions will continue to increase.

The application of dynamic technology, specifically ITS, is becoming a relatively common strategy for improving the operational efficiency of the transportation system. Examples include ramp meters that control the volume of drivers entering a highway, electronic signage that informs drivers of upcoming travel conditions, and traffic signalization that can encourage steady vehicular flow along a specific corridor (Lockwood 2008). ITS technology also allows for traffic management centers to respond promptly to roadway incidents, thereby lessening delay and potentially reducing GHG emissions.

Taking the traffic management center and ITS concept one step further, lane management is a strategy that allows a transportation agency to actively manage travel lanes in real time for optimal flow conditions. High-occupancy toll lanes allow carpools to ride for free, but charge other vehicles a toll that varies by time of day and traffic conditions. Conceptually, a high-occupancy toll lane increases highway efficiency by allowing additional vehicles to use an underutilized high-occupancy vehicle lane. The U.S. DOT's Urban Partnership Program provided funds for selected metropolitan areas to demonstrate different aspects of managed lanes operation. It is expected that the experiences of these metropolitan areas with the managed lane concept will provide the impetus for other metropolitan areas to adopt similar strategies.

Over the long run, however, GHG reductions that result from fuel savings from management and operational strategies are likely to be at least partially—if not completely—offset by induced demand, or the increase in travel that results from improved travel conditions. The *Moving Cooler* study concluded that when measured cumulatively through 2050, additional GHGs from induced travel in response to transportation improvements (including capacity expansion and operational improvements) would come close to offsetting the GHG emissions reduction benefits of reduced congestion (Cambridge Systematics 2009). The magnitude of the induced demand effect is subject to considerable uncertainty, and it is possible that under some assumptions, the increase in GHG emissions from induced travel could outweigh the congestion benefits. This may become particularly true in the future, as vehicle technologies (such as hybrids or electric vehicles) that are more efficient in low-speed operation become more widely adopted. Even without considering these effects, the efficiency benefits of congestion reduction will decline over time in proportion to increases in CAFE standards, as well as the adoption of less carbon-intensive fuels, as baseline GHG emissions decrease.

Real-time management of parking facilities, or performance parking, follows the same concept as managed lanes by varying the price of parking according to usage; that is, more demand for parking will yield a higher price. The price, which would vary in real time, is intended to maintain an 85% occupancy rate. Although only a few cities have successfully implemented parking management strategies, a recently proposed California Senate bill has called for statewide parking reform, with performance parking as a major component. The bill's purpose is to help California meet its GHG reduction goal of 1990 levels by 2020, as introduced by Assembly Bill 32 in 2006. In Senate Bill 518 of the California State Assembly, performance parking is identified as a strategy to communicate the true cost of parking to travelers and ultimately reduce vehicle trips and GHGs. It is hard to say whether performance parking will take hold in other regions of the United States. It seems likely, however, that pricing in all forms will be a much more important strategy for transportation officials in the future.

Future Scenarios for Energy Use, Supply, and Costs

Since the vast majority of transportation energy in the United States comes from petroleum, importing oil is going to remain a political necessity for decades into the future. This requires ceding a certain level of political influence and control to oil-exporting nations. Many of these oil-producing nations are among the most politically unstable in the world, which necessarily results in unavoidable uncertainty with regard to the oil supply. Furthermore, although overall worldwide supplies of petroleum are nowhere near exhaustion, it is likely that the ability to expand oil supply capacity cheaply is nearing its peak, and that in the near future it will become more difficult to expand oil production beyond current levels. When this occurs, energy production will expand to nonpetroleum sources, most of which are likely to reduce life-cycle GHG emissions. During the transition period, there will also be pressure to extract petroleum from sources that were not previously economical, such as tar sands. Such production methods are more energy intensive and their use may result in increased life-cycle GHG emissions per unit of fuel produced.

Several technologies are available or in development that could potentially reduce gasoline consumption and GHG emissions in the transportation sector. Many of these options, such as hydrogen fuel cells, would require a dramatic infrastructure investment before the technology could be implemented on a large scale. Biofuels and electrification require far more modest infrastructure investments, and therefore are more likely to be implemented in the foreseeable future. Biofuels require feedstocks that can be produced with very little energy input in order to reduce overall carbon emissions. However, concerns have been raised that the demand for biofuel feedstocks may reduce agricultural land for other purposes while increasing pressure to convert nonagricultural lands (such as forests) to agricultural production, which could cause sequestered carbon to be released. Likewise, plug-in electric vehicles require electricity production from low-carbon sources such as wind, solar, nuclear, and biomass to significantly decrease emissions.

The United States invests billions of dollars every year to promote energy efficiency, expand the energy supply, develop energy technologies, and reduce energy costs. Over $16 billion was spent on energy subsidies in 2007 (Energy Information Administration 2008). The 2007 Renewable Fuels Standard (RFS), signed into law as part of EISA, mandates that 36 billion gallons of biofuels will be used in the United States in the year 2022. In March 2010, EPA updated the RFS to encourage the production of low-GHG biofuels (U.S. Environmental Protection Agency 2010b). These changes include a higher standard in the short term to reflect existing production surpluses. In addition, the standards for advanced biofuels and biomass-based diesel have been modified to be stronger and more flexible. The RFS will result in a dramatic increase in the amount of ethanol being sold in the country over the next 15 years and could potentially reduce overall gasoline consumption.

The impact of any of these alternative fuels on transportation GHG emissions will range from modest to significant depending on the fuel and how it is produced. Figure 2.9, which is based on the Department of Energy's GREET

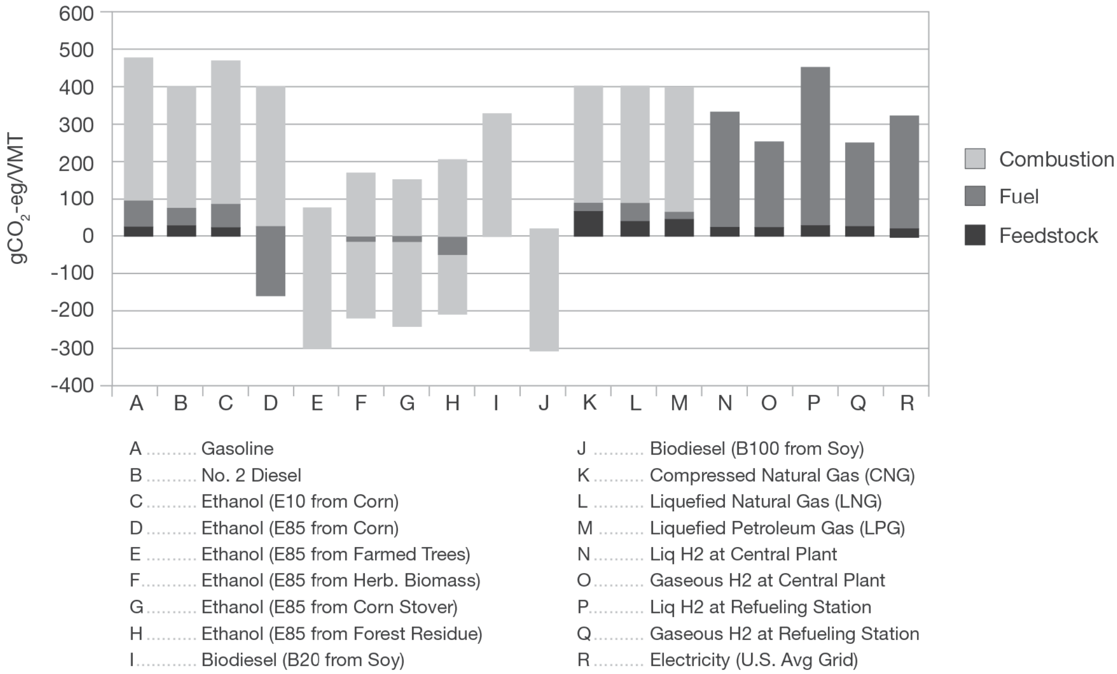

Figure 2.9. Relative GHG emissions from different fuels using GREET model.

(Greenhouse Gas, Regulated Emissions and Energy use in Transport) model (Version 1.8b), shows relative GHG emissions, including full fuel-cycle emissions, for a variety of transportation fuels (Cambridge Systematics and Eastern Research Group 2010). Compared with gasoline, emissions reductions range from about 16% for an 85% corn ethanol blend (E85) to 57% to 84% for ethanol from various cellulosic feedstocks. A 20% blend of soy-based biodiesel provides roughly an 18% reduction, and natural gas results in a reduction in the range of 16% to 30%. (Note that the model does not reflect the latest research on biofuel impacts as reported for the 2010 RFS2 rulemaking [U.S. Environmental Protection Agency 2010c]). Electricity shows roughly a 33% reduction with today's technology and electricity generation mix. Benefits of hydrogen vary greatly depending on the production method. The net impact of any of these fuels on total GHG emissions will depend not only on the per vehicle benefit but also the rate of market penetration, which will depend on a host of uncertain factors such as technology advancement, fuel supply, policy choices that may encourage or discourage specific fuels, and the relative prices of different fuels.

Conclusion

This chapter has identified the important role that the transportation sector plays in the U.S. GHG emissions inventory. If the United States is serious about reducing the amount of GHG emissions entering the atmosphere, the transportation sector will have to be a part of the national strategy because of its significant place as a major source of such emissions. This chapter also identified many population trends and likely characteristics of future transportation system management that could lead to improved and perhaps less polluting system operations. However, as noted, some studies argue that the growth in VMT will negate any possible benefits of reduced GHG emissions associated with improved system management: there will simply be more people traveling and goods moving. Thus, it is important in any discussion of incorporating GHG emissions into decision making that some understanding of the level of effectiveness associated with different GHG-reducing transportation strategies be part of the discussion. The next chapter presents such information.

CHAPTER 3

GHG-Reducing Transportation Strategies

Background

Many of the studies and research on transportation-related GHG reduction strategies have focused on changes in fuels and vehicle technology. Although such strategies are critical as part of a national strategy to reduce GHG emissions, most state and local transportation agencies have little authority over them. State governments can, however, exercise significant influence through taxation policies and mechanisms such as alternative fuel infrastructure investment and fuel and vehicle standards. State and local transportation agencies can directly influence a variety of strategies via normal transportation planning, investment, and operations decisions; others, such as pricing strategies, will remain specific to those jurisdictions willing to act on them. Table 3.1 presents a typology of transportation-related GHG reduction strategies and identifies the levels or sectors of government that are best suited to address each strategy.

The strategies considered for reducing GHG emissions are found in the nine major categories listed in the left-hand column of Table 3.1. Inclusion of any of these strategies or projects does not guarantee a reduction in GHG emissions; the GHG impacts of any given strategy or project must be evaluated based on local conditions and data. The strategies most directly under the influence of transportation agencies include

- Infrastructure provision, including the design, construction, and maintenance of highway, transit, and other transportation facilities and networks;
- Management and operation of the transportation system, such as technologies and operational practices to improve traffic flow or transportation system pricing policies; and
- Provision of transportation services and demand management measures to encourage the use of less carbon-intensive modes, such as transit service improvements, rideshare and vanpool programs, and worksite trip reduction.

Other strategies that may be influenced by transportation agencies include

- Land use planning, for which transportation agencies may provide regional coordination, funding, and/or technical assistance to support state and local efforts to develop more efficient land use patterns;
- Pricing strategies, such as tax and insurance policies, mileage-based pricing, or registration fees, for which transportation agencies may provide analysis support and encourage state-level policy changes; and
- Provision of alternative fuels infrastructure, as well as direct purchase of alternative fuel vehicles for agency fleets.

Opinions differ on which GHG reduction strategies should receive the greatest emphasis. Some analysts believe that technological innovations resulting in increased vehicle efficiency and/or the substitution of low-carbon fuels may be the only economically and politically feasible ways to achieve the transportation emissions reductions needed to meet GHG reduction targets, which range as high as an 83% reduction in 2050 compared with 1990 levels. Others believe that measures to affect travel activity—particularly a shift toward more compact and transit-oriented land use patterns, as well as other travel reduction measures such as improved transit service, extensive transportation demand management (TDM) programs, and travel pricing—can make significant contributions to GHG reduction and are a necessary component of achieving overall goals. In general, the comprehensive analyses that have been conducted suggest that vehicle and fuel technology strategies will yield the largest GHG benefits, but that by themselves they are unlikely to achieve the most aggressive GHG reduction goals. Additional reductions from travel activity and system efficiency strategies will likely be needed to meet such targets, especially over the short term and particularly for those portions of reduction targets assigned to DOTs (Mui et al. 2007; Green and Schafer 2003).

Table 3.1. State and Local Government Strategies That Can Influence Transportation-Related GHG Emissions and Energy Use

Strategy	Government Action	Primary Responsibility
Transportation system planning and design	• Transportation network design • Modal choices and investment priorities • Roadway design standards (affecting traffic speed and flow and pedestrian and bicycle accommodation)	Transportation agency (state, metro, local)
Construction and maintenance practices	• Pavement and materials (reduced energy consumption materials, durability and longevity, smoothness) • Construction and maintenance equipment and operations (idle reduction, more efficient and alternative fuel vehicles) • Right-of-way management (vegetation management to maximize vegetation as carbon sinks, minimize mowing, solar and wind alternative energy capture)	Transportation agency (state, local)
Transportation system management and operations	• Traffic management and control (signal optimization and coordination, integrated corridor management) • Speed management (speed limits, enforcement) • Idle reduction policies and enforcement • Real-time travel information • Incident management • Preferential treatment for vehicle types (high-occupancy vehicle lanes, bus priority) • Pricing (high-occupancy toll lanes, congestion pricing)	Transportation agency (state, metro, local)
Vehicle and fuel policies	• Vehicle emissions standards (possibly) • Feebates or carbon-based registration fees • Provision of low-carbon fuel infrastructure • Subsidies for low-carbon fuels • Transit vehicle fleet purchases or retrofits • State and local government fleet purchases • Older and inefficient vehicle scrappage	State government, transportation agency (fleet purchases)
Transportation planning and funding	• GHG consideration and analysis in planning • GHG emissions reduction targets • Funding incentives tied to GHG reduction • Multiagency working groups	Transportation agency (state, metro, local)
Land use codes, regulations, and other policies	• Integrated regional transportation and land use planning and visioning • Funding incentives and/or technical assistance for local policies for compact development, walkable communities, mixed-use development, reduced parking requirements • Infrastructure investments to support in-fill and transit-oriented development	Local government (mostly), state government, state and metro transportation agency (incentives, technical assistance)
Taxation and pricing	• State or local tax policies that discourage low-density development • Congestion pricing • Pay-as-you-drive insurance • Parking pricing • Mileage-based transportation user fees • Vehicle registration fees based on fuel efficiency, carbon emissions, or miles driven	State government (mostly), local government (development fee policies, parking pricing), transportation agency (congestion pricing)
Other travel demand management and public education	• Commute and worksite trip reduction programs • Telecommuting and alternative work schedules • Ridesharing and vanpooling incentives and services • Individualized marketing campaigns	Transportation agency (state, metro, local)
Other public education	• Eco-driving information, training, and in-vehicle feedback • Information on fuel economy, cost, and GHG impacts of vehicle purchase and travel decisions	State and local government, transportation agency

Cost-Effectiveness of Transportation Strategies

Information on the effectiveness and cost-effectiveness of different transportation-related GHG strategies was drawn from the existing literature, with a focus on recent reports that summarized estimates across multiple strategies. The feasibility assessment presented in this section is also based on information from the literature, as well as on the judgment and experience of the research team.

The information provided in this section must be interpreted with caution. The literature on transportation-related GHG reduction strategies is fairly new and focuses on summary estimates at a national level. There is considerable uncertainty surrounding the estimates for many strategies, and both the effectiveness and cost-effectiveness of individual strategies may vary significantly depending on local factors. The feasibility of a given strategy may also vary from location to location, and may change in the future depending on changes in technology, market trends, and changing political and societal viewpoints.

Metrics and Methodological Issues

Both the effectiveness (potential magnitude of GHG reductions) and cost-effectiveness (cost per unit of reduction) are important considerations when selecting a set of strategies through the transportation decision-making process. Effectiveness is typically measured in terms of metric tons (tonnes) of carbon dioxide equivalent (CO_2e) emissions reduced per year or cumulatively over a number of years. For comparison at different geographic scales, however, effectiveness should be measured as a percentage reduction of emissions from either a total transportation sector or a particular transportation subsector (e.g., on-road vehicles). Use of different comparison bases in the literature creates challenges for the development of consistent effectiveness estimates.

Cost-effectiveness is typically measured in terms of dollars per tonne of CO_2e reduced and can be compared more consistently across studies. To evaluate a string of future year benefits, costs are typically discounted to current year dollars using a standard discount rate. Future GHG emissions are usually not discounted, although practices vary. It is generally agreed that the benefit of reducing a tonne of GHG emissions is roughly the same whether that reduction occurs now or 10 years in the future. The most important metric is *cumulative* GHG reductions starting in the present and continuing through some analysis horizon (e.g., 2030 or 2050).

The types of costs included in a cost-effectiveness calculation are an important consideration. Some estimates of cost-effectiveness include public sector implementation costs only. Others include benefits to travelers, such as vehicle operating cost savings. Tolls and taxes (or rebates) are generally considered to be a transfer between one entity and another, and therefore are not a net social cost, although they affect the distribution of costs among different population groups. A particularly challenging issue is the incorporation of nonmonetary costs such as environmental externalities (e.g., air pollution or reduced oil dependency) into an assessment effort. For some strategies, these costs can be quite significant, but they are usually not monetized in GHG cost-effectiveness estimates. Net included costs refer to all the monetized costs included in the cost-effectiveness estimates. Readers should be aware that the use of net included cost-effectiveness measures is controversial, with the argument against their use being primarily that they ignore other positive benefits associated with such strategies and thus bias the results against highway improvement projects; these measures are not presented in Table 3.2.

Caution should be exercised when using cost-effectiveness indices alone. For example, a cost-effectiveness index could very well show that one strategy is better than another based on the relationship between benefits and costs, but that the overall reduction in GHG emissions might be greater from the strategy that has the lower cost-effectiveness index. This highlights the concept that cost-effectiveness evaluation must be done in the context of the overall goals of the policy or planning study.

Cobenefits of GHG Reduction Strategies

GHG emissions reductions are just one of the benefits and impacts that must be considered when evaluating any transportation action. Many strategies also have important cobenefits (positive impacts) or negative impacts. For example, congestion reduction strategies reduce traveler delay and improve mobility in addition to reducing fuel consumption and emissions. Provision of alternative modes (transit, walking, bicycling) can increase accessibility, especially for populations with limited car access. By increasing the cost of travel, pricing may have negative impacts unless these impacts are mitigated through revenue redistribution or enhancement of travel alternatives. Some strategies, especially pricing, may have equity impacts by disproportionately affecting a particular subset of the population (e.g., low-income travelers).

Sources of Cost-Effectiveness Estimates

Most of the literature on transportation-related GHG reduction strategies has focused on vehicle and fuel technology strategies. The literature on the cost-effectiveness of travel behavior (vehicle miles traveled [VMT] reduction) and system efficiency (e.g., congestion relief) strategies with respect to GHG reduction is quite limited and mostly new, having

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Table 3.2. Transportation System GHG Reduction Strategies

Strategy Name	Key Deployment Assumptions	Fuel/GHG Reduction in 2030 (%)	Direct Cost-Effectiveness	Data Source	Feasibility		
					Technical	Institutional	Political
Transportation System Planning, Funding, and Design							
Highways							
Capacity expansion[a, b, c]	25% to 100% increase in economically justified investments over current levels	0.07%–0.29% [0.25%–0.96%]	NA	Cambridge Systematics 2009	M	H	L–H
Bottleneck relief[a, b]	Improve top 100 to 200 bottlenecks nationwide by 2030	0.05%–0.21% [0.29%–0.66%]	NA	Cambridge Systematics 2009	M	H	L–H
HOV lanes	Convert all existing HOV lanes to 24-hour operation	0.02% 0.00%	$200	International Energy Agency 2005; Cambridge Systematics 2009	H	H	H
	Convert off-peak direction general-purpose lane to reversible HOV lane on congested freeways	0.07%–0.18%	$3,600–$4,000	Cambridge Systematics 2009	M	H	L–M
	Construct new HOV lanes on all urban freeways	0.05%	$1,200	International Energy Agency 2005	L	H	L–M
Truck-only toll lanes	Constructed to serve 10% to 40% of VMT in large and/or high-density urban areas	0.03%–0.15%	$670–$730	Cambridge Systematics 2009	L	H	L–M
Transit							
Urban fixed-guideway transit	Expansion rate of 2.4%–4.7% annually	0.17%–0.65%	$1,800–$2,000	Cambridge Systematics 2009	M	H	M
High-speed intercity rail	4 to 11 new HSR corridors	0.09%–0.18%	$1,000–$1,400	Cambridge Systematics 2009	M	M	M
Non-motorized							
Pedestrian improvements	Pedestrian improvements implemented near business districts, schools, transit stations	0.10%–0.31%	$190	Cambridge Systematics 2009	H	L–M	M
Bicycle Improvements	Comprehensive bicycle infrastructure implemented in moderate to high-density urban neighborhoods	0.09–0.28%	$80–$210	Cambridge Systematics 2009	M	L	M

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Table 3.2. Transportation System GHG Reduction Strategies (continued)

Strategy Name	Key Deployment Assumptions	Fuel/GHG Reduction in 2030 (%)	Direct Cost-Effectiveness	Data Source	Feasibility		
					Technical	Institutional	Political
			Freight				
Rail freight infrastructure	Aspirational estimates of potential truck–rail diversion resulting from major program of rail infrastructure investments	0.01%–0.22%	$80–$200	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M	M	L–H
Ports and marine infrastructure and operations	Land and marineside operational improvements at container ports	0.01%–0.02%	NA	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M	M	M–H
			Construction and Maintenance Practices				
Construction materials[d]	Fly-ash cement and warm-mix asphalt used in highway construction throughout U.S.	0.7%–0.8%	$0–$770	Cambridge Systematics forthcoming Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M–H	M	M–H
Other transportation agency activities[d]	Alternative fuel DOT fleet vehicles, LEED-certified DOT buildings	0.1%	NA	Cambridge Systematics forthcoming Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	M	M–H
			Transportation System Management and Operations				
Traffic management	Deployment of traffic management strategies on freeways and arterials at rate of 700 to 1,400 miles/year nationwide in locations of greatest congestion	0.07%–0.08% [0.89%–1.3%]	$40 to >$2,000				
Ramp metering[a]	Centrally controlled	0.01% [0.12%–0.22%]	$40–$90	Cambridge Systematics 2009	H	H	M
Incident management[a]	Detection and response, including coordination through traffic management center	0.02%–0.03% [0.24%–0.34%]	$80–$170	Cambridge Systematics 2009	H	M	H
Signal control management[a]	Upgrade to closed loop or traffic adaptive system	0.00% [0.01%–0.10%]	$340–$830	Cambridge Systematics 2009	H	M	H
Active traffic management[a]	Speed harmonization, lane control, queue warning, hard shoulder running	0.01%–0.02% [0.24%–0.29%]	$240–$340	Cambridge Systematics 2009	M	M	H
Integrated corridor management[a]	Multiple strategies	0.01%–0.02% [0.24%–0.29%]	$240–$340	Cambridge Systematics 2009	M	M	H
Real-time traffic information[a]	511, DOT website, personalized information	0.00% [0.02%–0.07%]	$160–$500	Cambridge Systematics 2009	M	M	H

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Table 3.2. Transportation System GHG Reduction Strategies (continued)

Strategy Name	Key Deployment Assumptions	Fuel/GHG Reduction in 2030 (%)	Direct Cost-Effectiveness	Data Source	Feasibility		
					Technical	Institutional	Political
Transit Service							
Fare reductions[e]	25%–50% fare reduction (Cambridge)	0.02%–0.09%	NA	Cambridge Systematics 2009	H	H	H
	50% fare reduction (EIA)	0.3%	$1,300	International Energy Agency 2005			
Improved headways and LOS	10%–30% improvement in travel speeds through infrastructure and operations strategies	0.05%–0.10%	$1,200–$3,000	Cambridge Systematics 2009	L–M	L–M	M–H
	Increase service (minimum: add 40% to off peak; maximum: also add 10% to peak)	0.2%–0.6%	$3,000–$3,300	International Energy Agency 2005	H	H	H
Intercity passenger rail service expansion	Minimum: Increase federal capital and operating assistance 5% annually versus trend. Maximum: Double federal operating assistance, then increase 10% annually	0.05%–0.11%	$420–$1,500	Cambridge Systematics 2009	H	H	H
Intercity bus service expansion	3% annual expansion in intercity bus service	0.06%	NA	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	M	H
Truck Operations							
Truck idling reduction[c]	30%–100% of truck stops allow trucks to plug in for local power	0.02%–0.06%	$50	Cambridge Systematics 2009	H	L–M	M–H
	26%–100% of sleeper cabs with on-board idle reduction technology	0.09%–0.28%	$20	Cambridge Systematics 2009	H	M	M
Truck size and weight limits	Allow heavy/long trucks for drayage and noninterstate natural resources hauls	0.03%	$0	Cambridge Systematics 2009	H	M	L–M
Urban consolidation centers	Consolidation centers established on periphery of large urbanized areas; permitting of urban deliveries to require consolidation	0.01%	$40–$70	Cambridge Systematics 2009	M	L	L–M

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Table 3.2. Transportation System GHG Reduction Strategies (continued)

Strategy Name	Key Deployment Assumptions	Fuel/GHG Reduction in 2030 (%)	Direct Cost-Effectiveness	Data Source	Feasibility		
					Technical	Institutional	Political
Reduced Speed Limits[f]	55 mph national speed limit	1.2%–2.0%	$10	Cambridge Systematics 2009; Gaffigan and Fleming 2008; International Energy Agency 2005	H	M–H	L
Land Use Codes, Regulations, and Policies							
Compact development	60%–90% of new urban growth in compact, walkable neighborhoods (+4,000 persons/sq mi or +5 gross units/acre) (Cambridge) 25%–75% of new urban growth in compact, mixed-use developments (*Special Report 298*)	0.2%–1.8% 0.4%–3.5% 1.2%–3.9%[a]	$10	Cambridge Systematics 2009 *Special Report 298* 2009 Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M	L	L
Parking management	All downtown workers pay for parking ($5/day average for those not already paying)	0.2%	NA	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	L	L
Taxation and Pricing							
Cap-and-trade or carbon tax	Allowance price of $30–$50/tonne in 2030, or similar carbon tax	2.8%–4.6%	NA	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M	M	L–M
VMT fees	VMT fee of 2¢ to 5¢/mile	0.8%–2.3%	$60–$150	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	L	H	L
Pay-as-you-drive insurance	Require states to permit PAYD insurance (low)/require companies to offer (high)	1.1%–3.5%	$30–$90	Cambridge Systematics 2009	L–M	L–M	M
Congestion pricing	Maintain LOS D on all roads (average fee of 65¢/mile applied to 29% of urban and 7% of rural VMT) (Cambridge) Areawide systems of managed lanes (EEA)	1.6% 0.5%–1.1%	$340	Cambridge Systematics 2009 Energy and Environmental Analysis 2008	L	H	L
Cordon pricing	Cordon charge on metro area CBDs (average fee of 65¢/mile)	0.1%	$500–$700	Cambridge Systematics 2009	M–H	M	L
Travel Demand Management							
Workplace TDM (general)	Widespread employer outreach and alternative mode support	0.1%–0.6%	$30–$180	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	L–H	H
Teleworking	Doubling of current levels	0.5%–0.6%	$1,200–$2,300	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M	L	M–H

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Table 3.2. Transportation System GHG Reduction Strategies (continued)

Strategy Name	Key Deployment Assumptions	Fuel/GHG Reduction in 2030 (%)	Direct Cost-Effectiveness	Data Source	Feasibility		
					Technical	Institutional	Political
Compressed work weeks	Minimum: 75% of government employees; maximum: double current private participation[a]	0.1%–0.3%	NA	International Energy Agency 2005	H	L	L–H
	Requirement to offer 4/40 workweek to those whose jobs are amenable (IEA)	2.4%	<$1	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010			
Ridematching, carpool, and vanpool	Extensive rideshare outreach and support	0.0%–0.2%	$80	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	L–M	H
Mass marketing	Mass marketing in 50 largest urban areas	0.14%	$270	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	M	H
Individualized marketing	Individualized marketing reaching 10% of population	0.14%–0.28%	$90	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	M	M	H
Carsharing	Subsidies for start-up and operations	0.05%–0.20%	<$10	Cambridge Systematics 2009	H	M	H
Other Public Education							
Driver education/ eco-driving	Reach 10%–50% of population + in-vehicle instrumentation	0.8%–2.3%	NA	Cambridge Systematics 2009	L	L	H
		3.7%		International Energy Agency 2005			
Information on vehicle purchase	Expansion of EPA SmartWay program (freight-oriented) and consumer information	0.09%–0.23%	NA	Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	H	H

Notes: L, M, and H = low, medium, and high, respectively; LOS = level of service.

[a] Top range (smaller reductions) includes induced demand effects as analyzed in *Moving Cooler* (Cambridge Systematics 2009); bottom range in brackets (larger reductions) does not. Cost-effectiveness estimates include induced demand effects.

[b] Cost-effectiveness for capacity expansion and bottleneck relief strategies calculated from *Moving Cooler* data are undefined because net 2010–2050 GHG benefits were negative (2009).

[c] Economically justified capacity expansion based on analysis using the FHWA Highway Economic Requirements System (HERS) model.

[d] Most of the emissions reduced are from other (nontransportation) sectors. Reductions are shown as a percentage of transportation sector emissions for comparison.

[e] Fare reductions are considered as a transfer in the *Moving Cooler* study and therefore have no net implementation cost (2009). The IEA study considers costs to the public sector (lost fare revenues).

[f] Percentage reduction from Gaffigan and Fleming (2008). Direct cost-effectiveness from International Energy Agency's *Saving Oil in a Hurry* (2005). Net included cost-effectiveness from *Moving Cooler* (2009).

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been published within the past 5 years. Although some of this literature represents original research and analysis, other literature provides valuable summary and syntheses of other sources, including research and evaluation results for individual strategies. Although GHG emissions have become an explicit analysis focus only recently, studies dating as far back as the 1970s have evaluated VMT and congestion reduction strategies for energy and/or air quality purposes. Some of this literature contains information useful to GHG assessment, but additional analysis is generally required to infer GHG impacts from reported VMT, energy, and/or air pollutant reductions.

The following sources provided the cost-effectiveness estimates of the transportation-related GHG reduction strategies discussed in this report. The strengths and limitations of each source are presented.

The 2010 U.S. DOT report to Congress, *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions,* provides a comprehensive summary of existing literature, and some original analysis, on the GHG impacts and cost-effectiveness of a full range of transportation strategies (Cambridge Systematics and Eastern Research Group 2010). The report covers six general strategy types for all transportation modes:

- Low-carbon fuels;
- Vehicle fuel efficiency;
- System efficiency;
- Reduction in carbon-intensive travel activity;
- Economywide market mechanisms; and
- Planning and funding approaches.

For system efficiency and travel activity strategies, individual study results are presented, and summary ranges (low to high) of nationwide effectiveness (expressed in million metric tons [MMT] CO_2e in 2030) and cost-effectiveness (dollars per tonne) are presented for each strategy. For vehicle and fuel strategies, original estimates (again, shown as low to high ranges) are developed based on data found in the existing literature for technology effectiveness, market penetration rates, and costs. The report also discusses cobenefits of each strategy, as well as issues affecting feasibility.

The *Moving Cooler* report represents the first attempt at a comprehensive analysis of the nationwide GHG reduction benefits and costs of system efficiency and reduction strategies for travel behavior and VMT (Cambridge Systematics 2009). Cumulative benefits and costs over 2010 to 2050 are estimated for each strategy, and snapshot results are provided for 2020, 2030, and 2050. Cost-effectiveness is not calculated directly, although it can be inferred based on cumulative 2010 to 2050 benefits and costs. Three levels of implementation aggressiveness are evaluated. Results are presented for six strategy bundles in addition to individual strategies. An analysis is also provided of equity implications, with the primary focus on pricing strategies.

Saving Oil in a Hurry provides sketch-level estimates of fuel savings for various VMT reduction strategies, as well as speed reduction, eco-driving, and alternative fuels (International Energy Agency 2005). The study is internationally focused in terms of its data sources and assumptions, and estimates are provided for different regions of the world, including the United States and Canada, Japan and Korea, Western Europe, and Australia and New Zealand. Some cost-effectiveness estimates (expressed in dollars per barrel of oil) are provided.

Transportation and Global Climate Change: A Review and Analysis of the Literature provides a synthesis of existing literature on travel reduction, fuel economy–focused, and alternative (reduced carbon content) fuel strategies and potential ranges of VMT, fuel savings, and/or GHG impacts (Federal Highway Administration 1998). Impacts are not expressed in consistent terms, but rather rely on the information available in the literature. The timing of benefits and implementation issues are also discussed.

The reports McKinsey and Company produced on reducing GHGs evaluate the GHG reduction benefits and cost-effectiveness of a full range of technology-focused GHG reduction strategies across all sectors of the U.S. economy (2007, 2009). Transportation technologies such as hybrid and battery-powered electric vehicles and low-carbon fuels are included. Important innovations of these reports include the comparison of all sectors in the same terms and the presentation of results in the form of a marginal abatement curve that displays both the magnitude of impacts and cost-effectiveness of all strategies on a single chart.

Lutsey (2008) applies consistent economic assumptions to develop a multibenefit, cost-effectiveness accounting tool that simultaneously evaluates the technology costs, lifetime energy-saving benefits, and GHG reductions from strategies in all sectors in a single cost per tonne–reduced metric. Both transportation vehicle efficiency and low-carbon fuel strategies are considered. Transportation technologies are found to represent approximately half of the no-regrets mitigation opportunities across all sectors (i.e., those that result in net cost savings) and about one-fifth of the least-cost GHG mitigation measures to achieve the benchmark 1990 GHG emissions level.

Burbank's 2009 NCHRP report develops scenarios of future transportation GHG emissions considering different levels of reduced VMT growth, enhanced system efficiency, and more aggressive vehicle and fuel CO_2 reductions based on evidence from the literature on the benefits achievable through these strategies. The report also summarizes GHG reduction estimates for vehicle improvements, low-carbon fuels, smart growth and transit, and other strategies evaluated in state climate action plans. Based on previous research, the report suggests that for the foreseeable future, $50 per ton of GHG emissions reduction is a useful benchmark for selecting transportation strategies to reduce GHG emissions.

Some state and metropolitan agencies are just beginning to document the potential benefits and costs of GHG reduction strategies in their respective regions. The most extensive efforts have been in the preparation of state climate action plans. Burbank identifies 37 states that have plans completed or in progress (2009). The Center for Climate Strategies has facilitated climate action plan development in many of these states, including strategy development and estimation of GHG reductions and cost-effectiveness. However, the methods and assumptions vary greatly from state to state, and some of the estimates reflect high aspirations.

One example is the Metropolitan Washington Council of Governments' *National Capital Region Climate Change Report* (2008). This cross-sectoral report establishes regional targets for GHG reduction, identifies strategies (including transportation strategies), and provides a qualitative assessment of the effectiveness and cost of each strategy, although it does not attempt to develop region-specific quantitative estimates. Extensive work is also underway throughout California to assess GHG reduction strategies in support of state planning requirements. The Maryland Department of Transportation has conducted follow-on analysis work to develop more detailed GHG estimates of the strategies proposed in the state climate action plan.

It is anticipated that more original analysis will be conducted in the future at the state and metropolitan levels to estimate the potential benefits and costs of GHG reduction strategies in specific local contexts.

Strategy Assessment

Tables 3.2 and 3.3 provide information from the literature regarding the effectiveness, cost-effectiveness, and feasibility of transportation GHG reduction strategies. Table 3.2 shows transportation system strategies directed at both the design and operation of the transportation system itself and the behavior of users of the system. This table includes infrastructure planning and investment decisions; construction and maintenance practices; highway, transit, and freight operations; land use; taxation and pricing; travel demand management; and other public education. With some exceptions (e.g., land use, many of the pricing strategies, and rail and port investment), the strategies shown in Tables 3.2 and 3.3 can largely be implemented by state and metropolitan transportation agencies. Table 3.3 shows vehicle and fuel technology strategies, which seek to reduce GHG emissions through the use of low-carbon fuels and/or more fuel-efficient vehicles. This table includes strategies that are primarily under the control of federal or state legislative bodies and regulatory agencies, rather than transportation agencies.

The strategies included in these tables represent strategies for which information on GHG impacts and cost-effectiveness was identified in one or more literature sources. Estimates were reviewed for reasonableness of assumptions, and in some cases, results were not presented if the assumptions were deemed to be too unrealistic. For example, the International Energy Agency's 2005 study estimates of carpooling reductions assumed that vehicle occupancies could be increased substantially (such as adding one person per vehicle to every commute trip). The context of the study was to provide information relevant to what might be achieved in response to a major oil supply disruption, in which case dramatic increases in fuel prices might be expected and could lead to or support significant changes in travel behavior. However, this estimate was not deemed realistic for an assessment of carpooling potential in the absence of such a major disruption.

Tables 3.2 and 3.3 present the following information:

- **Key deployment assumptions.** A description of the key strategy deployment assumptions in the underlying study;
- **Percentage fuel and GHG reductions.** Potential reductions in total transportation fuel consumption and GHG emissions, generally in 2030. Table 3.2 also shows 2050 savings for advanced technology strategies that will take many years to fully develop. The percentage reductions are based on reported GHG reductions from most sources, except for the International Energy Agency report (2005), which reports fuel (petroleum) use reductions. In some cases, the percentage reduction was taken directly from the source document. In others, the reduction was calculated based on absolute GHG reductions reported in the source document. In these cases, absolute reductions were converted to percentage reductions based on the U.S. Department of Energy's April 2009 *Annual Energy Outlook* reference case (Energy Information Administration 2009), with minor adjustments to account for non-CO_2 GHGs. The adjusted 2030 transportation sector baseline is 2,171 MMT CO_2e.
- **Direct cost-effectiveness.** Cost-effectiveness, expressed in dollars per tonne CO_2e reduced, considering implementation costs only (typically public sector costs for infrastructure, services, or programs; not shown for strategies in Table 3.3).
- **Net included cost-effectiveness.** Cost-effectiveness, expressed in dollars per tonne CO_2e reduced, considering implementation costs and other quantified costs. For vehicle and fuel technology strategies, net included costs include increases in vehicle capital costs and increases or decreases in fuel costs, all costs that are generally borne by the private sector (i.e., consumers).

Table 3.3. Vehicle and Fuel GHG Reduction Strategies

Strategy Name	Key Market Penetration and Per Vehicle Benefit Assumptions	Fuel/GHG Reduction (%)		Net Included Cost-Effectiveness	Feasibility		
		2030	2050		Technical	Institutional	Political
Low-Carbon Fuels							
Ethanol (corn)[a]	Maximum near-term corn ethanol production capacity; 68% increase to 60% benefit per E85 vehicle	(1.1%)–0.9%		\$90–∞	M	H	M
Ethanol (cellulosic)	Maximum cellulosic ethanol production capacity in 2030 (33% of LDV market at E85); 57%–115% GHG reduction per vehicle	11%–23%		\$10–\$30	L	L	?
Biodiesel[a]	Full substitution of diesel with B20 biodiesel blend from soy; 13% GHG reduction to 10% increase per vehicle	(1.9%)–2.9%		\$130–∞	M	M	?
Natural gas	2.5%–5% of total U.S. natural gas use diverted to transportation; 15% GHG reduction per vehicle	0.3%–0.6%		(\$130)	M	M	?
Electricity[b]	2030: 18% LDV market penetration, 40%–55% GHG reduction per vehicle 2050: 60% LDV market penetration, 79%–84% GHG reduction per vehicle	2.4%–3.4%	18%–22%	(\$160)–\$70	L	M	?
Hydrogen[b]	2030: 5% LDV market penetration, 68%–80% GHG reduction per vehicle 2050: 56% LDV market penetration, 78%–87% GHG reduction per vehicle	2.2%–2.5%	26%–30%	(\$20)–(\$110)	L	L	?
Advanced Vehicle Technology: Light-Duty							
Advanced conventional gasoline vehicles[b, c]	8%–30% efficiency benefit per vehicle; 60% market penetration in 2030, 100% in 2050	2.5%–9.0%	4.4%–16%	(\$180)–(\$30)	L–H	H	H

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Table 3.3. Vehicle and Fuel GHG Reduction Strategies (continued)

Strategy Name	Key Market Penetration and Per Vehicle Benefit Assumptions	Fuel/GHG Reduction (%)		Net Included Cost-Effectiveness	Feasibility		
		2030	2050		Technical	Institutional	Political
Diesel vehicles[b]	0%–16% efficiency benefit per vehicle; up to 45% market penetration in 2030, 100% in 2050	0%–4.1%	0%–9.9%	($240)–$660	H	H	M
Hybrid electric vehicles[b]	26%–54% efficiency benefit per vehicle; 28% market penetration in 2030, 56% in 2050	2.9%–5.9%	7.4%–15%	($140)–$20	M	H	H
Plug-in hybrid electric vehicles[b]	46%–70% efficiency benefit per vehicle, 15% market penetration in 2030; 49%–75% per vehicle, 56% market penetration in 2050	3.9%–5.9%	16.4%–26%	($40)–($110)	L	M	M
Advanced Vehicle Technology: Heavy-Duty							
On-road trucks[c]	Fleetwide deployment of engine/drivetrain and resistance reduction technologies, as appropriate for type of vehicle: 17%–42% per vehicle efficiency benefit	4.4%–6.4%		($140)–$40	L–H	L–M	M
Vehicle Air Conditioning Systems							
Refrigerants	Replacement of current a/c refrigerant with low global warming potential refrigerant	2.6%		$40–$90	M	M	M
Engine load reduction	Reflective window glazings, secondary loop a/c systems, and improved a/c system efficiency	0.6%–1.4%			M	M	M

Notes: The use of a "?" indicates that the feasibility of a particular strategy is unknown or is subject to political factors that could be either positive or negative depending on circumstances. Data are from the 2010 report *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions.* Estimates are original estimates based on data from numerous literature sources.

[a] Corn ethanol and biodiesel estimates account for indirect effects, such as indirect land use change associated with agricultural production practices, based on analysis by the EPA in support of the proposed Renewable Fuel Standard (RFS2) rulemaking in 2009. The estimates show a wide range of impacts, depending on feedstock source, production methods, and analysis assumptions, and suggest that these fuels may increase GHG emissions under some circumstances.

[b] Market penetration estimates represent the high end of estimates found in the literature and assume that technology will be developed to the point of marketability in the analysis time frame.

[c] For advanced gasoline LDV and on-road truck technology, some strategies are proven or well-advanced, but others are not.

- **Data sources.** References providing the source(s) of effectiveness and cost-effectiveness data for the strategy.
- **Feasibility.** Feasibility is assessed using a high, moderate, or low rating for three dimensions of feasibility:
  - *Technological.* Is the technology well-developed and proven in practice? What is the likelihood that the technology could be implemented in the near future at the deployment levels assumed in the analysis? Technological barriers can be low-tech as well as high-tech; for example, there may be right-of-way constraints to infrastructure expansion in urban areas.
  - *Institutional.* To what extent do the authority and resources exist for government agencies to implement the strategy, and what is the administrative ease of running a program and the level of coordination required among various stakeholders?
  - *Political.* Is the strategy generally popular or unpopular with any interested stakeholders, elected officials, and the general public? What is the political clout of those supporting versus those opposed to the strategy?

Feasibility is assessed *without respect to cost,* which was evaluated as part of the cost-effectiveness measure.

Combined Strategy Impacts and Benefits

Many GHG reduction strategies interact to produce different outcomes for total GHG reductions. The benefits of each strategy (or group of strategies) are not additive, and they may be reduced depending on other strategies that are implemented. However, some strategies are complementary or synergistic, and their effectiveness is likely to be enhanced if they are implemented in combination with each other.

As an example of synergy effects, transit, nonmotorized improvements, land use, and pricing strategies would be expected to be most effective when applied in combination. For example, a study by the Center for Transit-Oriented Development compared CO_2 emissions per household based on characteristics including access to rail transit and neighborhood land use characteristics to characterize location efficiency (Haas et al. 2010). The study found that compared with the average metropolitan area household, households in transit zones that fell into the two middle categories of location efficiency produced 10% and 31% lower transportation emissions, and households in the highest location-efficient category produced 78% lower transportation emissions than the average metropolitan area household (Haas et al. 2010). The *Moving Cooler* study also found that transit and nonmotorized improvements were more effective in areas of higher population density (Cambridge Systematics 2009). It further might be expected that strategies that encourage the use of alternative modes (such as road pricing) would have a greater impact when applied in conditions in which better alternatives exist (as would be found with increased transit investment and more compact land use patterns). This was the case in the London congestion pricing program, for which large investments in the city's bus system preceded the implementation of the pricing scheme.

Quantitative evidence on the interactive effects among various strategies in combination is limited, and existing evidence is generally based on simplified analysis. More sophisticated analysis of combined effects would require the use of an enhanced regional modeling system and careful selection of comparison scenarios.

Three research studies have made assumptions concerning the synergistic effects of implementing different GHG emissions mitigation actions as part of a GHG mitigation strategy. The *Moving Cooler* study created six strategy bundles and combined the individual benefits of strategies in each bundle in a multiplicative fashion. For example, if Strategy A results in a 10% GHG reduction, and Strategy B results in a 10% GHG reduction, the combined effect was assumed to be $(1 - 0.10) * (1 - 0.10) = 0.90 * 0.90 = 0.81$, or a 19% combined reduction, rather than a 20% reduction if they were simply added. The study also accounted for synergies among certain strategies; in particular, transit, bicycle, pedestrian, and carsharing strategies were assumed to be more effective in areas of greater population density, and therefore more effective under more aggressive land use scenarios. The six bundles resulted in a reduction in GHG emissions versus the surface transportation baseline ranging from 3% to 11% in 2030 at aggressive levels of implementation, increasing to as much as 18% in 2050. Reductions under a maximum implementation scenario ranged as high as 17% in 2030 and 24% in 2050.

Cost-effectiveness was also provided for each bundle. The estimated cost-effectiveness, including implementation costs only, ranged from a low of $80 per tonne for the low-cost bundle, to over $1,600 per tonne for a facility pricing bundle that combines infrastructure improvements with local and regional pricing measures to pay for these improvements. The study concluded that a net savings would be realized for most bundles if vehicle operating cost savings were counted against the direct implementation costs.

Using information later included in the 2010 U.S. DOT *Report to Congress,* Cambridge Systematics, Inc. (2009) developed combined GHG reduction estimates for each of five categories of strategies: pricing carbon, low-carbon fuels, vehicle fuel efficiency, system efficiency, and travel activity. Mutually exclusive or redundant strategies were excluded from the combined estimates. The results showed that in the long term the most effective strategies for reducing GHG emissions were introducing low-carbon fuels, increasing vehicle fuel efficiency, and reducing carbon-intensive activity.

The most rigorous attempt to consider the combined effects of different mitigation actions (or perhaps more correctly to avoid double-counting of energy reduction due to strategy implementation) is found in the Pew Center report on *Reducing Greenhouse Gas Emissions from U.S. Transportation* (Greene and Plotkin 2011). This study used equations that decomposed the contributing factors that determined emissions from different modes, vehicle types, and fuels. The analysis also considered the rebound effect, which occurs when energy efficiency strategies reduce the use of energy. This reduction in energy use lowers the cost of energy, leading to increased consumption of energy and in some portion offsetting the benefits of increased efficiency. Readers interested in this approach are encouraged to read the Pew report.

Other Studies

Other studies have examined the potential for transportation sector GHG reductions, but primarily for vehicle and fuel technology rather than travel activity and system efficiency. For example, Bandivadekar et al. (2008) conclude that

> a 30%–50% reduction in fuel consumption is feasible over the next 30 years. In the short-term, this will come as a result of improved gasoline and diesel engines and transmissions, gasoline hybrids, and reductions in vehicle weight and drag. . . . Over the longer term, plug-in hybrids and later still, hydrogen fuel cells may enter the fleet in numbers sufficient to have a significant impact on fuel use and emissions.

Lutsey (2008), considering costs and effectiveness from a cross-sectoral perspective, concludes that

> Transportation technologies are found to represent approximately half of the "no regrets" mitigation opportunities and about one-fifth of the least-cost GHG mitigation measures to achieve the benchmark 1990 GHG level. With the adoption of known near-term technologies, GHG emissions by 2030 could be reduced by 14% with net-zero-cost technologies, and emissions could be reduced by about 30% with technologies that each have net costs less than $30 per tonne of carbon dioxide equivalent reduced.

Lutsey also considers the VMT reductions needed to achieve aggressive GHG reduction targets (80% reduction below 1990 levels by 2050) even after vehicle and fuel technology strategies have been fully realized. He concludes that

> After deploying the level of GHG reduction technology for vehicles and fuels as described in this study (and no further advances), the travel demand reduction to achieve the 2050 target would be quite severe. For this amount of GHG reductions to come from travel reductions, national light-duty vehicle (LDV) travel would have to be reduced annually by approximately 4%, instead of the forecasted increase of about 1.8% annually from 2010 on. . . . Even after a new crop of vehicle and fuel technologies (e.g., plug-in hybrid-electric vehicles) emerges, it appears safe to speculate that some significant amount of reduction in vehicle-miles-traveled will be needed to augment technology shifts to achieve deeper, longer-term GHG reductions.

Top-down, aspirational or scenario estimates of potential travel activity and system efficiency benefits have also been developed. These estimates make assumptions regarding what percentage VMT reduction is needed or can be obtained to contribute to certain GHG reductions in conjunction with other (non-VMT) strategies, rather than building from the bottom up according to individual strategy effects. As an example, an EPA wedge analysis of the transportation sector assumed that a 10% to 15% reduction in VMT from TDM strategies, along with vehicle efficiency and low-carbon fuel improvements, could contribute to GHG reductions (Mui et al. 2007).

Another example of such a scenario approach is provided by the NCHRP Project 20-24 (Task 59) study (Burbank 2009), which examined transportation GHGs through 2050. This study made assumptions about the reduction in carbon intensity of the vehicle fleet (58% to 79% reduction in carbon emissions per vehicle mile), reduction in growth of VMT (to 0.5% to 1.0% annually), and improvements in system operating efficiencies (providing a 10% to 15% GHG reduction). The resulting GHG emissions were compared with 2050 goals as established in various national and international climate change proposals or initiatives. The various scenarios result in transportation GHG emissions levels from 44% to 76% below a 2005 baseline.

Conclusion

There are no simple answers to the questions of what are the most and least cost-effective transportation strategies for reducing GHG emissions. The cost-effectiveness of most transportation system strategies depends greatly on what is included in the assessment of costs and cost savings. One way to look at cost-effectiveness is simply from the public agency perspective of the direct implementation costs. Including vehicle operating cost savings generally provides a much different picture, because consumers save money on fuel and maintenance. However, even this is an incomplete accounting in that it does not consider factors such as travel time savings, other welfare gains or losses (due to accessibility and increased or decreased convenience), or equity (incidence of costs and benefits across population groups). These factors represent important impacts of transportation projects, but they are rarely quantified for GHG cost-effectiveness analysis. Therefore, the cost-effectiveness estimates shown in Table 3.2, in particular, are incomplete and may not accurately represent full social costs and benefits.

Furthermore, there is considerable uncertainty in the estimates for many strategies. Existing knowledge of both costs and benefits is in many cases limited, with estimates based on only a single study. In addition, drawing blanket conclusions about any particular strategy is risky. Many individual projects or policies may be cost-effective in one context but not at all cost-effective in another (e.g., a transit project in an area of high versus low population density). Also, the interactions among strategies can be exceedingly complex: TDM strategies can reduce emissions only to be offset by induced demands; however, pricing strategies and/or improvements in transit and land use could consolidate gains while promoting further emissions reductions, depending on the site-specific situation.

The cost-effectiveness estimates for the vehicle and fuel technology strategies shown in Table 3.3 are much closer to a full social cost representation, as the nonmonetary impacts of these strategies are for the most part relatively minor (there may be some impacts on vehicle performance, such as reduced range for electric vehicles). However, many of these estimates reflect considerable uncertainty over technological and economic factors, such as the time frame for technology advancement, future cost of the technology, future fuel prices, indirect effects of biofuels, and other factors.

With these caveats in mind, several conclusions can be drawn from the cost-effectiveness data presented in Tables 3.2 and 3.3. The largest absolute GHG benefits in the transportation sector are likely to come from *advancements to vehicle and fuel technologies.* Particularly promising technologies in the short- to midterm include advancements to conventional gasoline engines, truck engine improvements and drag reduction, and hybrid electric vehicles. In the longer term, ethanol from cellulosic sources, battery-powered electric vehicles, plug-in hybrid electric vehicles, and hydrogen fuel cell vehicles all show great promise for reducing GHGs, but only if the technologies can be advanced to the point of being marketable and cost-competitive. Most of these strategies show the potential for net cost savings to consumers.

The impacts of any single *transportation system* strategy (system efficiency and travel activity) are generally modest, with most strategies showing impacts of less than (and usually considerably less than) 1% of total transportation GHG emissions in 2030. A few strategies show larger impacts (greater than 1%), including reduced speed limits, compact development, various pricing measures, and eco-driving; but the ability to implement these strategies at sufficiently aggressive levels is uncertain due to institutional and/or political barriers. Despite the modest individual strategy impacts, the combined effects of all transportation system strategies may be significant, on the order of 5% to 20% of transportation GHG.

Transportation infrastructure investment, whether highway or transit investment, is generally high cost, with cost-effectiveness estimates of $500 to $1,000 per tonne or more. One study has suggested that cumulative GHG benefits of highway expansion strategies may actually be negative over the 2010 to 2050 time frame when induced travel effects are considered. Based on limited evidence, bicycle and pedestrian improvements may be relatively lower cost (in the range of $200 per tonne), although the magnitude of impacts is likely to be modest. Although major infrastructure investments are not among the most cost-effective GHG reduction strategies, they may be worthwhile for other purposes (e.g., mobility, safety, or livability) or as part of a package of strategies that is collectively more cost-effective (e.g., transit with land use, bottleneck relief with congestion pricing).

Virtually all studies assume that the existing system remains in a state of good repair and that lane closures, bridge postings, major diversions, increased congestion, and other *infrastructure maintenance* do not occur. Unfortunately, current expenditures do not support this assumption, and it may be that the most cost-effective thing a DOT can do is to keep the existing system intact.

Although *rail and marine freight* are on average considerably more energy efficient than truck travel, the absolute magnitude of reductions from freight mode shifting is limited because only certain types of goods (particularly long-haul, non-time-sensitive goods) can be competitively moved by rail. One estimate of the cost-effectiveness of rail freight infrastructure improvements falls in the range of $200 per tonne, but this is based on highly optimistic estimates of truck–rail mode shift. Improved estimates are needed to assess the GHG reduction and cost-effectiveness of rail and marine freight investments to encourage freight mode shift.

Transportation system management strategies that reduce congestion and improve traffic flow may provide modest GHG reductions at lower cost than capacity and/or system expansion (typically between $50 and $500 per tonne, with lower costs if operating cost savings to drivers are included). As with highway capacity strategies, however, there is considerable uncertainty in the GHG reduction estimates for these strategies because of uncertainty regarding the magnitude and treatment of induced demand. However, here again the synergies needed for effective reductions should be kept in mind. For example, any effective pricing system will need a companion intelligent transportation system component to be viable, and traveler advisories can increase transit use.

Like transit infrastructure improvements, *urban and intercity transit service improvements* have high direct (public sector) costs, generally over $1,000 per tonne, although they provide similar nonmonetary (mobility) benefits and in some circumstances they may yield net savings to travelers as a result of personal vehicle operating cost savings. The GHG benefits of any particular transit project will vary depending on ridership levels, and they could be negative if ridership does not reach high levels. Among other imponderables, improved transit and novel modes such as shared electric vehicles may eventually change travel behavior over the very long term.

Truck operations strategies, in particular idle reduction, can provide modest total benefits with a low public investment cost while yielding net cost savings to truckers. The most effective strategy is to require on-board idle reduction technology, which would require harmonization of state regulations.

Speed limit reductions can provide significant benefits at modest cost, although they are not likely to be popular, and would require strong enforcement to achieve these GHG benefits.

Land use strategies can potentially provide significant GHG reductions over the long term at very low public sector cost. Modest to moderate changes in land use patterns can probably be accomplished without significant loss of consumer welfare, but more far-reaching changes may not be popular and may be very difficult to achieve in the current political and economic environment.

Pricing strategies, especially those that affect all or a large portion of VMT (such as VMT-based fees or congestion pricing), can provide significant GHG reductions, but only by pricing at levels that may be unacceptable to the public. The 2- to 5-cents per mile fee analyzed in Table 3.2 is equivalent to a gas tax increase of $0.40 to $1.00 per gallon at today's fuel efficiency levels. Implementation costs are moderate (less than $100 per tonne to $300 per tonne or more) for most mechanisms, due to the technology and administrative requirements for VMT monitoring. Cost-effectiveness improves with higher fee levels, since the same monitoring and administration infrastructure is required regardless of the amount of the fee. Pricing strategies will also have significant equity impacts unless revenues are redistributed or reinvested to benefit lower-income travelers. A gas tax increase or carbon tax could be implemented at much lower administrative cost, but these strategies are not currently politically acceptable at a national level or in most states.

TDM strategies have a modest GHG reduction potential, also at moderate public cost (typically in the range of $100 to $300 per tonne), but they require widespread outreach efforts combined with financial incentives. Furthermore, the public sector has so far demonstrated little ability to influence strategies such as telecommuting and compressed work weeks, and adoption of these strategies has primarily been driven by private initiative.

Studies have suggested that *eco-driving* may have significant GHG reduction potential while providing a net savings to travelers. For example, a Dutch study found the cost-effectiveness of eco-driving to be $6.08 to $9.45 per CO_2 tonne avoided (Hoed et al. 2006). An eco-driving workshop held in Paris in 2007 found a potential for a 10% reduction in surface transportation CO_2 emissions from eco-driving. However, these results are based on limited European experience and may not be transferable in a widespread fashion to the United States.

CHAPTER 4

Technical Framework for GHG Emissions Analysis

This chapter describes an analysis framework for considering GHG emissions in transportation planning and project development. The framework assists in answering important questions for key decision points in the planning and decision-making processes. In particular, the information focuses on four levels of decision making identified in the TCAPP framework:

- Long-range transportation planning (LRP), including statewide, metropolitan, and other regional planning; programming (PRO), including statewide and metropolitan transportation improvement programs (TIPs);
- Corridor planning (COR); and
- Environmental review and National Environmental Policy Act (NEPA) compliance (ENV) and project permitting (PER).

The framework, discussed in greater detail in the *Practitioners Guide,* provides checklists, strategy options, options for analytic methods, and a basic overview of calculation methods and data sources for each method. A range of tools and methods applicable for different scales and resource inputs is provided. Although the planning process is relevant for different scales of analysis, the level of detail and tools and methods that are appropriate for GHG analysis and strategy development may differ widely from situation to situation. The framework and resource materials presented here are intended to be useful for planning at all scales of analysis and in all geographic contexts. They are also designed to be multimodal, including analysis methods for transit as well as highway travel.

This chapter also discusses emissions calculators. Although emissions calculators do not fit into the four decision-making contexts listed above, they are discussed here because of their increasing use in estimating the carbon footprint of facilities and services. Such estimators are used, in particular, by transit agencies to determine a GHG emissions baseline and an estimated reduction in CO_2 emissions for different types of strategies. It seems likely that transportation professionals will be called on to assess carbon footprints more often in the coming years, and thus this report provides an overview of the tools that are available.

Background

Much research has occurred on transportation and nontransportation GHG emissions. Walsh et al. (2008) compared emissions of cars, SUVs, peak and off-peak public transit, and bicyclists. Dürrenberger and Hartmann (2002) created a model, based on factors in Switzerland, for calculating regional CO_2 emissions based on households, transportation systems, and economic activity. Chu and Meyer (2009) analyzed CO_2 emissions of truck-only toll lanes using EPA's MOBILE6.2 modeling software. Stepp et al. (2009) used system dynamics functions to model transportation demand impacts on GHG mitigation. Smith et al. (2007) described the agricultural strategies of several countries, and Golub et al. (2009) noted that land use–based GHG mitigation policies must consider global and regional impacts.

A variety of methods have been used to develop a GHG emissions inventory for transportation, but most are of limited use for metropolitan planning organization (MPO) planning and strategy analysis. Most inventories are developed based on fuel type and fuel sales data by state or country, many following the Intergovernmental Panel on Climate Change guidelines for a national inventory (IPCC 2012). The main drawback with this methodology is its lack of distinction between different modes, vehicle types, and geographic areas, a breakdown that is required for strategy analysis.

Other methods use local inspection and maintenance data to develop registration and mileage accumulation or use vehicle miles traveled (VMT) data, usually compiled for transportation network planning (U.S. Environmental Protection Agency 2010a). Glaeser and Kahn (2008) used the

National Household Travel Survey, "which contains information on gasoline usage associated with travel by private automobile, family characteristics, and zip code characteristics." Although their study distinguishes road and rail traffic, and focuses at the regional level, it only includes two modes and does not distinguish fuel types. Like most other methods, freight is not addressed separately in their study.

Most studies only measure direct or tailpipe emissions associated with traffic movements. However, many recent life-cycle analysis (LCA) studies of alternative vehicle and fuel technologies indicate that the indirect emissions that result from supplying the vehicles, fuels, and built infrastructures are of a similar order of magnitude as the direct emissions and should be incorporated into studies on carbon footprints (DeLucchi 2003; U.S. Department of Energy 2012; U.S. Environmental Protection Agency 2010a; Chester and Horvath 2008; The Climate Registry 2008; Natural Resources Canada 2012). These indirect multipliers are found to vary a good deal across modes of travel, and they affect metropolitan areas differently, depending on the mix of auto and truck VMT.

GHG Analysis Framework

The analysis framework for conducting GHG emissions analysis is organized around 13 key questions grouped into five basic steps of analysis as shown in Table 4.1.

These analysis steps and key questions are, for the most part, common across all four decision-making contexts of the TCAPP framework; that is, they can be used for long-range planning, programming, corridor planning and environmental review and permitting. However, they might be addressed at different decision points in each context and could require different analysis methods. The 13-question process is presented as an idealized process. Iterations among the various questions might be necessary, and local agencies may consider issues in a different sequence than presented here. Readers are referred to the *Practitioners Guide* for more detailed information on how these questions relate specifically to TCAPP.

Determine Information Needs

1. *What stakeholders should be included in GHG strategy development and evaluation?*

Objective: Identify key stakeholders who should be included in the development and analysis of GHG mitigation strategies.

Discussion: Stakeholder involvement is an integral part of collaborative planning and decision making. This initial step in GHG planning ensures that key stakeholders with a specific interest in GHG emissions and climate change issues are included in the process. Table 4.2 provides a checklist of the key types of stakeholders that should be considered as part of GHG analysis. The TCAPP website provides guidance and techniques for creating meaningful stakeholder collaboration.

2. *What is the scope of GHG emissions analysis?*

Objective: Define the scope of GHG emissions considered as part of the long-range planning, programming,

Table 4.1. GHG Analysis Framework Analysis Step Key Questions

Step	Question
I. Determine information needs	1. What stakeholders should be included in GHG strategy development and evaluation?
	2. What is the scope of GHG emissions analysis?
II. Define goals, measures, and resources	3. What goals, objectives, and policies relate to GHG reduction?
	4. What GHG-related evaluation criteria and metrics will be used?
	5. What are the baseline emissions for the region or study area?
	6. What is the goal or target for GHG reduction?
	7. How will GHG considerations affect funding availability and needs?
III. Define range of strategies for consideration	8. What GHG reduction strategies should be considered?
	9. Are strategies and alternatives consistent with a long-range plan and/or other relevant plans that meet GHG reduction objectives?
IV. Evaluate GHG benefits and impacts of candidate strategies	10. What calculation methods and data sources will be used to evaluate the GHG impacts of projects and strategies?
	11. What are the emissions and other impacts of a particular project, strategy, or design feature?
V. Select strategies and document overall GHG benefits and impacts of alternatives	12. What GHG-reducing strategies should be part of the plan, program, or project?
	13. What are the net emissions impacts for the overall plan, program, corridor, or project alternatives considered and the selected alternative?

Table 4.2. Key Stakeholders in GHG Planning and Analysis

____ State DOT
____ Policy and executive
____ Planning
____ Environmental
____ Project development
____ Traffic operations
____ Metropolitan planning organization (MPO)/Regional planning agency (RPA)
____ Transit agencies—policy, capital planning, and operations
____ Counties and municipalities
____ Port authorities
____ Federal resource agency
____ Other state agencies
____ Environmental—policy, air quality, permitting
____ Energy
____ Planning
____ Housing, economic, and community development
____ Industry
____ Freight and logistics
____ Utilities
____ Construction
____ Advocacy groups
____ Philanthropic organizations
____ Academic and research
____ General public

corridor planning, or project development and environmental documentation.

Discussion: This step involves determining (1) emissions sources, (2) transportation modes, (3) the time frame of analysis, and (4) the geographic boundaries of the analysis. Table 4.3 provides a checklist and explanation of each topic. The scoping of GHG emissions may depend on issues that are considered in subsequent steps, such as any relevant policies or goals related to GHG emission reductions. For additional resources, see ICF Consulting (2006) for a discussion of target metrics, emissions sources covered, and measurement benchmarks.

Define Goals and Measures

3. *What goals, objectives, and policies relate to GHG reduction?*

Objective: Identify relevant policies related to GHG reduction, as well as goals and objectives for the plan or project that may inform what types of GHG targets should be set, metrics evaluated, analysis methods used, and strategies considered.

Discussion: Goals, objectives, and policies can come from many sources. They may originate from external policies and goals (e.g., federal or state); policies, goals, and objectives established by a higher-level planning document, such as an LRP; and goals and objectives established by stakeholders for a particular transportation plan, corridor study, or project. Participants should be aware of any existing policies that relate to GHG emissions, such as federal requirements or guidance for addressing GHGs in transportation planning, state reduction targets, long-range planning goals, or agency-wide policies to take actions that reduce GHG emissions. Stakeholders in plan or project development may set specific goals and objectives consistent with these policies, or in the absence of such policies may still decide that reducing GHG emissions is a goal of the plan or project. GHG-related policies, goals, and objectives, as well as the importance placed on GHG reduction, may affect the scope of GHG emissions to be considered (as defined in Step 2).

For the project development and environmental permitting step, in particular, an important question is whether GHG reductions are part of the purpose and need for the project. If they are, it may be especially important to demonstrate quantitatively that the project reduces GHG emissions and to include additional GHG reduction and mitigation strategies as appropriate. If GHG reductions are not part of the purpose and need statement, GHG may still be an important consideration, but this should be determined in consultation with project stakeholders.

4. *What GHG-related evaluation criteria and measures will be used?*

Objective: Define the GHG-related evaluation criteria and metrics to be used to measure the impact of the transportation project or program under consideration.

Discussion: This step involves determining what GHG-related measures will be reported, such as CO_2, total GHGs, or another proxy or related measure such as VMT or energy consumption. It also involves determining other GHG-related criteria on which projects and strategies will be evaluated, such as cost-effectiveness and feasibility. Table 4.4 provides a list of potential emissions metrics. The evaluation criteria and metrics selected should be consistent with any higher-level planning documents, such as the LRP.

CO_2 represents about 95% of all mobile-source GHG emissions. A complete accounting of GHGs will also include methane (CH_4), nitrous oxide (N_2O), and refrigerants, which can collectively be measured in CO_2 equivalents (CO_2e) based on the global warming potential of each. The GHG contribution of these other gases is usually small and may not be worth the additional effort of estimating them with precision. CH_4 and

Table 4.3. Scope of GHG Emissions Considered

Scope Consideration	Discussion
	Emissions Source
Direct emissions from vehicles (tailpipe emissions)	Direct calculation; should be included in all cases.
Full fuel-cycle emissions	Includes emissions from production and transport of fuel (including electricity generation). Important if strategies using alternative fuels (e.g., biofuels, electricity, hydrogen) are to be examined.
Construction, maintenance, and operations	May be important for capital-intensive strategies such as new construction, but existing data are limited.
Induced travel	Includes emissions from increased travel over time in response to improved travel conditions. May be important for strategies providing significant time and/or cost savings (particularly to highway travelers) or impacts on land use patterns.
	Modes
Private vehicles	Passenger cars, passenger trucks, and motorcycles. Typically included in all analyses.
Commercial vehicles	Light commercial trucks, single-unit trucks, combination trucks, and intercity buses. Typically included in most analyses, but may be omitted if looking only at strategies affecting passenger travel.
Transit: Buses	Important to include if strategies that affect the level or efficiency of transit service are to be evaluated.
Transit: Rail	Light rail, streetcar, heavy rail, and commuter rail.
Intercity passenger rail	For statewide and interregional analysis.
Air	For statewide and interregional analysis.
Rail and marine freight	May be included for comprehensive transportation sector analysis; important if strategies that involve mode shifting from truck to rail are to be analyzed.
Other	School buses, refuse trucks, government fleets. May be included as part of highway vehicle travel inventories (private and commercial vehicles).
	Time Frame
Base year: ____ Horizon/analysis year(s): _____ _______ Cumulative for period: ______ to ______	GHG reductions from a strategy or alternative may be compared against GHG emissions in the base year and/or baseline GHG emissions in the horizon/analysis year. Cumulative GHG emission reductions may also be of interest.
	Geographic Boundaries
State MPO planning area Corridor (boundaries defined in corridor study or _________________) Roadway segment (endpoints: _____________and___________________) Other: ________________________	Usually, the geographic analysis area for a state or metropolitan long-range plan or TIP will be the respective state or MPO planning area. A corridor study may address only a single transportation facility that is the focus of the study, or it may be defined to include a broader area of influence as set forth in the study scope.

N_2O can be calculated from emission factor models such as U.S. EPA's motor vehicle emissions model MOVES (Motor Vehicle Emission Simulator) and the California Air Resources Board's EMFAC (Emission Factors), but refrigerants cannot. However, it may be important to include them when strategies that might affect these particular GHGs are evaluated. Examples include natural gas vehicles (which have high methane emissions) and programs to recapture refrigerants. In other cases, it may be reasonable to simply factor CO_2 emissions by a ratio of total GHGs to CO_2 emissions by vehicle type to gain a complete accounting of GHG emissions (i.e., CO_2e). Finally, black carbon is a potential GHG, but existing science and analytic methods are insufficient to support quantifying it in a GHG inventory.

VMT may be an adequate proxy for GHG emissions if only strategies affecting VMT are analyzed. It will not be an appropriate metric for strategies that affect traffic flow conditions or vehicle and fuel technology, and its usefulness will be limited for strategies that include mode shifting to transit or rail (which may increase VMT for some vehicle types while decreasing it for others with different efficiency). The transportation agency may also decide to focus on energy

Table 4.4. Possible GHG Emissions Metrics

Carbon dioxide (CO_2)
Carbon dioxide equivalents (CO_2e), including ___Methane (CH_4) and nitrous oxide (N_2O) ___Refrigerants
VMT (as proxy)

consumption (often measured in British thermal units [Btu]) as a supplement or alternative to GHG emissions. The relationship between energy consumption and GHG emissions depends on the fuel type. However, if alternative fuel strategies are not being evaluated, GHG emissions will closely track energy consumption. Energy consumption may be of interest for other reasons (e.g., energy security and energy independence) aside from the environmental motivations associated with climate change.

Cost-effectiveness is typically measured in dollars spent per metric ton of GHG emissions reduced (see Chapter 3). The cost-effectiveness calculation could be based only on the direct costs of implementing a project or strategy, or it may include other monetary and nonmonetary costs and benefits such as vehicle operating cost savings, travel time savings, crash cost savings, or the value of air pollution versus health benefits. Costs can be distinguished according to costs to the public sector versus net costs or benefits to society as a whole. A negative cost per ton indicates that the strategy results in net social benefits.

Other common evaluation criteria include

- Feasibility: Including political, institutional, financial, and/or technical feasibility;
- Equity: The extent to which different population groups are positively or negatively affected;
- Certainty: The level of confidence that the projected GHG reductions can actually be achieved;
- Leakage: Whether the projected GHG reductions might result in GHG increases outside of the planning area; and
- Synergistic effects: Whether the project or strategy is likely to lead to other outcomes or support other actions that will further reduce GHG emissions.

For additional resources, see ICF Consulting (2006) for a discussion of target metrics, emissions sources covered, and measurement benchmarks.

5. *What are the baseline emissions for the region or study area?*

Objective: Establish a baseline (no-action) GHG emissions inventory using the selected GHG-related metric(s) and scope of emissions for both the base year and any analysis year(s). The baseline inventory should account for any adopted state, multistate, or federal regulation such as vehicle fuel efficiency standards, GHG emissions standards, and low-carbon or renewable fuel standards.

Discussion: The baseline inventory is normally developed considering all relevant transportation activity occurring within the study area (e.g., MPO model area or a defined corridor), as well as the adopted baseline land use and socioeconomic forecasts. Different methods can be used to develop a baseline inventory. The method should be selected based on data availability, level of effort, and accuracy or precision of information needed. In addition, the method for developing the baseline inventory is likely to serve as a starting point for analyzing the GHG impacts of proposed alternatives.

If quantitative reduction targets or metrics related to a percentage reduction in emissions are not set, it may not be necessary to develop a baseline inventory. Instead it may only be necessary to evaluate, either quantitatively or qualitatively, the *expected change* in GHG emissions as a result of a particular project or strategy.

Methods A and B for estimating baseline GHG emissions are oriented primarily toward a systems- or network-level analysis; Methods C and D are more suited to corridor- or project-level analysis (see Table 4.5):

- Method A: VMT trend extrapolation with VMT-based emission factors;
- Method B: Travel demand and emissions factor models;
- Method C: Traffic counts, forecasts, and transit operating data with emission factors; and
- Method D: Traffic simulation models. If this method produces fuel consumption estimates, CO_2 emission factors can be applied directly as shown in Table 4.6.

6. *What is the goal or target for GHG reduction?*

Objective: Define a quantitative target or qualitative goal for GHG reductions compared with the baseline inventory or forecast. Goals or targets may be externally determined (e.g., with state or federal guidance) or may be established for the project or plan through a stakeholder and public involvement process.

Discussion: Quantitative targets may be expressed in absolute terms (metric tons CO_2 or CO_2e), percentage terms, or as a not-to-exceed threshold. They may be expressed compared with a base year, historic year (e.g., 1990), or baseline forecast in the analysis year. A target may be set specifically for transportation emissions to be affected by the plan or process (e.g., reduce net corridor emissions by 10% from baseline through project strategies), or the planning activity or project may be measured for its ability to contribute to a broader cross-sectoral target (e.g., support the state's effort to reduce GHG emissions by 20% in 2050 from 1990 levels). Some options for expressing goals or targets are shown in Table 4.7.

Table 4.5. Methods for Estimating Baseline GHG Emissions

Method	Comments
Method A: VMT trend extrapolation with VMT-based emission factors	Description: The simplest approach available for transportation GHG inventory development at a substate level. It relies on externally generated data to develop a regional estimate of GHG emissions.
	Situations in which to apply: • Travel model is not available, does not cover all modes, or forecasts for analysis year(s) not yet developed. • Detailed and precise inventory not needed.
	Calculation methods: • Highway (passenger and commercial vehicles) – Obtain historic VMT data by vehicle type for the past 10 or more years for the analysis area from the Highway Performance Monitoring System (HPMS). – Extrapolate to future years using trend projection or a projection already developed by a state or regional agency. – Apply GHG emission factors (g/mi) appropriate for base and horizon years (see *Practitioners Guide*). • Transit – Obtain National Transit Database (NTD) service and fuel consumption data for the past 5 to 10 years, apply GHG emission factors, and extrapolate to future. Consult with local transit agencies to project service levels for future years under existing service plans (e.g., continue same service levels, grow in proportion to population) and characteristics of transit fleet (fuel type and efficiency). Emissions from buses running on public roads should be subtracted from the highway inventory to avoid double-counting, since buses will be included in vehicle counts.
	Data sources: • HPMS: historic VMT data. • The Climate Registry's General Reporting Protocol (GRP): Emission rates (g/gal for CO_2, g/mi for CH_4 and N_2O). • National Transit Database (NTD): Historic transit VMT and fuel consumption by transit mode. • EPA Emissions and Generation Resource Integrated Database (eGRID): Historic GHG emissions rates for electricity (g/mW-h). • U.S. Department of Energy's *Annual Energy Outlook:* Projections of fuel efficiency by mode and regional emissions rate (for electricity consumption) through 2030.
Method B: Travel demand and emissions factor models	Description: This approach uses the regional or statewide travel demand model and HPMS data to develop forecasts of VMT by road type, vehicle type, and speed to which emission factors from EPA's MOVES model or another emission factor model (such as EMFAC) are applied.
	Situations in which to apply: • Long-range planning and programming: Recommended when a travel model is available and a no-build scenario has been developed. The no-build scenario refers to a future scenario that does not include projects proposed in the long-range plan. In some areas, this may be referred to as the existing plus committed (E+C) scenario. E+C forecasts represent conditions if no further transportation improvements were implemented beyond what is already funded to complete construction within the last year of the TIP. • Corridor planning: Recommended when a travel model has sufficient network detail to represent traffic conditions in the study corridor.
	Calculation methods: • Run the regional travel demand model for the no-build scenario; output link-level volumes and speeds by MOVES road type. • Run MOVES to obtain a lookup table of CO_2 emission factors by vehicle type, facility type, and speed. • Adjust emission factors for any differences in future year vehicle efficiency and/or carbon content standards not reflected in MOVES. • Apply adjusted MOVES emission factors to travel demand model output. • Calculate base and horizon year(s) transit VMT by mode based on performance statistics (route miles and headways) from the travel demand model or operating data and projections from local transit agencies. • Apply transit emission factors.
	Data sources: • HPMS and travel demand model outputs (VMT by speed and vehicle type). • MOVES emission factors (g/mi). • VMT percentage distribution by vehicle type could come from HPMS, roadside vehicle counts, inspection and maintenance program odometer data, or MOVES national defaults. • Other data (transit, emissions).

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Table 4.5. Methods for Estimating Baseline GHG Emissions (continued)

Method	Comments
Method C: Traffic counts, forecasts, and transit operating data with emission factors	Description: Traffic counts for the base year are projected to future years using growth factors, and VMT- or speed-based emission factors are applied.
	Situations in which to apply: • When this method is already being used to determine base year and design year no-build traffic forecasts with associated traffic capacity analyses for documenting project need. • When the analysis is focused on improving GHG emissions from a subset of a roadway network as opposed to a regional network change. • When an adopted regional forecasting model is not available, but it is expected that area population and employment growth will not follow growth trends of the previous 10 years.
	Calculation methods: • Identify affected road network links, including all those whose traffic is expected to be affected by the project. • Conduct traffic counts to determining existing volumes and peaking characteristics on links. • Determine existing land use served by links. • Determine trip generation by land use. • Identify existing through trips. • Identify percentage of various vehicle types in existing traffic. • Determine future land use in the design year. • Grow traffic volumes to the design year based on additional land use, while assuming trip generation and peaking characteristics similar to the base year. • Determine (based on peaking characteristics and road capacity) the number of congested and uncongested hours or periods per year. • Estimate link speeds during congested periods. There could be more than one congested speed given that different hours will have different levels of congestion. The link speed limit can be assumed for uncongested periods. • Determine VMT traveled by speed (base year and no-build design year) within the GHG study area. • Apply MOVES or EMFAC emission factors to determine GHG emissions for the base year and design year.
	Data sources: • Available counts, forecasts, and vehicle mix from past studies or ongoing traffic monitoring programs. • New project area traffic counts, forecasts, and vehicle mix done specifically for the project. • Land use growth forecasts from land use plans, recently approved traffic impact assessments, and/or interviews with local planners. • Road link characteristics. • MOVES or EMFAC model.
Method D: Traffic simulation model	Description: A traffic simulation model is used in conjunction with operations-based emission factors to model current and forecast operating conditions and GHG emissions.
	Situations in which to apply: Traffic simulation models offer an opportunity to add additional variables in both traffic capacity analysis and GHG analysis. Simulations can account for the effect on GHG emissions of intersection and interchange operations, including queuing in highly congested situations, as well as design characteristics such as sharp curves and steep grades. Simulations might be used in GHG analysis when • Simulation modeling is already being done as a part of traffic capacity analysis. • It is important to the selection of a preferred alternative to capture additional subtleties in traffic-related GHG emissions. • It is important to capture the effect of project design and operations on the emissions of a variety of different motor vehicle types; e.g., bus fleets using buses with different fuel types. • The GHG study area is targeted enough to make it reasonable to create and run a simulation model. Simulations are typically used for analysis in areas with heavy peaking, congestion, queuing, or stop-and-go operations. Also, simulations are generally done to analyze peak travel periods and often focus on a portion of a road network. Therefore, simulation model results should be used with results from the traffic counts method above to capture all GHG emissions across the links potentially affected by a proposed project.

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Table 4.5. Methods for Estimating Baseline GHG Emissions (continued)

Method	Comments
	Calculation methods: • Standard traffic simulation models can be used. • Outputs from simulation models useful to GHG emissions include VMT by vehicle type and by speed, the number of hours spent idling, and fuel consumption (if available). Existing traffic simulation models do not provide outputs of GHG emissions, so these need to be postprocessed. • If the traffic simulation model produces fuel consumption estimates, CO_2 emission factors can be applied directly (see Table 4.6). • If the traffic simulation model does not produce fuel consumption estimates, either average speeds should be calculated by link and used in conjunction with speed-based emission factors from MOVES or EMFAC or, preferably, the detailed traffic model output should be postprocessed for use with the MOVES model. (See *Practitioners Guide.*)
	Data sources: • Traffic forecasts derived as noted in previous method and intersection and/or interchange turning movement studies. • Design characteristics taken from conceptual or preliminary designs, including lanes, grades, curves, and so forth.

Not all projects or plans will have quantitative targets. In some cases, projects or strategies may be evaluated simply for their ability to contribute to GHG reductions (expected direction of impact). In such cases, a qualitative goal may be established, such as "ensure that the project does not increase GHG emissions compared with the baseline" or "ensure that the project contributes to GHG reductions." Quantitative targets are most likely to be applied at the system level (statewide or regional LRP or improvement program), and less likely to be applied at a corridor or project level. However, the selection and scoping of corridor and project studies should be consistent with regional and statewide long-range plans that have been developed to meet any applicable GHG reduction goals or targets.

7. *How will GHG consideration affect funding availability and needs?*

Objective: Determine how considering GHG issues in the transportation process may affect revenue sources, as well as revenue needs for planning and implementation.

Discussion: This question is most likely to be relevant at the long-range plan and programming levels, although it may also affect corridor- and project-level decisions. GHG considerations may affect transportation plan and program finance in at least three ways:

- Revenue sources (such as federal or state funds) may be available that are specifically dedicated toward GHG reduction or that require GHG reductions as a condition for funding. As of the fall of 2010 there were no federal aid highway programs specifically directed at GHG reduction, although there has been discussion of incorporating GHG criteria into the Congestion Mitigation and Air Quality Improvement Program or establishing a similar dedicated program for air quality and/or GHG improvements. The Federal Transit Administration's Transit Investments for Greenhouse Gas and Energy Reduction program explicitly funded GHG reduction projects;
- Some GHG reduction strategies, such as tolling and pricing strategies, may generate additional transportation revenues that are then made available for implementation of GHG reduction strategies and/or other transportation purposes; and
- The evaluation of GHG strategies within the planning and project development process may require additional funding to provide personnel resources to develop inventories,

Table 4.6. CO_2 Emission Factors by Fuel Type

Fuel	CO_2 Emission Factor (kg/gal)
Gasoline	8.81
Diesel	10.15
E10 (gasoline with 10% ethanol)	7.98

Table 4.7. Target Reduction Targets

Percent reduction: ___% from year _____ levels by year _____
Absolute reduction: ___ metric tons CO_2e versus baseline case or current year in year ____
Threshold value: no greater than ____ metric tons CO_2e in year _____

conduct planning for GHG strategies, and analyze emissions reductions. It is also possible that the desire to fund GHG-reducing projects may be a significant factor influencing decisions about overall transportation revenue streams.

Define Range of Strategies for Consideration

8. *What GHG reduction strategies should be considered?*

Objective: Identify GHG-reducing projects or strategies that should be evaluated for inclusion in the LRP, TIP, corridor plan, or project design.

Discussion: The process for screening potential GHG reduction strategies typically involves four basic steps:

- Identify projects or strategies already considered for other purposes, such as air quality improvement or congestion relief, that may have GHG benefits;
- Develop a list of other potential strategies;
- Assess the general magnitude of effectiveness, cost-effectiveness, cobenefits and impacts, political feasibility, jurisdictional authority, and funding constraints for each strategy; and
- Select strategies for further consideration based on these factors.

At the screening stage, existing studies on strategy effectiveness are generally used to identify the general level of GHG benefit, cost, cost-effectiveness, and cobenefits associated with each strategy. More detailed evaluation is often conducted at later stages to refine these estimates for local conditions. The screening stage could also consider what planned or proposed projects may *increase* GHG emissions and whether these should be evaluated further for their GHG impacts.

Table 4.8 provides a list of potential GHG reduction projects and strategies and identifies the level(s) of TCAPP application for which each is most suited. It is likely that transportation agencies are already undertaking a number of these strategies.

Table 4.8. Potential GHG Reduction Projects and Strategies

Potential GHG Reduction Projects and Strategies	Likely Levels of Application			
	LRP	PRO	COR	ENV
Transportation System Planning and Design				
Bottleneck relief	X	X	X	X
High-occupancy vehicle/high-occupancy toll (HOV/HOT) lanes	X	X	X	X
Toll lanes or roads	X	X	X	X
Truck-only toll lanes	X	X	X	X
Fixed-guideway transit expansion	X	X	X	X
Intercity rail and high-speed rail	X	X	X	X
Bicycle facilities and accommodation	X	X	X	X
Pedestrian facilities and accommodation	X	X	X	X
Rail system improvements	X	X	X	X
Marine system improvements	X	X	X	
Intermodal facility and access improvements	X	X	X	X
Transportation System Management and Operations				
Traffic signal timing and synchronization	X	X	X	X
Incident management	X	X	X	X
Traveler information systems	X	X	X	X
Advanced traffic management systems	X	X	X	X
Access management	X		X	X
Congestion pricing	X	X	X	X
Speed management (limits, enforcement)	X		X	X

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Table 4.8. Potential GHG Reduction Projects and Strategies (continued)

Potential GHG Reduction Projects and Strategies	Likely Levels of Application			
	LRP	PRO	COR	ENV
Truck and bus idle reduction	X	X	X	
Transit fare measures (discounts and incentives)	X		X	
Transit frequency, Level of Service, and coverage	X		X	
Transit priority measures (signal preemption, queue bypass lanes, shoulder running)	X	X	X	X
Land Use and Smart Growth				
Integrated transportation and land use planning	X		X	
Funding incentives and technical assistance to local governments for code revision, planning, and design practices	X		X	
Parking management and pricing	X		X	X
Designated growth areas, growth boundaries, and urban service boundaries	X			
Transit-oriented development, infill, and other location-targeting incentives	X		X	X
Freight villages and consolidation facilities	X		X	
Travel Demand Management and Public Education				
Employer-based commute programs	X		X	
Ridesharing and vanpooling programs	X		X	
Telework and compressed work week	X		X	
Nonwork transportation demand management programs (e.g., school pool, social marketing, individualized marketing)	X		X	
Eco-driving	X			
Vehicle and Fuel Policies				
Alternative fuel and/or high-efficiency transit vehicle purchase	X	X	X	X
Alternative fuel and electric vehicle infrastructure	X		X	
Government fleet purchases	X			
Construction, Maintenance, and Operations Practices				
Low-energy and/or GHG pavement and materials	X			X
Construction and maintenance equipment and operations	X			X
Alternative energy sources or carbon offsets	X		X	X
Right-of-way management (e.g., vegetation)	X			X
Building and equipment energy efficiency improvements	X			X

Note: Inclusion of type of strategy or project in this table does not guarantee that it will reduce GHG emissions. The GHG impacts of any given strategy or project must be evaluated based on local conditions and data.

In such cases, they may want to assess whether the benefits of existing strategies have been adequately quantified, or whether more analysis should be done to quantify these benefits.

9. *Are program, corridor, or project alternatives consistent with a long-range plan and/or other relevant plans that meet GHG reduction objectives?*

Objective: Determine whether projects considered for the TIP, corridor alternatives and strategies, or project alternatives and strategies are consistent with a higher-level plan (such as an LRP) that has been developed with GHG reduction goals in mind.

Discussion: The LRP is intended to be an overarching transportation plan and policy document for a state or region. As such, projects listed in the TIP are expected to be consistent with the goals, objectives, policies, and major projects set forth in this plan. Corridor-planning processes and projects selected for more detailed development activities should also be consistent with the LRP. In addition, if a corridor plan has been developed for a transportation corridor, projects evaluated within this corridor should be consistent with that plan. Ideally, the LRP or corridor plan will have been developed considering land use, as well as transportation issues (e.g., as part of a regional or corridor vision for transportation and growth), since land use patterns can significantly affect transportation flows and thus GHG emissions at this level.

If the state or region has not yet developed a plan that includes GHG reduction objectives, it may not be possible to screen projects or strategies according to this criterion. However, consideration may still be given to whether a project would be expected to increase or decrease GHG emissions.

Evaluate GHG Benefits or Impacts of Projects and Strategies

10. *What calculation methods and data sources will be used to evaluate the GHG impacts of projects and strategies?*

Objective: Define what level of analysis is required to support the decision-making process, and identify appropriate analysis tools and data.

Discussion: Three general levels of analysis are defined in Table 4.9: (A) order of magnitude assessment, (B) sketch-level analysis, and (C) analysis using network or simulation models. Different amounts of effort may be appropriate for different strategies based on the importance of that strategy for GHG reductions, uncertainty with respect to its impacts, and availability of resources and data for assessment.

This step may include consideration of how to evaluate projects or other strategies that are proposed specifically with the objective of reducing GHG emissions. It also may include consideration of how to evaluate the GHG impacts of projects or actions that are proposed for inclusion in the plan for other purposes such as mobility, safety, or air quality. Table 4.9 shows the different methods that can be considered for estimating the GHG impacts of projects and strategies.

11. *What are the emissions impacts of specific projects and strategies?*

Objective: Apply appropriate analysis tools to analyze strategies and estimate GHG emissions impacts of individual projects or strategies proposed for inclusion in a long-range plan, TIP, corridor plan, or project design.

Discussion: A variety of tools and methods are available for analyzing the GHG benefits of different transportation projects, policies, strategies, or design features. These are briefly described below. Some of the available tools and methods do not directly calculate GHG emissions, but only calculate travel impacts. This listing is not a comprehensive assessment of these tools; examples of other tools not listed here may include transit ridership forecasting models, freight analysis tools, and land use scenario planning tools. With any of these approaches, travel impacts (changes in VMT and, optionally, speeds by mode) can be used as a basis for estimating GHG emissions if they are applied with emission factors developed from an emissions factor model or method.

Tables 4.10 and 4.11 show how different analysis tools can be used. There is considerable research and development underway on GHG analysis methods, and this list may not include all currently available tools or reflect the most recent updates to models. In addition, individual agencies or consultants have developed their own tools or methods for proprietary or internal use that could be applied or adapted in other settings.

Select Strategies and Document Overall GHG Benefits and Impacts of Alternatives

12. *What GHG-reducing strategies should be part of the plan or project?*

Objective: Determine which strategies should be part of the final plan or project.

Discussion: The selection of final strategies will consider GHG impacts as part of a larger process of selecting projects or strategies considering the full range of evaluation criteria. Typically, some sort of multicriteria evaluation process will be used, such as a weighted scoring system (in which points are assigned to various evaluation factors) or a multicriteria matrix (in which impacts for each factor are arrayed in a table and evaluated qualitatively by decision makers). Projects or strategies that are specifically intended to support GHG reduction may be advanced at this time. This may include consideration of whether projects or actions that increase GHG emissions should be excluded.

Information on the GHG benefits and cost-effectiveness of individual strategies, developed in previous steps, may be considered as part of the overall process of developing a plan or project alternative. In addition, consideration should be given to potential interactive effects among strategies to develop plan or project alternatives that include logical groupings of strategies. For example, a regional plan that includes transit as a GHG reduction strategy may also logically include transit-supportive land use policies to enhance the benefits of transit. Roadway improvement projects to relieve congestion might logically include pricing to manage demand.

13. *What are the net emissions impacts for the overall LRP, TIP, corridor, or project alternatives considered and the selected alternative?*

Objective: Estimate GHG emissions for draft LRP alternatives, TIP, corridor, or project alternatives compared with baseline emissions and GHG reduction goals.

Discussion: This step is an assessment of the overall impacts of proposed and final alternative(s) considering the various GHG reduction or mitigation strategies that are

Table 4.9. Calculation Methods and Data Sources

Level of Analysis	Comments
(A) Order of magnitude assessment	Description: This approach uses existing data from other sources to provide information on the approximated magnitude of benefits and cost-effectiveness that might be expected from different GHG reduction strategies.
	Situations in which to apply: • Initial screening of strategies for more detailed analysis • Limited time and resources available • Locally specific estimates not needed
	Calculation methods: • Review existing sources of effectiveness and cost-effectiveness data. • Consider factors unique to metropolitan area that might affect effectiveness of specific strategies, such as – Size of region – Land use patterns – Congestion levels – Availability and competitiveness of transit and nonmotorized modes – Amount of freight traffic in region – Electricity generation sources (affects light and heavy rail transit benefits) – Political climate and effects on feasibility (including public acceptability).
	Data source: • A summary of cost-effectiveness by strategy is provided in the *Practitioners Guide* Appendix.
(B) Sketch-level analysis	Description: This approach involves basic, off-model analysis (i.e., not using a travel demand or simulation model) of the GHG impacts of individual strategies, using a variety of methods as appropriate for each strategy.
	Situations in which to apply: • Strategy screening and/or selection is desired using locally specific data • Limited time and resources are available • Order-of-magnitude estimates are desired, but precise, rigorous estimates are not required.
	Calculation methods: • A variety of analysis tools and methods, each with different data requirements, may be needed for different types of strategies. Examples of methods include elasticities, spreadsheet calculators, the COMMUTER or TRIMMS model, or other techniques such as the APTA methodology for transit GHG benefits. • Refer to Table 4.11 for an overview of applicable tools by strategy. More details on analysis tools are provided in the *Practitioners Guide* Appendix.
	Data sources: Because of their wide variation, sketch methods are not described in detail in this report, but examples are provided in other reports as referenced in the *Practitioners Guide* Appendix.
(C) Network or simulation model analysis	Description: This approach involves using a network model such as the regional travel demand model (in conjunction with other preprocessor, postprocessor, or off-model techniques) to analyze strategies at a systems level or a traffic simulation model to analyze strategies at a corridor or project level.
	Situations in which to apply: • Strong regional importance is placed on GHG emission reductions and the selection of the most effective and cost-effective strategies is desired. • Robust calculations are needed to support meeting state and/or regional targets • Sufficient data and analysis resources are available, including a travel demand model with adequate capabilities.
	Calculation methods: • Network models may be directly suitable for analyzing some strategies, such as major capacity improvements, transit investments, land use, pricing, and nonmotorized improvements; however, only the more sophisticated models may be suitable for some of these strategies. See Section 6 in the *Practitioners Guide* Appendix for further discussion. • Additional analysis tools and methods may be used in conjunction with travel model data for strategies that cannot be directly modeled. Examples include the use of a 4-D postprocessor to analyze microscale land use and nonmotorized changes, or the ITS deployment and analysis system (IDAS) model for analyzing intelligent transportation systems (ITS) strategies. • The use of traffic simulation models for strategy analysis is similar to their use for corridor- or project-level inventory development, as described in Step 5, Method D. Refer to Table 4.11 for an overview of methods by strategy. See Section 6 in the *Practitioners Guide* Appendix for more detail on these methods.
	Data sources: Network model and off-model techniques are not described in detail in the *Practitioners Guide* or its Appendix.

Table 4.10. Example Analysis Tools for GHG Analysis

Category of Tool	Description	Examples
Travel demand and related models	Regional, statewide, or subarea models of the transportation network.	Travel demand models (Cube, EMME/2, TransCAD, VISSUM) Integrated transportation-land use models (PECAS, TRANUS, UrbanSim) Intelligent Transportation Systems Deployment and Analysis System (IDAS)
Traffic simulation models	Detailed models to evaluate traffic conditions on specific facilities or for areawide networks.	TSIS-CORSIM, VISSIM, Paramics, SimTraffic, TransModeler, SIDRA TRIP
GHG inventory and policy analysis tools	Tools specifically designed for creating GHG inventories and analyzing reduction strategies.	CCAP Transportation Emissions Guidebook Clean Air and Climate Protection (CACP) Climate and Air Pollution Planning Assistant (CAPPA) Climate Leadership in Parks (CLIP) FHWA carbon calculator tool GreenDOT GreenSTEP State Inventory Tool (SIT) URBEMIS
Other travel demand analysis tools	Models and tools for assessing the impacts of strategies to reduce vehicle travel.	COMMUTER model TRIMMS Land use scenario planning tools (INDEX, Smart Growth INDEX PLACE^{3}S, CommunityViz, CorPlan, and others)
Emissions factor and fuel economy models	Models for developing emissions or energy use factors that can be applied to travel changes.	GlobeWarm Motor Vehicle Emissions Simulator (MOVES) Emission Factor model (EMFAC) Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model VISION model
Other off-model methods	Application of elasticities, case examples, and other customized methods to analyze specific strategies.	Elasticities Case examples Other tools

proposed for inclusion. It may be conducted for multiple alternatives for the purpose of assisting with the selection of a preferred alternative, or as documentation that the selected alternative meets its reduction target.

Various methodologies are available for calculating GHG emissions at the overall plan or project level, similar to the methodologies used to calculate a baseline for the study area (Question 5). However, it may also be necessary to apply adjustments to account for strategies that cannot be directly modeled using the baseline assessment tools. The methods discussed in Table 4.12 include

- Travel demand and emissions factor models;
- Travel demand model with enhancements and/or off-model strategy analysis;
- Traffic forecasts and transit projections with emission factors; and
- Traffic simulation models.

The *Practitioners Guide* is cited in Table 4.12, as well as in other tables. Very specific information is presented in this *Guide* on the analysis tools used for GHG emissions analysis and their requirements. For example, an entire section of the *Guide* is devoted to the use of the MOVES model. Readers interested in greater detail on analysis tools should refer to this document.

Carbon Footprint Analysis and GHG Emissions Calculators

One of the GHG analysis (and institutional) contexts that has received increasing attention in recent years has been the estimation of the carbon footprint of a system, service, or facility. These analyses differ from those presented earlier in this chapter. But as they are likely to be much more common in the future, information on the types of tools that are available for such analyses is presented here. Such analyses use an emissions

Table 4.11. Greenhouse Gas Strategy Evaluation Tools by Strategy

Tool or Method	GHG Inventory Development	Highway Network Improvements	Urban Transit Expansion	Intercity Rail and Bus	Nonmotorized Improvements	Rail & Marine Improvements	ITS/Operations & Management	Speed Management	Idle Reduction	Transit Service Improvements	Roadway Pricing	Land Use & Smart Growth	TDM & Public Education	Vehicle & Fuel Policies	Construction and Maintenance Practices
Travel Demand and Related Models															
Travel demand models: Basic[a]	X	X										X			
Travel demand models: Enhanced[b]	X	X	X	X[c]	X	X				X	X	X			
Integrated transportation–land use models	X	X	X	X[c]						X	X	X			
ITS Deployment Analysis System (IDAS)							X								
Traffic microsimulation models		X					X	X							
GHG Inventory and Policy Analysis Tools															
Center for Clean Air Policy (CCAP) *Guidebook*			X		X					X	X	X	X	X	
Clean Air and Climate Protection (CACP)	X														
Climate and Air Pollution Planning Assistant (CAPPA)			X		X				X	X	X	X	X	X	X
Climate Leadership in National Parks (CLIP)		X	X		X				X				X	X	X
FHWA carbon calculator tool	X	TBD													
GreenDOT	X							X	X					X	X
GreenSTEP	X	X	X		X		X			X	X	X	X	X	
State inventory tool	X														
URBEMIS					X					X		X			
Other Travel Demand Analysis Tools															
COMMUTER model											X		X		
TRIMMS											X		X		
Land use scenario planning tools					X							X			
Emissions Factor and Fuel Economy Models[d]															
GlobeWarm	X	X					X	X			X	X	X	X	
MOVES	X	X					X	X	X		X	X	X	X	
EMFAC	X	X					X	X	X		X	X	X	X	
GREET	X													X	
VISION	X													X	
Other Off-Model Methods															
Elasticities					X	X				X	X	X	X		
Case examples		Various													

Notes:

[a] Basic regional travel demand models typically do not include transit or nonmotorized modes, auto ownership, freight, or time-of-day effects.

[b] Enhanced regional travel demand models may include some or all of the following: transit networks and mode choice, nonmotorized conditions and mode choice, consideration of time-of-day shifting, a freight model, or feedback improvements to better capture network effects.

[c] Intercity policy and project analysis requires a statewide model (with inclusion of transit for transit strategies).

[d] Emissions factor and fuel economy models must be used in conjunction with transportation models to analyze strategies that affect travel activity. The strategies associated with these models cannot be analyzed by the models listed here directly, but they can be analyzed with the travel activity models that provide inputs to these emissions factor models. In addition to these models, other data sources exist for emissions factors for different modes, including the *Annual Energy Outlook, Transportation Energy Data Book,* and EPA's eGRID database.

Table 4.12. Calculation Methods and Data Sources for GHG Analysis

Method	Comments
(A) Travel demand and emissions factor models	Description: This approach uses only the regional or statewide travel demand model and an emissions factor model to assess the GHG emissions associated with the LRP, TIP, or corridor plan.
	Situations in which to apply: • Network model used to develop baseline GHG projections for LRP. • Off-model strategies not proposed for inclusion. • Off-model strategies assessed, but do not need to be included in GHG inventory.
	Calculation methods: • Run the travel demand model for the LRP, TIP, or corridor plan and output link-level volumes and speeds by MOVES road type (see *Practitioners Guide*). • Run MOVES to compute emission factors and apply to travel demand model output to calculate total emissions. For details on interfacing the travel demand model with MOVES, see *Practitioners Guide.* • If the travel demand model does not have a transit component, determine transit VMT by mode and/or vehicle type under each plan alternative and apply emission factors.
	Data sources: See Methods A and B in Table 4.5.
(B) Travel demand model with enhancements and/or off-model strategy analysis	Description: This approach applies additional modeling enhancements and/or off-model techniques to include the impacts of strategies not directly assessed in the regional model (e.g., transportation demand management, nonmotorized investment, microscale land use design, traffic operations) in the quantitative inventory.
	Situations in which to apply: • Total GHG needs to be compared with state or regional targets. • There is a desire to include a full range of strategy impacts in the quantitative plan or TIP assessment.
	Calculation methods and data sources: • Run the travel demand model with the MOVES emissions factor model, incorporating any model enhancements developed for specific strategy analysis (see *Practitioners Guide*). • Apply adjustments for off-model strategies as described in *Practitioners Guide.* • Compare total emissions for the plan or TIP to target reductions, if applicable.
	Data sources: See Methods A and B in Table 4.5 and *Practitioners Guide.*
(C) Traffic forecasts and transit projections with emission factors	Description: Forecast traffic volumes and transit vehicle frequencies, multiplied by road segment length within the study area, to which are applied VMT or speed-based emission factors.
	Situations in which to apply: • See Method C in Table 4.5. The same methods and level of detail would be used for the assessment of alternatives as for establishing base year and design year no-build conditions. • Traffic forecasts that account for induced development estimated as a part of an indirect impacts assessment may need to be developed.
	Calculation methods: • See Method C in Table 4.5. The same methods and level of detail would be used for the assessment of alternatives as for establishing base year and design year no-build conditions. However, they would be applied to each year from the opening of the proposed project to the design year. VMT by speed information would be generated for the year of project opening and the design year. • Interim year forecasts can be determined by straight-line projection unless information is available that indicates population and employment growth will occur at another rate. • The results for each year are totaled to obtain GHG emissions for the no-build alternative and each detailed study alternative over the life of the project. • No-build and build results are compared.
	Data sources: • See Method C in Table 4.5. • Growth rates from local land use plans.

(continued on next page)

Table 4.12. Calculation Methods and Data Sources for GHG Analysis (continued)

Method	Comments
(D) Traffic simulation models	Description: A traffic simulation model is used in conjunction with operations-based emission factors to model current and forecasted operating conditions and GHG emissions.
	Situations in which to apply: • See Method D in Table 4.5. The same methods and level of detail would be used for the assessment of alternatives as for establishing base year and design year no-build conditions. • Traffic forecasts that account for induced development estimated as a part of an indirect impacts assessment may need to be developed.
	Calculation methods: See Method D in Table 4.5.
	Data sources: See Method D in Table 4.5.

calculator, a methodology that identifies the many sources of carbon emissions that can be associated with the development, construction, operation, and recycling of a system's components. This section reviews some of the major analysis tools for conducting a carbon footprint, especially for transit applications. Much of this section is drawn from Weigel et al. (2010).

In the transportation sector, publicly available GHG emissions calculators fall under two main categories, each reflecting different emerging needs of GHG emissions reporting:

1. Registry and inventory-based calculators, most suitable for standardized voluntary reporting, carbon trading, and regulatory compliance; and
2. Life-cycle analysis (LCA) calculators, most suitable for pursuit of government funding and for demonstrating the benefits of transit over private automobile travel, or the advantages of one type of transit submode or vehicle type over another.

Inventory calculators are designed for a broad user base of corporations and municipalities and quantify total agency end-use GHG emissions, which may be reported to a voluntary data registry (e.g., EPA's Climate Leaders program) or a registry for carbon credit trading (e.g., the Chicago Climate Exchange). LCA calculators quantify not only end-use GHG emissions, but also upstream and/or downstream GHG emissions associated with the provision (and disposal) of fuels and vehicles. LCA calculators may enable the evaluation of government-sponsored initiatives to reduce full life-cycle emissions from agency operations.

Most GHG emissions calculators estimate only the total quantity of GHG emissions; see Tables 4.13 and 4.14 (Weigel et al. 2010). Among the calculators identified in these two tables, the GREET fuel-cycle model (U.S. Department of Energy 2012), LEM (Delucchi 2003), and GHGenius (Natural Resources Canada 2012) normalize GHG emissions estimates by available energy. Many of the life-cycle calculators provide distance-normalized outputs of GHGs (U.S. Department of Energy 2009; Natural Resources Canada 2012; Transport Canada 2012; Center for Neighborhood Technology 2012). Transport Canada's Urban Transportation Emission Calculator outputs passenger-distance normalized GHG emissions, but only for nonroad modes (Transport Canada 2012). Although many of the calculators do not normalize GHG emissions, normalization may be possible through input data used to generate estimates of total GHG emissions. For example, in a mobile emissions calculator in which CH_4 and N_2O emissions are estimated from VMT data (either historic or forecasted), the same VMT data may be used to normalize the emissions. In the case of a purchased electricity calculator, GHG emissions calculations will not require VMT or passenger miles traveled data, but the normalization of the calculation results will require the collection of such data.

Inventory calculators based on a reporting protocol (The Climate Registry 2008; U.S. Environmental Protection Agency 2012; World Resources Institute 2004; ICLEI et al. 2008) follow what has become a standard three-scope division of emissions: direct emissions controlled by the agency (Scope 1), indirect emissions that occur outside of the agency (Scope 2), and optional emissions (Scope 3).

Guidance reports for many of these calculators typically provide instructions on how to perform GHG emissions calculations for various combinations of input data, including guidance on the preferred hierarchy of calculation methods, calculation formulas, default emissions factors by vehicle and fuel technology, and example calculations. Spreadsheet resources, such as the EPA's simplified GHG emissions calculators (U.S. Environmental Protection Agency

Table 4.13. Lifecycle GHG Emissions Calculators for Vehicles and Fuels

Calculator	Format	Output
Puget Sound Clean Air Agency and Puget Sound Clean Cities Coalition: Evergreen Fleets Emissions Calculator[a]	Online forms	For each vehicle, total tons of CO_2.
Transport Canada: Urban Transportation Emission Calculator[a]	Guidance report and online forms	For each vehicle type: kg CO_2e (upstream, operation, and total); kg criteria air contaminants; vehicle kilometers (road vehicles) and passenger kilometers (nonroad vehicles) of annual travel.
Travel Matters, Center for Neighborhood Technology: Transit Planning Calculator[a]	Online forms and spreadsheets	Total annual lbs CO_2 by mode; lbs CO_2/mile by vehicle type.
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Fleet Footprint Calculator 1.0[a]	Spreadsheet with user guide	Total short tons of CO_2e and barrels of petroleum used.
GREET Fuel-Cycle Model 1.8c.0[a]	Software and reference spreadsheets	For each fuel type: Well-to-pump Btu/mmBtu of energy consumption; g/mmBtu of CO_2e, CO_2, CH_4, and N_2O; well-to-wheel Btu/mile of energy consumption; and g/mile of CO_2e, CO_2, CH_4, and N_2O.
GREET Vehicle-Cycle Model 2.7	Spreadsheets	For each vehicle type: Well-to-pump, vehicle cycle, vehicle operation, and total Btu/mile of energy consumption; and g/mile of CO_2e, CO_2, CH_4, and N_2O.
Life-cycle Emissions Model (LEM)	Software	For each combination of vehicle type and fuel type process: Well-to-pump g/GJ of CO_2e, CO_2, CH_4, N_2O, and HFC-134a; life cycle g/mi of CO_2e, CO_2, CH_4, and N_2O, and HFC-134a.
GHGenius 3.15	Spreadsheets	For each combination of vehicle-type and fuel-type process: Well-to-pump g/GJ of CO_2e, CO_2, CH_4, N_2O, and HFC-134a; life-cycle g/km of CO^2e, CO_2, CH_4, N_2O, and HFC-134a.
Economic Input–Output Life-Cycle Analysis (EIO-LCA)	Online forms	Per $1M of economic activity and for each sector: Total metric tonnes of CO_2e and total CO_2e of CO_2, CH_4, N_2O, and CFCs.
EPA: Motor Vehicle Emission Simulator (MOVES)[a,b]	Software	CO_2e and total energy consumption.

[a] Partial lifecycle: upstream fuel emissions.

[b] MOVES is currently available in a draft version. A complete version is scheduled to officially replace Mobile 6.2 as the U.S. EPA's on-road, mobile source, emission factor software.

2012), generally enable calculations through built-in formulas and default or user-entered emission factors. Online calculators, such as CRIS (The Climate Registry 2012), provide similar functionality through an internet web browser, although downloadable software programs typically provide a calculation capability based on a significantly larger number of user inputs, selections, or reference data sets.

In transportation applications, a key focus of GHG emissions calculations relates to the types of vehicles and fuels that will be present during the analysis time frame. Two main approaches are used by the calculators to estimate mobile combustion GHG emissions, one based on the amount of fuel used and the other based on the number of vehicle miles traveled.

The most accurate method for estimating CO_2 emissions from mobile combustion is to estimate by the volume of fuel used, the measured carbon content of the fuel per unit of energy (or per unit of volume or mass), and the measured heat content (or density) of the fuel used, represented as

$$E_{CO_2} = F \times R \times K \times (44/12)$$

where

E_{CO_2} = emissions of CO_2 (kg),
F = fuel use (gal),
R = heat content (Btu/gal) (or fuel density [kg/gal]), and
K = carbon content (kg C/Btu) (or kg C/kg fuel).

CH_4 and N_2O emissions may also be estimated by multiplying the amount of fuel used by the vehicle fuel economy, and a distance-based emission factor, represented as

$$E_{CH_4} = F \times M \times G$$

Table 4.14. Vehicle and Fuel Scopes of GHG Emissions Calculators

Calculator	Vehicle Scope	Fuel Scope
World Resources Institute: The Greenhouse Gas Protocol—Calculating CO_2 Emissions from Mobile Sources	taxi, bus, local bus, coach, freight truck, light rail, tram, subway, (gasoline, diesel, CNG, ethanol) bus, (gasoline) passenger car and (diesel) locomotive.	gasoline, diesel, residual fuel oil, LPG, CNG, LNG, ethanol, B100, jet fuel, aviation gasoline, E85 (both with biofuel or fossil fuel), B20 (both with biofuel or fossil fuel)
The Climate Registry: General Reporting Protocol Version 1.1, CRIS, Mobile Combustion[a]	(gasoline and diesel) passenger cars, light trucks, heavy-duty vehicles, ships and boats, (diesel) locomotives, (methanol, CNG, and ethanol) buses, light-duty vehicles, and heavy-duty vehicles, (LPG) light duty-vehicles and heavy-duty vehicles, and (LNG) heavy-duty vehicles.	motor gasoline, diesel fuel No. 1 and No. 2, aviation gasoline, jet fuel (Jet A or A-1), kerosene, residual fuel oil (#5 and #6), crude oil, B100, E100, methanol, LNG, LPG, propane, ethane, isobutane, n-butane, CNG
California Climate Action Registry: General Reporting Protocol Version 3.1, Direct Emissions from Mobile Combustion[a]	(gasoline and diesel) passenger cars, light trucks, ships and boats, (diesel) locomotives, heavy-duty vehicles, (biodiesel) heavy-duty vehicles, (methanol, CNG, and ethanol) buses, light-duty vehicles, and heavy-duty vehicles, (LPG) light-duty vehicles and heavy-duty vehicles and (LNG) heavy-duty vehicles.	motor gasoline, diesel fuel No. 1 and No. 2, aviation gasoline, jet fuel (Jet A or A-1), kerosene, residual fuel oil (#5 and #6), crude oil, B100, E100, methanol, LNG, LPG, propane, ethane, isobutane, n-butane, CNG
ICLEI Local Government Operations Protocol: Vehicle Fleet (Mobile Combustion)[a]	(gasoline and diesel) passenger cars, light trucks, heavy-duty vehicles, ships and boats, (diesel) locomotives, (methanol, CNG, and ethanol) buses, light-duty vehicles, and heavy-duty vehicles, (LPG) light-duty vehicles and heavy-duty vehicles and (LNG) heavy-duty vehicles.	motor gasoline, diesel fuel No. 1 and No. 2, aviation gasoline, jet fuel (Jet A or A-1), kerosene, residual fuel oil (#5 and #6), crude oil, B100, E100, methanol, LNG, LPG, propane, ethane, isobutane, n-butane, CNG
Environmental Defense Fund Fleet Greenhouse Gas Emissions Calculator[b]	(gasoline, diesel, residual fuel oil #5 & #6, avgas, jet fuel, LPG, ethanol, biodiesel, LNG, CNG, electricity) passenger cars, light-duty trucks, vans, SUVs, medium and heavy-duty vehicles, (gasoline and diesel) ships and boats, (diesel) locomotives, (residual oil #5 & #6) ships and boats.	gasoline, diesel, residual fuel oil #5 and #6, avgas, jet fuel, LPG, ethanol, biodiesel, LNG, CNG, electricity
EPA Climate Leaders: Simplified GHG Emissions Calculator—Direct Emissions from Mobile Combustion Sources[a,c]	(gasoline and diesel) passenger cars, light trucks, heavy-duty vehicles, ships and boats, (diesel) locomotives, (*methanol,* CNG, and ethanol) buses, light-duty vehicles, and heavy-duty vehicles, (LPG) light-duty vehicles and heavy-duty vehicles, and (LNG) heavy-duty vehicles.	motor gasoline, diesel fuel No. 1 and No. 2, aviation gasoline, jet fuel, residual fuel oil (#5 and #6), crude oil, *B100,* ethanol, *E100, methanol,* LNG, LPG, *propane, ethane, isobutane, n-butane,* CNG
Puget Sound Clean Air Agency and Puget Sound Clean Cities Coalition: Evergreen Fleets Emissions Calculator[b]	(gasoline, ethanol) small cars, midsize cars, large cars, light vans, heavy vans, pick-up trucks, full size SUV trucks, large >10,000 lbs trucks, (diesel, biodiesel) small trucks, large >10,000 lbs., (hybrid) Prius, Civic, Camry, and Escape.	gasoline, E85 (corn), E85 (cellulosic), diesel, B99, B75, B50, B20, B5
Transport Canada: Urban Transportation Emission Calculator	light-duty passenger vehicles, light-duty commercial vehicles, medium-duty commercial vehicles, heavy-duty commercial vehicles, public transit buses, public transit trolley buses, light rail, subway/metro, heavy rail (diesel-fueled) commuter rail.	gasoline, diesel, propane, CNG, LNG, E10, E85, M85, ED10, B100, hybrid, plug-in hybrid, electric vehicle, fuel cell
LEM	light-duty passenger cars, battery-powered electric vehicles, fuel cell vehicles, full-size buses, minibuses, minicars, heavy-rail transit, light-rail transit, medium- and heavy-duty trucks, diesel trains.	gasoline, methanol, ethanol, diesel, biodiesels, CNG, LNG. Electricity: Coal, petroleum, natural gas, nuclear, solar, biomass, hydro.

(continued on next page)

Table 4.14. Vehicle and Fuel Scopes of GHG Emissions Calculators (continued)

Calculator	Vehicle Scope	Fuel Scope
GHGenius 3.15	For fuel calculations: Light-duty vehicle, heavy-duty vehicle, bus, truck. For vehicle calculations: passenger cars, light trucks, other.	gasoline, methanol, ethanol, butanol, petrol diesel, FT diesel, biodiesels, H_2, CNG, LNG; Electricity: coal, fuel oil, natural gas, nuclear, wind, biomass, hydro, other.
Economic Input–Output Life-Cycle Assessment	automobile, light truck, heavy-duty truck, railroad rolling stock, ships and boats.	petroleum (oil and gas), electricity
GREET Fuel-Cycle Model 1.8c.0	passenger cars, light-duty vehicles 1, light-duty vehicles 2.	gasoline, diesel, CaRFG, LPG, crude naphtha, CNG, LNG, methanol, dimethyl ether, FT diesel, naphtha, LPG, E5-10, E50-90, E100, gaseous hydrogen, liquid hydrogen, biodiesel. Electricity: Residual oil, natural gas, coal, nuclear power, biomass, other; Ethanol: Corn, woody biomass, herbaceous biomass, corn stover, forest residue, sugar cane
GREET Fleet Footprint Calculator 1.0	school bus, transit bus, shuttle/paratransit bus, transport/freight truck, medium-/heavy-duty pickup truck, other.	gasoline, diesel, biodiesel (B100), corn ethanol (E100), cellulosic ethanol (E100), CNG, LNG, LPG, liquid hydrogen, gaseous hydrogen; Electricity: Residual oil, natural gas, coal, nuclear power, biomass, wind/solar/hydro
GREET Vehicle-Cycle Model 2.7	For both passenger car and SUV (conventional or lightweight materials): Internal combustion engine vehicle, hybrid electric vehicle, fuel cell vehicle.	Process fuels: residual oil, diesel, natural gas, coal, electricity
Travel Matters, Center for Neighborhood Technology: Transit Planning Calculator	Online form: vehicles reported by transit agency on Form 408 (Revenue Vehicle Inventory Form) for National Transit Database 2002 data report. Spreadsheet: Bus, commuter rail, heavy rail, light rail/trolleybus.	Online form: (bus and van): diesel, B20, biodiesel (B100), CNG, electrodiesel, ethanol, fuel cell/natural gas, fuel cell/electrolysis; (rail electricity): biomass, coal, gas, geothermal, hydro, nuclear, oil, solar, wind, other Spreadsheet: (bus) diesel, B20, CNG/LNG, electricity, fuel cell/electrolysis, (rail) electricity
EPA: MOVES	intercity bus, light commercial truck, motor home, passenger car, passenger truck, school bus, transit bus. Alternative vehicle and fuel technologies: Conventional internal combustion (IC), advanced IC, moderate hybrid–conventional IC, full hybrid–conventional IC, hybrid-advanced IC, moderate hybrid–advanced IC, full hybrid–advanced IC, electric, fuel cell, hybrid fuel cell.	CNG, diesel fuel, electricity, E85, gasoline, LPG

Note: CNG = compressed natural gas; LPG = liquid petroleum gas; LNG = liquid natural gas; CRIS = Climate Registry Information System; FT = Fischer–Tropsch; CaRFG = California reformulated gasoline.

[a] CH_4 and N_2O calculations are limited to combinations of vehicles and fuels shown in the fuel scope field, in which fuels are shown in parentheses, followed by the vehicles available for the fuel type. CO_2 calculations are performed for any vehicle shown.

[b] Calculations are limited to combinations of vehicles and fuels shown in the fuel scope field, in which fuels are shown in parentheses, followed by the vehicles available for the fuel type.

[c] Fuels shown in italics are not available in the spreadsheet calculator, but are available in the calculation guide.

Source: Weigel et al. 2010.

where

E_{CH_4} = emissions of CH_4 (g),
F = fuel use (gal),
M = vehicle fuel economy (mi/gal), and
G = emission factor (g CH_4/mi).

If fuel usage data are unavailable for a particular vehicle type, CO_2 emissions may be estimated from VMT by dividing data for each vehicle type by its corresponding fuel economy using data from the EPA, which are typically included within the calculators. From this fuel usage estimate, CO_2 emissions may be calculated by

$$E_{CO_2} = (V/M) \times R \times K \times (44/12)$$

where

E_{CO_2} = emissions of CO_2 (kg),
V = VMT,
M = vehicle fuel economy (mi/gal),
R = heat content (Btu/gal) (or fuel density [kg/gal]), and
K = carbon content (kg C/Btu) (or kg C/kg fuel).

In addition to the operations-oriented GHG emissions, most carbon footprint analyses include both upstream and downstream emissions associated with the construction and disposal of materials associated with providing transportation service.

Many more carbon footprint analyses applied to transportation services and agencies are likely simply because of the significant role that the transportation sector plays in GHG emissions. The institutional motivation for conducting such analyses will likely fall into two major areas: (1) monitoring of GHG emissions footprints over time in response to program requirements or (2) providing information to key stakeholders and the public on the impact of a particular organization or service on GHG emissions. More sophisticated approaches and methods will probably be developed in the coming years to account for all transportation-related GHG sources. However, as noted by Weigel et al. (2010), though many existing calculators may be drawn on to develop a complete analysis of vehicle and fuel GHG emissions, such an analysis usually requires careful integration and modification of existing calculators in order to match the agency's decision-making requirements.

Conclusion

This chapter has presented a framework for GHG emissions analysis. It is intended simply to provide an overview of the analysis approach; the *Practitioners Guide* and its Appendix provide much greater detail on how this framework can be used and the tools and data that are available to transportation professionals for conducting GHG emissions analysis. Importantly, the framework outlined in this chapter can be used at different levels of analysis, from metropolitan or regional planning to project development studies. The types of tools and data that analysts would use vary by scale of application, but the questions they should be asking themselves are still those found in Table 4.1.

CHAPTER 5

Case Studies of GHG Emissions Analysis

This chapter presents case studies of GHG emissions analysis or policy context that have occurred in recent years in the United States. The analysis covers both highway and transit projects, as well as analyses that were undertaken at the policy or planning level and at the project development level. The case studies presented illustrate a variety of state-level and regional GHG emissions analyses:

- *California Senate Bill 375:* State-level process to develop regional GHG reduction targets for passenger vehicles using regional travel demand models, sketch planning, and best management practices spreadsheet tools;
- *Maryland Department of Transportation:* State-level application using regional travel demand models, EPA MOVES (Motor Vehicle Emission Simulator) model, and sketch models;
- *North Jersey Transportation Planning Authority:* Regional on-road GHG inventory using regional travel demand model and MOVES; life-cycle assessment using the GREET (Greenhouse Gas, Regulated Emissions and Energy use in Transport) model;
- *North Jersey Transportation Planning Authority:* Regional nonroad GHG inventory using National Emissions Inventory, *Annual Energy Outlook,* and GREET.
- *Atlanta Regional Commission:* Regional land use scenario analysis using travel demand model and emissions factor model;
- *Hillsborough County, Florida:* Regional on-road GHG inventory and long-range plan evaluation using MOVES, regional travel demand model, and *Annual Energy Outlook;*
- *New York State Department of Environmental Conservation:* Regional and project-level environmental analysis; and
- *Columbia River Crossing:* Regional and project-level multimodal analysis, sensitivity analyses of key variables, and construction-related emissions analysis.

California Senate Bill 375

Goal: Meet regional GHG emissions reductions targets for passenger vehicles
Level of analysis: Statewide
Methods and/or models used: Regional travel demand models, sketch planning tools, best management practices spreadsheet tool
Emissions analyzed: CO_2

Summary

The State of California has established a goal of achieving 1990 levels of GHG emissions by 2020, and 80% below 1990 levels by 2050, compared with 2005 levels. In 2008 the state developed a Climate Change Scoping Plan (California Air Resources Board 2008b), following the adoption of Assembly Bill 32 (AB 32), California's Global Warming Solutions Act. Out of 18 specific GHG emissions reduction measures in the scoping plan, seven measures were transportation- and land use–related. One of the measures specifically related to the development of regional GHG targets for passenger vehicles is being implemented under the adoption of Senate Bill 375 (SB 375). To implement the new law, SB 375 required the California Air Resources Board (CARB) to develop passenger vehicle GHG emissions reductions targets for 2020 and 2035, in consultation with the state's metropolitan planning organizations (MPOs), by September 30, 2010. Through a collaborative process and the appointment of a Regional Targets Advisory Committee, factors and methodologies were considered in the establishment of the targets. As part of the regional transportation planning process, MPOs are required to prepare a sustainable communities strategy to reach the regional target provided by CARB.

Background

California's Global Warming Solutions Act (AB 32), adopted in 2006, set GHG targets for the state to 1990 levels by 2020 (about a 30% reduction from business-as-usual levels). By the Governor's Executive Order, further reductions of 80% below 1990 levels by 2050 were called for.

To achieve the GHG reduction targets of AB 32, CARB adopted a Climate Change Scoping Plan in 2008. This marked the first comprehensive, multisector program of regulatory and market mechanisms in the United States for achieving designated GHG reductions. For the transportation sector, SB 375, also known as the Sustainable Communities and Climate Protection Act of 2008, was the implementing legislation for regional transportation-related, nontechnology-based GHG emissions reductions. The emissions reduction goals for each of the state's 18 MPOs were to be developed in the form of regional targets for passenger vehicles and light trucks for years 2020 and 2035 (California Air Resources Board 2010). Each MPO would be responsible for demonstrating how it would achieve the regional targets provided by CARB through the development of a Sustainable Communities Strategy as part of the regional transportation planning process.

Methodology

CARB developed proposed regional targets through an extensive 18-month process, with the appointment of a 21-member Regional Targets Advisory Committee (RTAC) with representatives from MPOs; air districts; local governments; transportation agencies; homebuilders; environmental, planning, and affordable housing organizations; and the public.

A bottom-up approach was taken to estimate the anticipated changes and differences among regions using data and analysis developed by the regions. Together, the 18 MPOs represent nearly 98% of the state's population and emissions. Due to the uniqueness of each MPO and region, proposed targets were looked at in the following groups:

- The four largest MPOs in the Los Angeles, San Francisco Bay Area, San Diego, and Sacramento regions, representing about 82% of the state's current population and major source of projected growth;
- The eight MPOs in the San Joaquin Valley (Fresno, Kern, San Joaquin Council of Governments, Stanislaus Council of Governments, Tulare, Merced, Kings, and Madera), which have unique challenges with respect to resources and technical capability. They are exploring the potential for collaboration on a multiregional planning process; and
- The six remaining MPOs (Tahoe, Shasta, Butte, Monterey Bay, San Luis Obispo Council of Governments, and Santa Barbara Association of Governments), which represent a small fraction of the state's total population and emissions and are limited in their ability to generate the forecasts and data needed to provide a strong technical basis for setting targets. As a result, CARB proposed targets that reflect current projections in the six MPOs' most recently adopted regional plans, with a commitment to revisit the targets in 2014 when improved modeling tools are available.

The RTAC process for setting GHG reduction targets under SB 375 was a collaborative effort among the state's MPOs and CARB, with support from Caltrans and the California Transportation Commission regarding modeling and regional transportation plan guidance. RTAC recommended a seven-step process for the target-setting analysis, with the final step being the adoption of targets by CARB in September 2010:

- Step 1. Individual MPO analysis of existing regional transportation plans;
- Step 2. CARB staff analysis of existing regional transportation plan base cases for all MPOs;
- Step 3. Preparation of alternative scenarios;
- Step 4. Analysis of alternative scenarios by MPOs;
- Step 5. CARB staff analysis of MPO alternative scenarios and stakeholder feedback;
- Step 6. CARB staff recommendation of draft targets to its board; and
- Step 7. Continued technical information exchange and modeling of results by CARB, MPOs, and other stakeholders before final target setting by September 2010.

RTAC recommended that targets be expressed as a percentage reduction in per capita GHG emissions from a 2005 base year. These metrics were chosen because they take into account population growth, and 2005 was the most recent year that could be used uniformly for all MPOs. The MPOs prepared an analysis of their adopted fiscally constrained regional transportation plans, including estimates of per capita GHG emissions for the 2005 base year and for years 2020 and 2035. MPO and CARB staffs worked together to ensure consistency in analysis, including use of the following long-range planning assumptions:

- Existing and forecasted fuel prices and auto operating costs;
- Assumptions about fleet mix and auto fuel efficiency standards provided by CARB;
- Updated population forecasts that reflected demographic trends, as well as the results of the recent economic recession;
- Adjustments to transportation assumptions to reflect observed transportation operation funding shortfalls between plan adoption and the present;

- Assumptions contained within existing regional transportation plans regarding the interaction of goods movement–related travel demand with that of passenger vehicles; and
- Exclusion of external trips (those that begin and end outside of a region).

In preparing alternative scenarios, MPOs considered a variety of GHG reduction strategies related to transportation demand management, transportation systems management, transportation system improvements, land use measures, and pricing measures. Examples of strategies included

- Increased transportation funding and system investments in modes that would reduce GHG emissions, such as public transit, rail transportation, and nonmotorized transportation;
- Improved integration between land use and transportation policies;
- Locating schools in neighborhoods that house the student population or maximize access by alternate modes;
- Increased funding for and/or supply of housing affordable to the local workforce;
- Promotion of infill, higher densities, mixed uses, improved pedestrian and bicycle connections, and open space preservation;
- Increased use of transportation systems management measures that improve system efficiency;
- Increased use of transportation demand management measures (e.g., commuter and telework programs and carpool and vanpool services) to reduce single-occupant vehicle travel demand; and
- Use of pricing options, such as freeway toll express lanes, dynamic parking pricing, and various fuel taxes or fees.

A list of measures, alternative scenarios, and data outputs related to performance indicators were identified for each MPO. Performance indicators included GHG emissions levels at target years and performance measures of specified transportation, economic, social equity, housing production, and other environmental issues and concerns.

Conclusion

Using the data and analysis provided by the MPOs through the RTAC process, CARB proposed per capita GHG reductions for the four largest MPOs, the eight MPOs in the San Joaquin Valley, and the six remaining MPOs. For California's largest urban areas, CARB proposed per capita GHG reductions of 7% to 8% in 2020, and between 13% and 16% in 2035 through regional land use and nontechnology-based transportation strategies. For the San Joaquin Valley region, CARB proposed per capita GHG reductions of 5% in 2020 and 10% in 2035 (see Table 5.1). CARB's proposed targets for the six smallest MPOs reflected current projections in their most recently adopted regional plans. When improved modeling tools are available in 2014, CARB will revisit the targets for these MPOs.

For the 18 MPOs statewide, the proposed targets would result in GHG emissions reductions of over three million metric tons of carbon dioxide (3 MMT CO_2) per year in 2020 and 15 MMT CO_2 per year in 2035 (see Table 5.2).

Achieving the 3-MMT CO_2 per year GHG savings in 2020 with the implementation of SB 375 by California's 18 MPOs would help achieve the nontechnology, transportation-related reductions needed to meet the goals set forth in the AB 32 Scoping Plan (California Air Resources Board 2008a). Figure 5.1 illustrates the various GHG emissions reduction measures outlined in the Scoping Plan and their respective share of the overall state strategy to achieve 1990 emission levels by 2020.

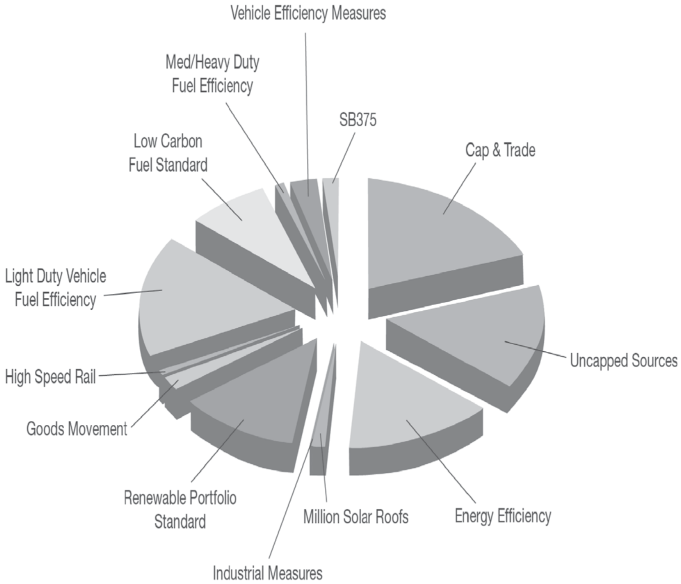
Table 5.1. Summary of MPO GHG Reduction Targets Per Capita

Group	MPO	2020	2035
4 Largest MPOs	MTC	7%	15%
	SANDAG	7%	13%
	SCAG	8%	13%
	SACOG	7%	16%
8 San Joaquin Valley MPOs	(all 8 MPOs)	5%	10%
6 Smallest MPOs	TMPO	7%	6%[a]
	SCRTPA	0%	0%
	BCAG	0%	1%
	SLOCOG	8%	8%
	SBCAG	6%[a]	4%[a]
	AMBAG	13%[a]	14%[a]

[a] Indicates percentage increase in per capita emissions.

Table 5.2. Summary of Resulting GHG Emissions Statewide

18 MPOs	2020	2035
Population	42,234,974	48,341,306
Baseline annual CO_2 emissions (MMT CO_2/year)	131.8	152.6
Annual CO_2 emissions based on proposed target (MMT CO_2/year)	128.5	137.5
Change in annual CO_2 emissions due to proposed targets (MMT CO_2/year)	–3.4	–15.1



Source: California Air Resources Board 2008a.

Figure 5.1. California GHG emissions reduction measures for 2020.

Before MPOs and local jurisdictions adopt a Sustainable Communities Strategy, which will demonstrate how they will achieve the GHG reduction target set by CARB in its Regional Transportation Plan, they will first have to face several challenges, including housing costs, anticipated decreases in sales tax revenues, and sustainable operations and maintenance funding of the current transportation system. CARB staff will continue to work with MPOs and will reassess in 2012 if a target recalibration process will be needed to reflect new data, modeling improvements, or other information in 2014.

Maryland Department of Transportation

Goal: Implement climate change action plan
Level of analysis: Statewide
Methods and/or models used: Regional travel demand models, EPA State Inventory Tool (SIT), MOBILE6.2, draft MOVES 2009, sketch models
Emissions analyzed: CO_2 equivalent (CO_2, CH_4, N_2O)

Summary

The State of Maryland has established a goal of reducing GHG emissions by 25%, compared with 2006 levels, in 2020. In 2008, the state developed a Climate Action Plan that included eight transportation and land use policy options. The Maryland Department of Transportation (MDOT) was given the lead responsibility to design and implement most of these policies. To develop the policies in more detail, MDOT conducted a baseline inventory of statewide transportation GHG emissions for 2006 and 2020 and then analyzed the GHG benefits and costs of a variety of existing, planned, and proposed transportation strategies.

The analysis examined vehicle and fuel technology strategies, such as federal and state adopted fuel economy standards; regional transportation plans with committed projects; committed emissions reduction measures implemented for air quality purposes; and a set of additional unfunded GHG reduction strategies identified in the 2008 Climate Action Plan and by a coordinating committee led by MDOT consisting of state, regional, and local transportation officials.

Background

In April 2007, Maryland's governor established the Maryland Commission on Climate Change. The commission was charged with developing a Climate Action Plan that identified the drivers and consequences of climate change, recommended the necessary state preparations, and established benchmarks and timetables for policy implementation. The plan was completed in August 2008.

The Climate Action Plan includes a climate impact assessment prepared by the Commission's Scientific and Technical Working Group. At the plan's core is a suite of 61 policy options developed by a Greenhouse Gas and Carbon Mitigation Working Group and an Adaptation and Response Working Group; 42 of these options focus on ways to mitigate GHG emissions across all sectors.

The commission also recommended a state GHG reduction goal of 25% of 2006 GHG levels by 2020. This goal was codified with the passage of the Greenhouse Gas Emissions Reduction Act of 2009, which established deadlines for the development of a statewide GHG inventory and baseline emissions projection, a proposed and final GHG emissions reduction plan, and a progress report by 2015. In 2016, the legislature will determine whether to continue, adjust, or eliminate the requirement to achieve a 25% reduction by 2020 (Maryland Department of the Environment 2009).

Of the 42 cross-sector GHG reduction policies, eight are transportation and land use strategies. MDOT was given the lead responsibility to design and implement most of these policies in collaboration with other state agencies, including the Maryland Department of Planning, Maryland Department of the Environment, and Maryland Insurance Administration. The selected transportation and land use (TLU) policy options are shown in Table 5.3.

In January 2009, MDOT began a multiphase work plan to define specific programs, actions, and strategies to address the eight options shown in Table 5.3. Phase I of the work program established a collaborative process comprising seven working groups focused on each policy option (MDOT worked directly

Table 5.3. Transportation and Land Use Policies in the Maryland Climate Change Action Plan

Policy Number	Policy	Lead Agency
TLU-2	Land use and location efficiency	Maryland Department of Planning
TLU-3	Transit	MDOT
TLU-5	Intercity travel	MDOT
TLU-6	Pay-as-you-drive insurance	Maryland Insurance Administration
TLU-8	Bike and pedestrian infrastructure	MDOT
TLU-9	Incentive, pricing and resource measures	MDOT
TLU-10	Transportation technology	Maryland Department of the Environment and MDOT
TLU-11	Evaluation of GHG emissions from major projects	MDOT

with Maryland Insurance Administration on TLU-6). The working groups defined 72 strategies and prioritized 44 for detailed analysis as part of a Phase II work program. To avoid any double-counting of transportation program element benefits, the TLU strategy elements included in the analysis were not part of the funded state transportation improvement program (TIP).

Analysis activities undertaken in Phase II included

- Establishing an updated transportation sector 2006 baseline GHG emissions inventory and a business-as-usual GHG emissions forecast through 2020 based on current roadway and transit systems performance;
- Determining the 2020 transportation sector GHG emissions target (25% below 2006 baseline emissions);
- Quantifying GHG reductions from the Maryland state TIP, which includes the Maryland Consolidated Transportation Plan and MPOs' TIPs and comprehensive long-range plans through 2020, including all air quality transportation emissions reduction measures and off-highway projects; and
- Refining TLU strategy definitions and tracking all 44 recommended strategies' forecasted emissions reductions, costs, and implementation requirements through 2020.

Methodology

2006 and 2020 Baseline GHG Emissions Inventory

The updated GHG inventory for Maryland's transportation sector included 2006 baseline and 2020 forecast analysis years. The inventory was determined by estimating emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and converting these emissions to carbon dioxide equivalents, measured in million metric tons (MMT CO_2e).

For on-road emissions, the MOBILE6.2 model and available postprocessing software (PPSUITE) that works with Maryland's regional travel demand models were used to perform GHG calculations based on link-level vehicle miles traveled (VMT) for the regional roadway networks covered by the state's MPOs. For rural counties not included in an MPO or travel demand model domain, VMT data from the Highway Performance Monitoring System (HPMS) were used. The 2009 draft MOVES model was used to develop speed adjustments to the CO_2 emission factors to support the analyses. Fuel economy values were adjusted to reflect actual on-road performance (typically 15% lower) using degradation factors provided by the U.S. Department of Energy (Energy Information Administration 2007b).

EPA's SIT was used to estimate on-road CH_4 and N_2O emissions based on VMT inputs and SIT defaults for fleet characteristics and vehicle technology. VMT was based on available 2005 to 2006 Maryland state highway traffic data and reported 2006 HPMS VMT.

The off-road GHG emissions analysis relied on the emission factors and methodologies provided in SIT, which estimates off-road CO_2, CH_4, and N_2O emissions based on historic fuel consumption data. Inputs to SIT for the 2006 baseline inventory were based on EIA state energy data. MDOT reviewed and confirmed all baseline and business-as-usual emissions analysis assumptions and methodologies with the Maryland Department of the Environment.

A 2020 business-as-usual transportation sector GHG emissions forecast was prepared assuming future projected VMT growth and vehicle technology. For on-road emissions, HPMS VMT growth rates by county over the 1990 to 2006 period were extrapolated to project future VMT. This method resulted in a statewide annual average VMT growth rate of 1.8%.

For off-road emissions forecasts, historic fuel consumption trends were used to project future fuel consumption using three approaches: (1) extrapolation of trends over the 1990 to 2007 period, (2) extrapolation of trends over the 2000 to 2007 period, and (3) an assumption of no growth. Aviation forecasts were obtained from the Federal Aviation Administration's Aviation Policy and Plans Office terminal area forecasts. Different growth rate bases were ultimately selected for different sectors based on professional judgment.

Table 5.4 presents baseline emissions estimates in 2006 and 2020 for the on-road and off-road sectors, with on-road projections based on HPMS trends.

Table 5.4. Baseline GHG Emissions for Maryland

Source Type	CO_2e (MMT)	
	2006	2020
On-road	30.51	34.67
Off-road	3.03	3.10
Total transportation	33.54	37.77
Goal: 25% below 2006	—	25.15

Strategy Analysis

MDOT estimated the GHG emissions reductions and associated costs for the following strategies:

- Technology improvements and fuels,
- Committed projects in the Consolidated Transportation Plan and MPO TIPs and long-range-plans,
- Currently programmed transportation emissions reduction measures, and
- Additional transportation and land use strategies identified in the Climate Action Plan.

Technology Improvements and Fuels

The technology and fuels improvements strategies included the then-proposed federal fuel economy standards for model years 2011 through 2016; the Maryland Clean Car Program, which incorporates California emissions standards for model years through 2020; and EPA's then-proposed revisions to the National Renewable Fuel Standard program, which set targets for the total amount of renewable fuels that must be used for transportation fuels each year.

The effects of these programs were modeled by adjusting emission rates from MOBILE6.2 to account for fuel economy standards and for reductions in the carbon intensity of fuels. For 2012 to 2016, it was assumed that the average light-duty emission factor in 2016 is 250 g CO_2/mile, with a linear phase-in to meet this level between 2012 and 2015 (this phase-in was advanced 1 year to account for earlier implementation consistent with the Maryland Clean Car Program). Between 2017 and 2020, the CO_2 estimates are based on targets from the California Air Resources Board analysis of the California Pavley Phase 2 regulation.

The renewable fuel standard adjustment was based on an approach used by the Metropolitan Washington Council of Governments, reflecting a 2% reduction in total mobile CO_2 emissions in 2030 as a result of using renewable fuels. For this analysis, a 1% overall reduction in 2020 on-road emissions was assumed to result from the implementation of the proposed renewable fuel standard.

Committed Transportation Projects

To account for the impact of planned transportation plans and programs in 2020, available MPO-forecasted travel and land use data were employed to evaluate VMT growth. The growth rates under this scenario incorporated the impacts of future regional demographic projections from each MPO and the impacts of planned highway and transit transportation projects in the regional TIPs and long-range transportation plans. Under this scenario, the average statewide annualized VMT growth rate was 1.4%. This compared with a baseline growth of 1.8% annually based on historic VMT trends from the HPMS. The existing plans and projects were therefore assumed to be equivalent to the difference in the base VMT growth rate (1.8%) versus the model-forecasted 1.4% growth rate.

Transportation Emissions Reduction Measures

The Clean Air Act Amendments of 1990 and the Safe, Accountable, Flexible, Efficient, Transportation Equity Act (SAFETEA-LU) required MPOs and state DOTs to perform air quality analyses to ensure that the transportation plan and program conformed to the state mobile emissions budget established for criteria pollutants. To support air quality attainment, Maryland transportation agencies had identified transportation emissions reduction measures that provide criteria pollutant emissions reduction benefits. These measures have been assessed in conformity documentation that included specific information on the costs and expected air quality benefits.

The transportation emissions reduction measures identified in the 2009 to 2014 Consolidated Transportation Plan and the MPOs' TIPs and long-range transportation plans, as well as the continuation of current programs such as those focused on commute alternatives, incident management, and traffic operations coordination, were assessed to estimate GHG emissions reductions and costs through 2020.

Reductions in VMT or fuel consumption as estimated by the Baltimore and Washington MPOs, MDOT, and Maryland Department of the Environment were adjusted to reflect 2020 conditions and converted to GHG emissions reductions using GHG emission factors per mile or per gallon of fuel. For the strategies for which a prior benefits analysis had not been completed, observed data on the benefits of these strategies in other locations or research reports were used to determine potential 2020 benefits.

The key methods and assumptions for each type of strategy analyzed are shown in Table 5.5.

Results

As a point of comparison to meet the 25% reduction target, MDOT assessed the benefits of all the reduction strategies

Table 5.5. TLU Strategy Analysis Methods

	Strategy	Analysis Methods
TLU-2	Land use and location efficiency	Data on per capita VMT by census tract density combined with assumptions about population growth in different density ranges.
TLU-3	Transit	Ridership and service growth needed to reach previously established state goal of doubling 2000 ridership by 2020 compared with extrapolation of existing ridership and service trends (incorporating Baltimore and Washington regional trends and committed projects).
TLU-5	Intercity travel	Assumed increased transit mode share to BWI Marshall Airport; assumed increased MARC (Maryland-based commuter rail) and Amtrak ridership compared with existing levels as a result of service improvements.
TLU-6	Pay-as-you-drive insurance	Applied VMT percentage reductions from other PAYD pilot studies to different assumptions regarding percentage of policies covered in Maryland by 2020.
TLU-8	Bike and pedestrian infrastructure	For trails, compared existing walk and bike mode shares in areas near trails with other areas; assumed greater trail coverage consistent with Maryland Strategic Trail Plan and resulting mode impacts for residents near new trails.
		For pedestrian infrastructure, applied an elasticity of VMT with respect to a pedestrian environment factor to assumed changes in the pedestrian environment factor as a result of neighborhood pedestrian improvements in business districts and near schools and transit stations; baseline mode shares varied by population density.
TLU-9	Incentive, pricing, and resource measures	Applied VMT elasticities (change in VMT with respect to change in travel cost) to VMT fees and congestion pricing. EPA COMMUTER model used to assess impact of expanded workplace-based travel demand management programs.
TLU-10	Transportation technology	Traffic management benefits projected from existing evaluations of the Maryland Coordinated Highways Action Response Team program.
		Benefits for idle reduction programs, truck fuel economy improvements, and off-road vehicle retrofits projected from various assumptions regarding technology benefits and fleet penetration.
TLU-11	Evaluation of GHG emissions from major projects	Not applied.

compared with a goal of reducing statewide GHG emissions by 12.62 MMT CO_2e in 2020. This is equivalent to a 33% reduction in projected statewide GHG emissions from all sectors compared with the 2020 baseline.

Figure 5.2 shows how the various reduction strategies add up. From its initial forecast growth of 13%, federal and state fuel economy and renewable fuel standards reduced the 2020 GHG forecast by 4.76 MMT, or slightly below 2006 levels. Existing transportation plans and programs, combined with existing emissions reduction measures, reduced projected 2020 emissions by an additional 2.11 MMT, or 9% below 2006 levels. Implementation of the eight unfunded TLU policy options at different levels of deployment creates a range of a 1.62- to 3.16-MMT reduction in 2020, thus accounting for an additional 30% to 60% of the target shortfall. At the highest level of potential TLU strategy deployment through 2020, plus the benefits of existing statewide transportation sector strategies, the transportation sector was estimated to achieve a reduction of 82% of the 2020 shortfall. In other words, compared with the Climate Action Plan and Maryland GHG Emissions Reduction Act goal of a 25% reduction of 2006 emissions in 2020, the transportation sector could reduce GHG emissions by 20.4% in 2020.

The analysis also provided an initial cost estimate (capital investment only) for the TLU strategies of $4,796 to $6,002 million *over* the existing funded transportation plans and programs through 2020. As a point of reference, the existing funded state capital program in the 2009 to 2014 Consolidated Transportation Plan totaled $12,302 million. This potential level of investment represented roughly a 40% to 50% increase in funded transportation system capital investment in the 2009 to 2014 plan.

Conclusion

This case study examined how one state DOT conducted a GHG baseline inventory and strategy assessment in support of the state's Climate Action Plan and legislated GHG reduction targets. The inventory included both emissions from on-road and off-road sources and used available data sources and modeling tools, including regional travel demand models, EPA's MOBILE6 model, HPMS data, and EPA's SIT. The

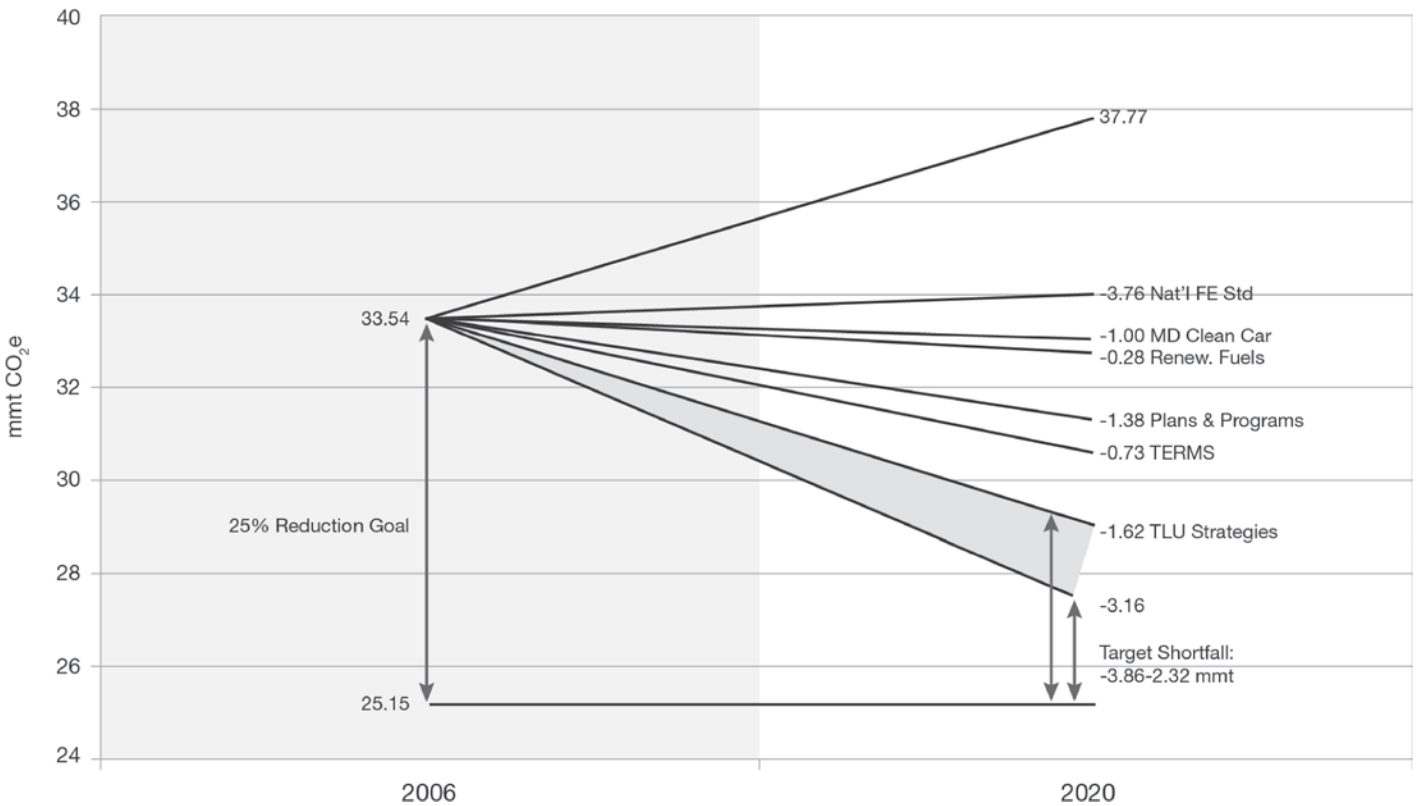


Figure 5.2. GHG emissions scenarios, Maryland.

assessment accounted for existing and planned federal and state fuel economy and renewable fuel standards, state and regionally programmed transportation projects, and planned air quality emissions reduction measures. Finally, the assessment used a variety of sketch methods to estimate the potential GHG emissions reductions and costs of transportation and land use strategies prioritized in the state's Climate Action Plan.

MDOT and its state and regional partner agencies will continue to consider implementation of the strategies evaluated in the plan. This ongoing assessment will include outreach and coordination activities with the modal agencies, MPOs, other state agencies, and local jurisdictions to build consensus, gain buy-in, and assist in the planning and implementation of the transportation sector climate change–related strategies. The Greenhouse Gas Emissions Reduction Act of 2009 requires annual updates to the Maryland Commission on Climate Change from each state agency regarding progress in implementing GHG emissions mitigation measures. This includes tracking of the implementation of specific GHG beneficial projects and programs. Also, in 2011 and 2012, as required by the Greenhouse Gas Emissions Reduction Act, MDOT worked with other state agencies to develop a publicly reviewed state implementation plan for meeting the 2020 GHG reduction targets.

North Jersey Transportation Planning Authority Regional On-Road GHG Inventory

Goal: To allocate total GHG emissions among sources and serve as a baseline for future projections.
Level of analysis: Regional
Methods and/or models used: Regional travel demand model, MOVES, GREET
Emissions analyzed: CO_2 equivalent (CO_2, CH_4, N_2O)

Summary

The North Jersey Transportation Planning Authority (NJTPA) is the MPO for 6 million people in the 13-county northern New Jersey region. NJTPA has completed a multisectoral GHG emissions inventory for the entire NJTPA region. The inventory is intended to allocate total GHG emissions among sources and down to the county and municipal level, as well as to serve as a baseline for future projections. This inventory is designed to help state, regional, and local policy makers and citizens understand GHG emissions sources so that well-informed policy decisions can be made to reduce these emissions.

The regionwide GHG inventory is part of a larger multiyear climate change initiative at NJTPA that includes mitigation and adaptation research and planning, conducting an inventory of climate-vulnerable facilities within the region, and creating a framework for incorporating climate impacts into evaluation criteria for programs and project selection and prioritization.

Background

NJTPA has developed base year and forecast year GHG emission estimates. The GHG inventory and forecast were conducted for all emissions sectors for the North Jersey region and will be used to inform decision makers concerned with mitigation planning across different sectors. This case study focuses on the on-road portion of the overall GHG analysis; the following case study describes the nonroad GHG emissions inventory for the NJTPA region. The project demonstrates the types of data needs that arise in GHG planning and how data gaps can be addressed. Because NJTPA has its own regional transportation model (the North Jersey Regional Transportation Model–Enhanced, or NJRTME), this model was used in conjunction with the EPA's MOVES model to estimate on-road vehicle GHG emissions.

Methodology

The inventory effort estimated the emissions from all on-road vehicles in the 13-county North Jersey area. Emissions sources included passenger cars and trucks, motorcycles, commercial trucks, heavy-duty vehicles, and buses, fueled by gasoline, diesel, or other alternative fuels. All three major pollutants (CO_2, CH_4, and N_2O) were estimated in three categories: direct emissions, consumption-based emissions, and energy-cycle emissions, which included upstream well-to-pump emissions. The direct emissions estimate showed the impacts of emissions within the region's borders. The consumption estimate represents the emissions from trips that begin and/or end in North Jersey, thus representing emissions that could be controlled by local jurisdictions. The energy-cycle estimate builds on the consumption estimate to provide an idea of total upstream emissions (from fuel refining and transportation) that accompany the North Jersey emissions inventory.

Emission factors were estimated using the MOVES 2010 model. Emissions in this analysis were calculated at the level of detail of 13 MOVES source types and the four MOVES road types. The analysis used the base year of 2006 and forecast years of 2020, 2035, and 2050. This range provided an estimate longer than the window for the long-range transportation plan (typically 20 to 30 years). In this case, NJTPA extended its own VMT growth estimates from 2035 to 2050.

Direct Emissions

The direct emissions associated with on-road transportation included all of the GHG emissions for highway vehicle travel that occur within the geographical boundaries of the NJTPA region, including emissions associated with vehicle starts and stops, and exclude the portion of a trip's emissions that might occur outside the region. Emissions were presented at the municipal civil division level, which provided information at a subcounty level to assist decision makers at all levels of government.

VMT was the primary activity factor used in the emissions calculation for on-road transportation. VMT for the North Jersey region was estimated using NJTPA's travel demand model, which provided link-based VMT by vehicle type. The estimates were then input into MOVES. Since the travel model provided only an approximation of actual conditions, the traffic volumes produced by the model were adjusted to be consistent with reported HPMS totals. The 2006 HPMS VMT adjustments were applied for both base year (2006) and forecast year estimates.

The vehicle types provided by the transportation model were mapped into MOVES source types using an aggregate version of New Jersey vehicle registration data for the NJTPA region. Table 5.6 shows how the NJRTME vehicle types were mapped to the corresponding MOVES source types in this analysis.

MOVES inputs included information on meteorology, vehicle age distributions, aggregated motor vehicle registrations, fuel properties, and vehicle inspection and maintenance program information. These data were provided by the New Jersey Department of Environmental Protection.

MOVES runs generated emission rates for each analysis year and each county. To estimate direct emissions, the volumes on each link in the network by source type were applied to the corresponding emission rates from the MOVES lookup database. Emissions were then aggregated to the level of the corresponding municipality with the data indexed by source type.

Consumption-Based Emissions

Consumption-based emissions were estimated by municipality of origin for each of the four analysis years (2006, 2020, 2035, and 2050). Unlike direct emissions, which were computed for individual highway links and allocated to the municipality in which the link was located, consumption-based emissions were calculated for each origin-to-destination trip in the region, then allocated to the origins and destinations that produced and attracted those trips. VMT associated with travel outside the NJTPA region (i.e., Connecticut and Maryland) was discarded. This consumption estimate provided a different perspective on the region's emissions, because trips which neither begin nor end in

Table 5.6. Transportation Model Vehicle Types Split to Source Types

NJRTME Vehicle Type	MOVES Source Type Code	MOVES Source Type Description	Split
Auto	11	Motorcycle	3.0%
	21	Passenger car	59.8%
	31	Passenger truck	37.0%
	54	Motor home	0.2%
Heavy truck	51	Refuse truck	4.45%
	61	Combination short-haul truck	18.95%
	62	Combination long-haul truck	76.60%
Commercial truck	32	Light commercial truck	100.0%
Medium truck	41	Intercity bus	3.0%
	43	School bus	42.9%
	52	Single unit short-haul truck	50.3%
	53	Single unit long-haul truck	3.8%
From New Jersey transit model	42	Transit bus	

the North Jersey area are less important to local decision makers.

Trip distances for trips within the region were estimated using a traffic analysis zone (TAZ) to TAZ distance table (skim matrix), which was available from the NJTPA travel demand model. The distance between each TAZ pair was estimated based on the shortest path through the congested network as determined via the final iteration of the highway assignment process. Corrections were applied to estimate travel distances for external–internal trips, whose distance was estimated from the TAZ to the region's boundary line. For each origin–destination pair (6.5 million such pairs in the NJRTME), vehicle hours of travel and speed, vehicle type, road type, and time of day were applied against the MOVES emissions rate lookup table (with MOVES emissions rates calculated as described in the direct emissions section) and multiplied by the appropriate VMT; emissions were then calculated for that origin–destination movement. VMT and emissions were split 50% to the origin TAZ and 50% to the destination TAZ. Finally, TAZ emission and VMT totals were aggregated by municipality and by county.

Energy-Cycle Emissions

Energy-cycle GHG emissions in the on-road sector are associated with the production, refining, and transport of motor vehicle fuels. The Argonne National Laboratory's GREET model was used to estimate the energy-cycle emissions of all transportation fuels in this analysis.

Energy-cycle GHG emissions estimates were developed for on-road vehicles using an estimate of the portion of the fuel consumption for each vehicle type by fuel type. The fuel type was needed because the energy-cycle emission rates for gasoline, diesel, and ethanol vary. Emissions were not tracked by fuel type in the direct or consumption-based emissions analyses. Therefore, a rough method for estimating the portion of fuel consumption by fuel type was developed from the consumption emissions analysis. A MOVES run using default data for Bergen County, New Jersey, in 2006 was developed to obtain the output of energy consumption by fuel type and source type. This fuel type breakdown was applied in all analysis years and to the entire NJTPA region.

When comparing emissions from fuel combustion (from The Climate Registry's General Reporting Protocol) with energy-cycle emissions (from the GREET model), energy-cycle emissions for gasoline were 23.0% higher than direct emissions (assuming that gasoline includes 10% corn ethanol by volume), and diesel energy-cycle emissions were 10.8% higher than direct emissions. These energy-cycle emissions estimates were developed using GREET 1.8b emission factors. In order to estimate energy-cycle emissions, the consumption-based GHG estimates were multiplied by the appropriate energy-cycle multiplier, which varied between 11% and 23% depending on the amount of diesel versus gasoline used. For example, light commercial trucks used (84.7% gasoline × 23.0% increase) + (15.3% diesel × 10.8% increase). This resulted in an estimated increase in energy-cycle emissions for all light-duty commercial trucks of 21.2%. These percentages were then applied to the consumption-based emissions to estimate energy-cycle emissions from on-road vehicles.

Table 5.7. Summary of On-Road Vehicle GHG Emissions Estimates in North Jersey

	2006	2020	2035	2050
Direct emissions total (MMT CO_2e)	21.8	23.1	32.5	30.8
Consumption emissions total (MMT CO_2e)	17.0	21.2	29.1	26.6
Energy-cycle emissions total (MMT CO_2e)	20.8	25.9	35.5	32.4
Direct VMT (billion mi)	53.9	62.7	69.9	76.6

Results

Direct and consumption-based approaches employed different methodologies to estimate emissions. Because energy-cycle emissions were calculated by applying a percentage increase to the consumption-based emissions estimates, energy-cycle emissions will always be higher than consumption-based emissions, but not necessarily higher than direct emissions estimates. The difference between the three methodologies can be seen in Table 5.7.

Figure 5.3 shows the difference between direct, consumption, and energy-cycle emissions in all NJTPA counties in 2006. In general, counties with direct emissions higher than consumption emissions are those with larger populations. More densely populated counties have more and larger highways going through them, which increases emissions from through traffic.

Conclusion

Energy use and GHG emissions at a state or national level are often estimated based on fuel sales. Fuel sales are difficult to measure at a regional or other substate level, however, as sales are typically reported at a statewide level. In order to develop an energy cycle–based GHG emissions estimate it is therefore necessary to use estimates of on-road fuel consumption by fuel type. In this study, these estimates were developed based on VMT by vehicle type and fuel type and average fuel economies. The regional split between gasoline and diesel fuel use was compared with the statewide split based on statewide gasoline and diesel sales.

Providing different estimation methods for GHG can also assist local decision makers. The total emissions of an area were contained in the direct emissions estimate. Direct emissions are those most often reported in GHG inventories and GHG registries. The consumption-based estimate is an important metric for measuring the effectiveness of local initiatives to reduce vehicle travel because it represents emissions local decision makers can influence (through traffic is

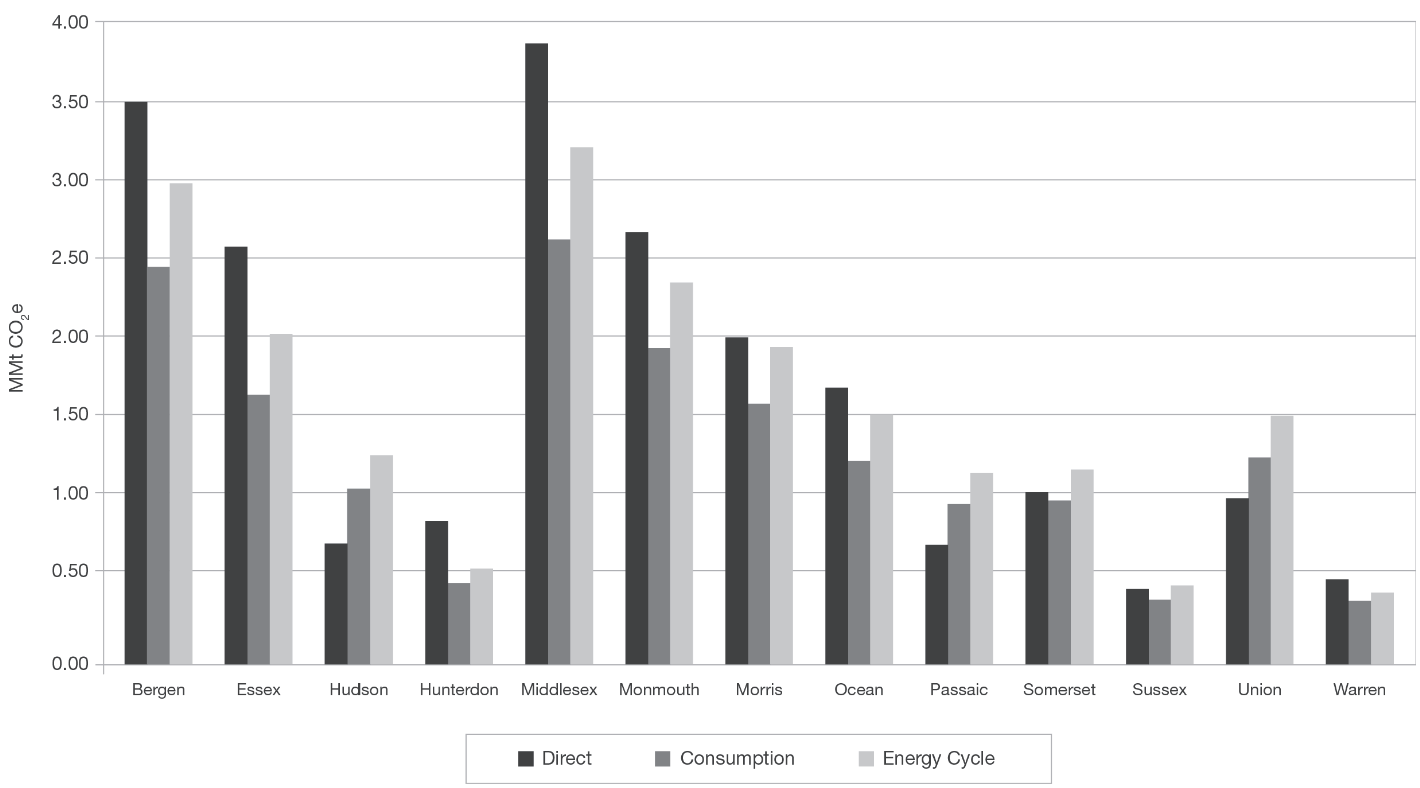


Figure 5.3. Direct, consumption, and energy-cycle emissions by northern New Jersey county in 2006.

unlikely to be affected by local initiatives). The energy-cycle estimate provides an additional layer of information, because upstream emissions from fuel processing and distribution should also be considered to better understand overall emissions. This is particularly important in fuel choice decisions. Although these upstream emissions may not occur within the North Jersey transportation planning area, they are an unavoidable result of on-road activity in the region.

North Jersey Transportation Planning Authority Regional Nonroad GHG Inventory

Goal: Estimate future year emissions in the NJTPA region on a long-term basis
Level of analysis: Regional (nonroad)
Methods and/or models used: EPA 2008 National Emissions Inventory, *Annual Energy Outlook* 2010, Federal Aviation Administration's Terminal Area Forecast System, GREET
Emissions analyzed: CO_2 equivalent (CO_2, CH_4, N_2O)

Summary

This case study focuses on the methods used to estimate current and future year emissions in the NJTPA region for nonroad transportation sources, including air travel, commercial marine vessels (CMVs), and railways. The case study above describes the estimation of on-road emissions and provides background on the overall GHG inventory effort.

Background

Nonroad transportation emissions were estimated for the 13-county North Jersey area. Nonroad vehicles, including aircraft, marine vessels, and locomotives, are powered by diesel, aviation gas, jet fuel, or electricity. The three major GHGs (CO_2, CH_4, and N_2O) are included in the inventory, which covered a 2006 base year and forecasts emissions for years 2020, 2035, and 2050. This range provided a longer estimate than the typical 20- to 25-year window for a long-range transportation plan. However, in GHG planning, a focus on long-term initiatives is essential, and therefore a 40-year window is likely to be beneficial.

Methodology

Emissions were estimated using three methods: direct emissions, consumption-based emissions (railways only), and energy-cycle emissions. The direct estimate included those emissions that occur within the region's borders. The consumption estimate represented the emissions from trips that begin and/or end in the region. The consumption-based approach was applied for railways to account for their use of electric power (much of which is generated outside the region) and to reflect the emissions from rail trips originating in or destined for outside the region, while excluding trips that only pass through the region. The energy-cycle estimate provided a broader picture as it covered emissions from all upstream activities, including material extraction, processing, and transport of fuel. Capturing energy-cycle GHG reductions is an important aspect of mitigation planning when considering options such as low-carbon fuels.

A consumption-based and energy-cycle approach is the most appropriate for mitigation planners, enabling the comparison of the full costs and benefits of proposed actions that affect trips beginning and/or ending within the region. However, the state, national, and some city and county inventories are developed using direct emissions. If neighboring jurisdictions have developed inventories on the basis of direct emissions, using a consumption-based approach will not result in inventories that can be directly compared or added together across regions.

Aviation

Direct Emissions

The geographic boundary for this analysis included all public airports within the NJTPA area. The organizational boundary included all aircraft operations up to 3,000 feet. Although airport emissions included aircraft engines plus airport ground support equipment, only aircraft emissions were addressed in this analysis, which focuses on travel. The methodology used to develop this GHG analysis followed the Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC 2012), which are also consistent with the 2009 *Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories* from the Airport Cooperative Research Program (Kim et al.).

Aircraft emissions estimates for 2006 were developed based on two sources: the Port Authority of New York and New Jersey (PANYNJ) GHG emissions inventory for Newark and Teterboro airports and 2008 National Emissions Inventory landing–takeoff (LTO) data for all other applicable airports (U.S. Environmental Protection Agency 2008). All estimates were based on the fuel combusted during an LTO cycle (emissions occurring below 3,000 feet during landing and takeoff). This method was consistent with the development of criteria and toxic air pollutant inventories. However, it required data on aircraft and engine type for all LTOs at an airport, which were not available for most of the smaller airports (the Port Authority provided such data for its two airports). When LTO data were not accessible from the airport authority, they were retrieved from the National Emissions Inventory airport facilities database. National Emissions Inventory LTO data are divided into four categories: general aviation piston, general aviation turbine, air taxi piston, and air taxi turbine. Each aircraft type was assigned an emission rate based on its engine type, which allowed a more exact allocation of emission factors to aircraft types than an estimate based on average emissions per LTO. The representative aircraft were selected based on their similarity with respect to the National Emissions Inventory emissions rates for other pollutants (carbon monoxide, volatile organic compounds, nitrogen oxides, and sulfur dioxide). CO_2 emissions for these representative aircraft came from the 2006 IPCC guidelines (IPCC 2012).

Aircraft emissions were projected from 2006 through 2030 using general aviation and commercial aircraft operations projections data from the Federal Aviation Administration's terminal area forecast system. Forecast year estimates were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon) as reported in the 2010 *Annual Energy Outlook* (Energy Information Administration 2010). Terminal area forecast data were available for 15 of the 24 airports in North Jersey. For airports without these data, emissions were estimated according to an average of the growth expected in other North Jersey airports. Because airports with higher annual LTOs have terminal area forecast data available, this average growth estimate was only used on 9% of overall North Jersey flights. For all airport forecasts, estimated emissions growth rates for 2025 to 2030 were held constant for 2030 to 2050.

Consumption-Based Emissions and Energy-Cycle Emissions

Due to the difficulty in differentiating fuel consumption that occurs in the LTO cycle from consumption that occurs en route, a separate consumption-based accounting of emissions from the aircraft sector was not developed.

GREET model Version 1.8c was used to estimate the energy-cycle emissions of all transportation fuels in this analysis. Aircraft use either aviation gas or jet fuel, depending on the aircraft type. Energy-cycle emissions factors from GREET were compared with direct emissions factors from The Climate Registry. The GREET model does not have an energy-cycle emissions estimate specifically for aviation fuels, so diesel fuel was used as a surrogate. This produced a 24.8% increase over direct emissions when energy-cycle emissions were considered.

Marine

Direct Emissions

The emissions estimates for CMVs cover all major marine emissions categories, including oceangoing vessels, harbor boats, towboats, dredging boats, ferry boats, excursion vessels, and government boats. Small, privately owned vessels are not included in the commercial category. Only emissions occurring within the 3-mile demarcation line of the shore were included in this analysis. This range is consistent with the boundary used for the ozone nonattainment area State Implementation Plan emissions inventory and the PANYNJ GHG inventory. Emissions came from fuel combusted in these vessels, both in the main engines for propulsion and in the secondary engines for electrical power and other onboard services. This fuel combustion resulted in emissions of CO_2, CH_4, and N_2O, primarily from the combustion of diesel fuel. Large ships can also burn residual oil (a less refined fuel), but that fuel is less common than diesel.

The majority of CMV activity data were obtained from an earlier detailed CMV activity survey for the New York City harbor. This survey provided activity data for the 2000 calendar year in kilowatt hours (kW-h) and horsepower hours (hp-h) for main and auxiliary engines and metric tons of fuel for boilers for the entire ozone nonattainment area. For port terminals for which a recent local vessel activity survey was not available, it was possible to develop a rough estimate of fuel use based on state-level CMV fuel use and allocating that state estimate to counties by using a surrogate indicator. Another option, which is common practice in regional-scale criteria pollutant emissions inventories, is to find a similar-sized port for which a survey has been performed and use that port to estimate activity and resulting fuel use for the port of interest.

The 2000 activity data were extrapolated to 2006 for each vessel type using historic portwide ship call data. Activity data corresponding to towboat activity over the period were not available and were based on advice provided by PANYNJ. It was assumed that there was zero growth in towboat activity across the period. Dredging data (in cubic yards) for 2006 were obtained from the U.S. Army Corps of Engineers Waterborne Commerce section. Total emissions were allocated across the different counties: in the case of oceangoing vessels, emissions were allocated based on the terminal they would eventually use; all other vessels' emissions were allocated to counties according to the percentage of time spent in that county, as estimated in the CMV activity survey.

CMV emissions were forecast through 2050 using 2010 *Annual Energy Outlook* projections (Energy Information Administration 2010). The *Outlook* has a forecast for total commercial shipping in the United States, which is expected to decline at an annual rate of 0.3% between 2006 and 2020. In the longer term, fuel consumption in shipping is predicted to increase by 0.2% annually between 2020 and 2035. At present the *Annual Energy Outlook* does not estimate emissions beyond 2035, so the growth factor for 2020 to 2035 was held constant through 2050.

Consumption-Based Emissions and Energy-Cycle Emissions

A separate consumption-based accounting of emissions for CMVs was not developed for this project because oceangoing vessels' origins and destinations were not known. Energy-cycle GHG emissions within the CMV sector are associated with the production, refining, and transport of diesel fuel. Energy-cycle emissions estimates were developed with the GREET model in order to take into account those upstream emissions. Accurately estimating the upstream GHG emissions associated with fuel extraction, processing, and transport can be difficult for the CMV sector, because little information is available on the energy-cycle emissions associated with diesel for marine use. In this analysis, energy-cycle emissions estimates for on-road diesel fuel were used as a surrogate. This resulted in a 24.8% increase over direct emissions when energy-cycle emissions were considered.

Rail

The railway sector covers emissions associated with the operation of both passenger rail and freight rail locomotives. The primary GHG sources are the combustion of diesel fuel and indirect electricity usage. Indirect electricity usage means that the railway purchases electricity to run the trains, but does not generate electricity directly. Direct emissions include only diesel emissions, but consumption-based emissions include both diesel and electric. In the NJTPA region, the railway sector includes the following components:

- New Jersey Transit (NJ Transit) passenger service: electric and diesel rail and electric light rail;
- Port Authority Trans-Hudson (PATH) passenger service: electric service only;
- Amtrak passenger service: electric service only; and
- Heavy freight rail: diesel only.

Direct Emissions

NJ Transit and PATH passenger rail annual fuel consumption data for 2006 were obtained through NJ Transit's 2007 carbon footprint assessment. Fuel consumption data for individual transit operators, by mode, can also be obtained from the Federal Transit Administration's National Transit Database if a local inventory has not been conducted. Direct emissions were allocated to the minor civil division level based on the fraction of train-trip miles along NJ Transit's commuter rail line for trips within the NJTPA region.

Freight is transported in New Jersey by 14 short-line railroads, two regional railroads, and three national railroads. Average freight rail traffic densities (ton-miles per mile) for individual lines from the NJ freight plan were used to estimate total ton-miles transported within each county. Because these data only include densities for 2000, growth factors were applied to estimate 2006 base year emissions.

Growth rates for individual lines within the NJ Transit rail system were based on estimates obtained from NJ Transit. Most of the growth was expected to occur on the commuter lines that were projected to have new access to New York City as a result of a major tunnel project that would increase passenger rail capacity across the Hudson River; growth would not begin until after the tunnel was completed in 2018. (This project was stopped by New Jersey's governor in 2010). Emissions were assumed to grow linearly between 2018 and 2030 and to remain constant past 2030. Emissions forecasts for the NJ Transit light rail system were based on ridership forecasts produced for the tunnel project's final environmental impact statement. An annual growth factor was calculated for the years between the 2000 base year and the 2030 build year. It was then assumed that annual growth remained constant for years beyond 2030.

Forecasts for direct emissions associated with freight were based on growth in commodity tonnage shipped to and from the NJTPA region between 2002 and 2035, as projected by the Federal Highway Administration's Freight Analysis Framework (Version 2.2). It was assumed that the growth between 2000 (the base year for the freight data) and 2002 was the same as that projected for 2002 to 2010. Future long-term estimates assumed a constant annual growth rate.

Consumption-Based Emissions and Energy-Cycle Emissions

NJ Transit and PATH passenger rail annual electricity and fuel consumption data for 2006 were obtained through NJ Transit's 2007 carbon footprint assessment and PATH's 2008 electric traction summary. GHG emissions for the entire NJTPA region were calculated based on the fuel and electricity consumption data using the electricity, fuel, and incremental energy-cycle emission rates commonly applied to all sectors of this inventory. The consumption-based and energy-cycle approaches allocated the additional emissions associated with the system's electric consumption and reallocated the direct emissions based on ridership origin and destination, allocating 50% each to origin and destination.

To allocate emissions using a consumption-based approach, NJ Transit ridership data were obtained from NJ Transit, including daily on–off passenger counts for each station. At each station the number of passengers on board from previous stations was estimated by adding the total number of boarding passengers from previous stations and subtracting the total number of alighting passengers from these stations. The number of passengers exiting the train at a station was assumed to be allocated by origin in the same proportions as those on the train. Passenger boarding counts were added to the train and allocated to the current station, resulting in an estimate of trips by origin and destination. Passenger miles traveled were then calculated by origin and destination stations. Passenger miles were divided evenly between the corresponding origin and destination stations. Commuter rail stations were further divided between miles traveled on diesel- and electric-powered trains. Emissions were allocated to the minor civil division level based on the number of passenger miles allocated to each station and its location.

PATH ridership data included 2007 station entry counts along with passenger destination mixes by origin station. Passenger miles traveled by origin and destination were then calculated. PATH emissions were allocated to the minor civil division level in a manner similar to that described above for the NJ Transit systems.

Ridership data for 2008, 2009, and 2010 for the PATH system and annual growth factors for future years were provided by PANYNJ. Growth was assumed to represent the growth in the PATH system's emissions due to future expansion of the system's capacity. The long-term emissions forecast assumed a constant average annual growth for future years.

For the freight consumption-based inventory, the tonnage of freight associated with each county in the North Jersey region was provided by NJTPA. Total ton-miles were estimated by multiplying the tonnage by the average distance traveled for freight with an origin or destination in the New York–Newark–Bridgeport area from the 2007 Commodity Flow Survey (U.S. Census 2007). Consumption-based emissions for the region were then estimated using a national average energy factor per ton-mile transported of 302 Btu per ton-mile. Freight rail emissions were not allocated to the minor civil division level because of data availability limitations and because decisions regarding freight rail are not generally made at this level.

Energy-cycle GHG emissions within the railway sector are associated with the production, refining, and transport of diesel fuel and electricity. Energy-cycle emissions estimates were developed with the GREET model to take into account those upstream emissions. The increase due to upstream emissions was added to the consumption-based emissions. In this analysis, energy-cycle emissions factors for on-road diesel fuel were used as a surrogate for the diesel used in rail locomotives because their upstream emissions should be similar.

Results

Aviation

Table 5.8 presents the total emissions associated with the air travel sector in 2006, 2020, 2035, and 2050 based on a direct approach and an energy-cycle approach. The results are illustrated for 2006, by county, in Figure 5.4.

Table 5.8. Summary of Air Travel GHG Emissions Estimates in North Jersey

Total Emissions by Type	Estimated Air Travel GHG Emissions (tCO_2e)			
	2006	2020	2035	2050
Direct	912,255	926,710	1,071,361	1,239,562
Energy cycle	1,138,691	1,156,734	1,337,290	1,547,242

The energy-cycle emissions rate would be more accurate if it were based on jet fuel and aviation fuel rather than on-road diesel fuel. The energy-cycle estimates are based on diesel fuel only since the GREET model does not have an energy-cycle emissions estimate for aviation fuels.

Marine

Table 5.9 presents total emissions, based on a direct approach and an energy-cycle approach, for the CMV sector in 2006, 2020, 2035, and 2050. The results are illustrated for 2006, by county, in Figure 5.5.

The energy-cycle emissions rate would be more accurate if it were based on diesel fuel for CMVs rather than on-road diesel fuel. In addition, the primary data source for this analysis was an assessment of CMV emissions conducted for the year 2000. A more recent inventory would generate less uncertainty than having to increase the 2000 estimate to compute 2006 baseline emissions. Finally, the growth factors used were based on a national average of growth in CMV fuel consumption from the 2010 *Annual Energy Outlook.* Growth in the NJTPA region may differ significantly if expansions or other changes to the port are planned.

Rail

Table 5.10 presents the total emissions, based on direct, consumption-based, and energy-cycle approaches, associated with the rail sector in 2006, 2020, 2035, and 2050. The results are illustrated for 2006, by county, in Figure 5.6. The total emissions were divided between freight and passenger rail. The emissions are listed in Tables 5.11 and 5.12 and illustrated in Figures 5.7 and 5.8. The consumption-based emissions estimates for passenger rail are much higher than the direct GHG emissions estimates for counties near New York City because of the use of electricity to run many of these trains. These same counties also tend to have higher consumption-based freight rail emissions because they are origins and destinations for longer external train trips.

Atlanta Regional Commission

Goal: Regional scenario analysis
Level of analysis: Regional
Methods and/or models used: Travel demand model, MOBILE6
Emissions analyzed: CO_2

Summary

The Atlanta, Georgia, region faces many challenges that can potentially increase GHG emissions. Envision6, the regional transportation plan adopted in 2007, contained strategies

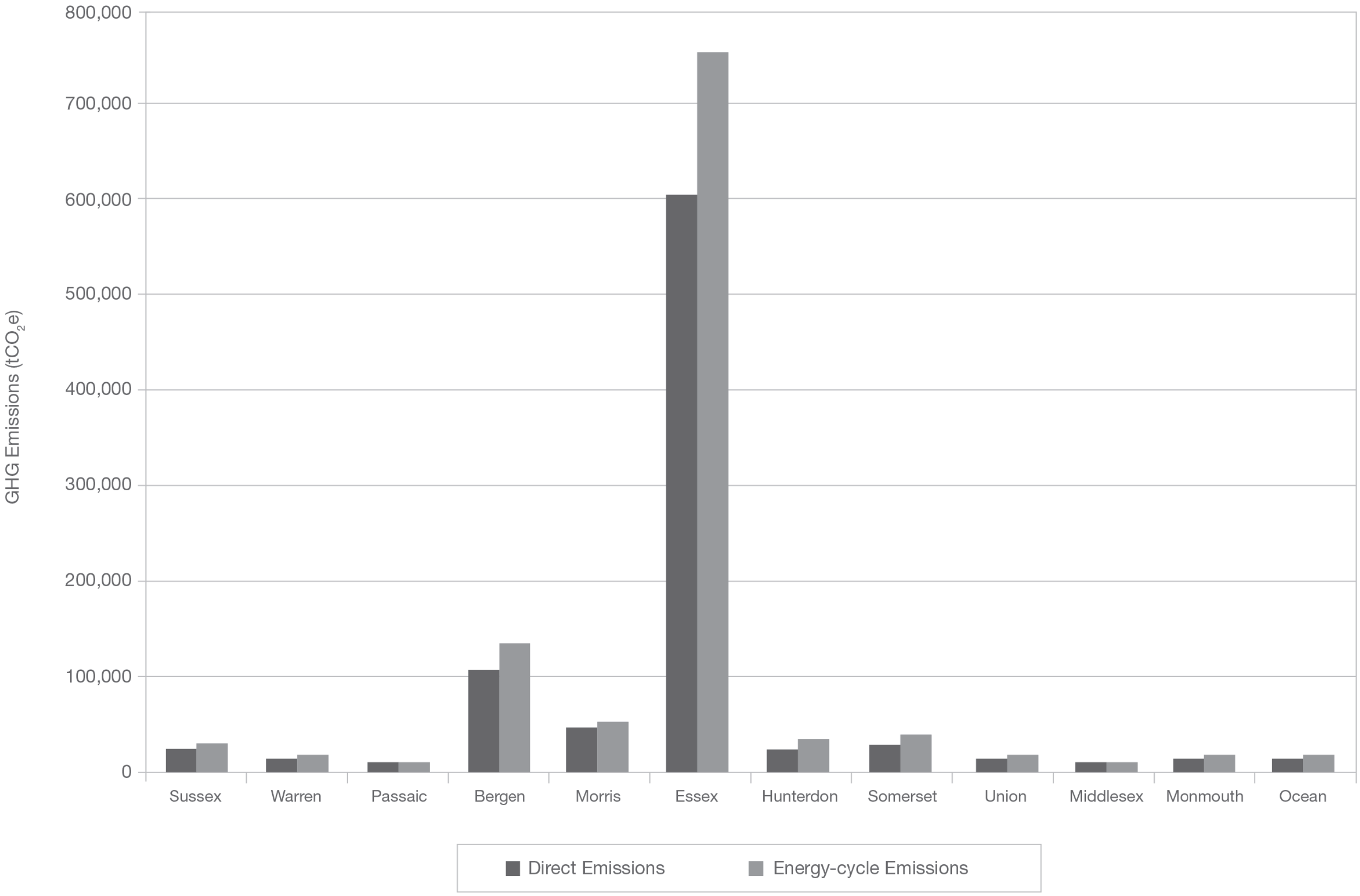


Figure 5.4. Direct and energy-cycle air travel emissions by NJTPA county in 2006.

that led to reductions of primary pollutants and CO_2 emissions. However, CO_2 emissions and reduction strategies were not explicitly evaluated in developing this plan.

The Atlanta Regional Commission (ARC), the MPO for the Atlanta region, has begun to consider strategies for reducing transportation-based GHG emissions and has evaluated the role these strategies might play in the region's next transportation plan, Plan 2040. The focus of Plan 2040 will be how the metro Atlanta area can accommodate economic and population growth sustainably over the next 30 years. ARC's analysis evaluated the extent to which alternative transportation and land use scenarios, combined with recently adopted federal fuel efficiency standards, can reduce GHG emissions over the plan horizon.

Table 5.9. Summary of Marine GHG Emissions Estimates in North Jersey

Total Emissions by Type	Estimated Marine GHG Emissions (tCO_2e)			
	2006	2020	2035	2050
Direct	275,829	263,141	269,758	276,543
Energy cycle	343,641	327,834	336,078	344,532

Background

To inform development of the region's next transportation plan, ARC evaluated the effects of alternative land use scenarios, combined with new federal fuel economy standards, on future GHG emissions. Projected emissions through the year 2030 were compared with 1990 and 2005 emissions levels.

Envision6, the 2007 regional transportation plan, included the consideration of alternative land use scenarios for the Atlanta region. With input from local governments and the general public, four scenarios were evaluated for GHG impacts:

- Continuation of future local land use policies (trend);
- The Envision6 plan, with a somewhat greater focus on compact development;

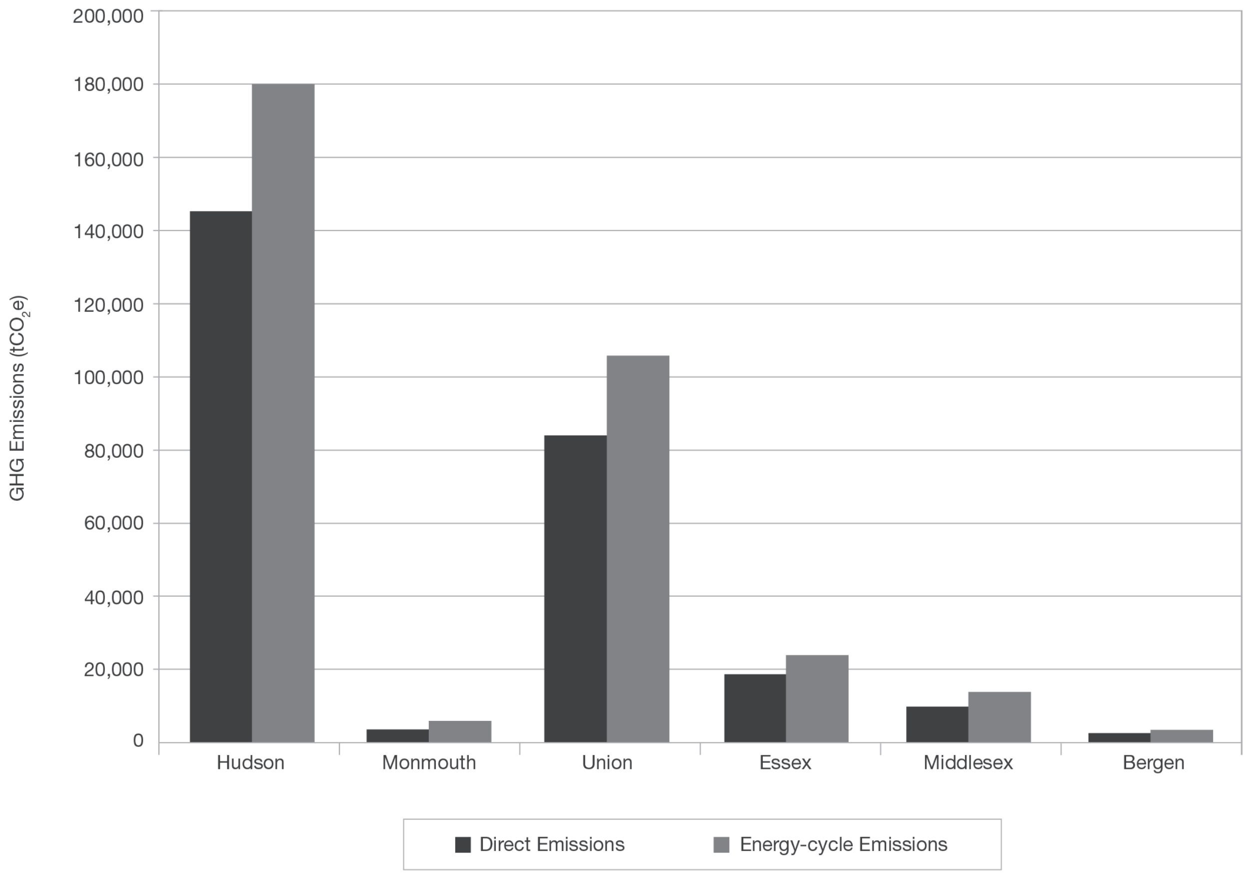


Figure 5.5. Direct and energy-cycle marine emissions by NJTPA county in 2006.

- A still more aggressive land use scenario with greater densities in the region's core area (density land use); and
- A transit-focused land use scenario, which includes greater concentration of development around transit stations.

The Envision6 scenario planning process resulted in a set of 18 land use policies, a unified growth policy map, and a matrix of corresponding development types for the region. Realizing that land use and transportation are mutually dependent, Envision6 included a livable centers initiative program, a green communities program, a 50-year visioning process, and a program to encourage infill development. These successful programs, which have been underway for more than a decade, are already increasing the amount of development occurring in compact communities throughout the region.

Table 5.10. Summary of Rail GHG Emissions Estimates in North Jersey

Total Emissions by Type	Estimated Rail GHG Emissions (tCO_2e)			
	2006	**2020**	**2035**	**2050**
Direct	350,846	432,705	522,130	618,156
Consumption based	723,936	886,482	1,034,638	1,318,309
Energy cycle	841,060	1,023,478	1,206,801	1,535,682

Methodology

All four land use scenarios were evaluated assuming the 2009 implementation of federal corporate average fuel economy (CAFE) standards pursuant to the 2007 Energy Independence and Security Act (EISA). In addition, the trend and Envision6 scenarios were compared without these standards to see what GHG emissions would have been in the absence of this federal action. Finally, the most aggressive scenario was also compared assuming the implementation of the accelerated CAFE standards promulgated in May 2010, which harmonized federal standards with California standards for GHG emissions over the 2011 to 2016 period (most of the analysis was conducted before the adoption of these standards, which is why the EISA standards were used as the primary basis for comparison.)

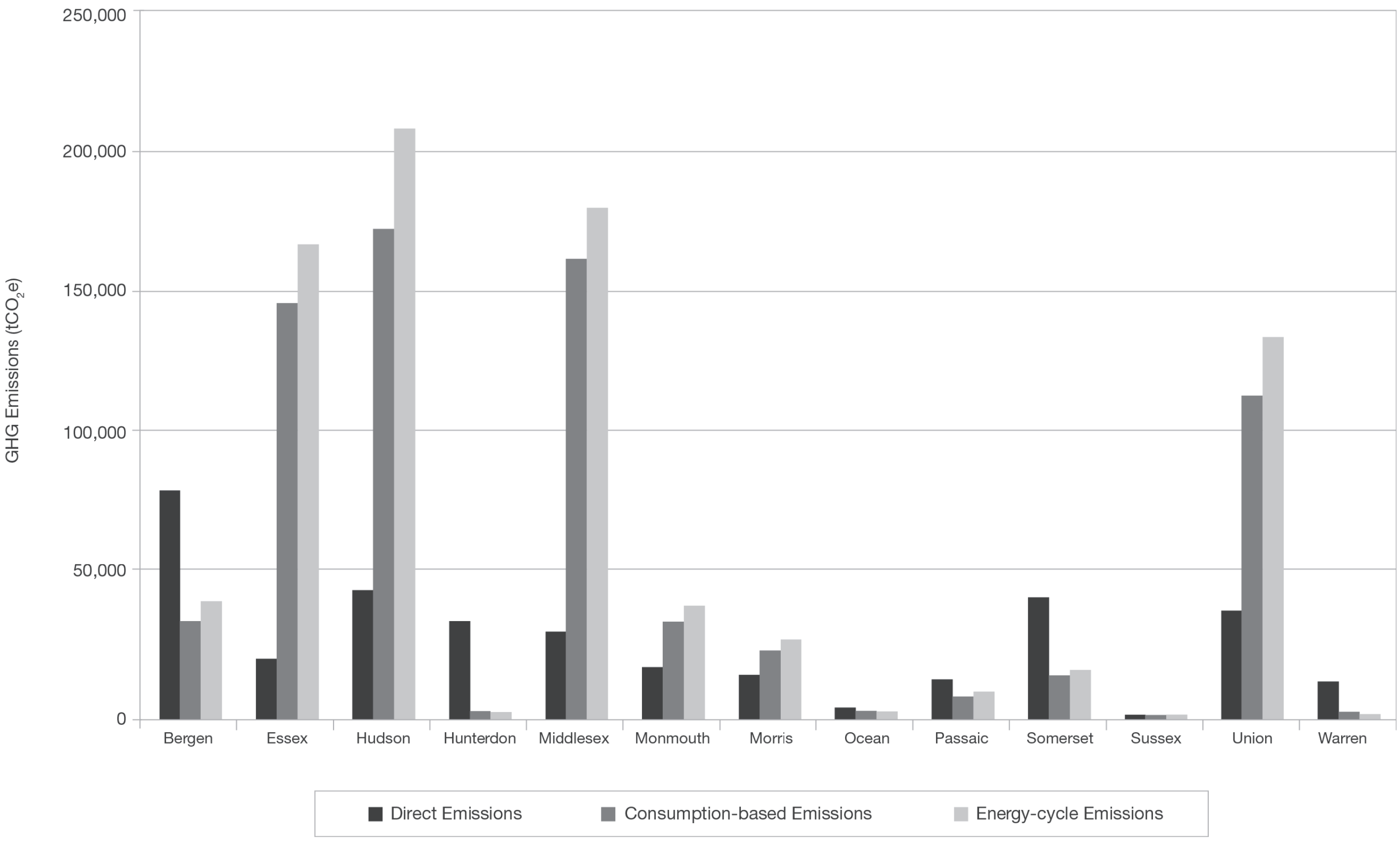


Figure 5.6. Direct, consumption-based, and energy-cycle railway emissions by NJTPA county in 2006.

Figure 5.9 shows an example of a land use scenario developed for the Atlanta region. This map shows changes in the future number of households by traffic analysis zone for the core scenario case compared with the base case in 2040. This scenario is included here for illustrative purposes, and does not correspond to the four scenarios analyzed for GHG benefits. Under this scenario, the region's core area will have 62% of the region's jobs and 52% of the region's households in 2040 compared with 37% and 19%, respectively, in 2010. This is a very aggressive scenario that goes far beyond the shifting in jobs and employment associated with the Envision6 adopted land use plan.

ARC used the EPA's MOBILE6 model to produce CO_2 emission factors for 16 vehicle types and multiplied them by the respective VMT from the regional travel demand model. The proportion of VMT for light-duty versus heavy-duty vehicles was taken from the regional travel demand model, and further proportioned among classes based on a 2002 study of registration data for a 13-county subset of the area, similar to the assumptions used by ARC in air quality conformity analysis. This model was run with different land use inputs (distribution of population and employment by traffic analysis zone) for the four land use

Table 5.11. Summary of Freight Railway GHG Emissions Estimates in North Jersey

Total Emissions by Type	Estimated Freight Rail GHG Emissions (tCO_2e)			
	2006	2020	2035	2050
Direct	230,686	290,339	368,693	464,719
Consumption based	346,382	411,244	513,881	663,566
Energy cycle	431,421	512,208	640,043	826,477

Table 5.12. Summary of Passenger Railway GHG Emissions Estimates in North Jersey

Total Emissions by Type	Estimated Passenger Rail GHG Emissions (tCO_2e)			
	2006	2020	2035	2050
Direct	120,161	142,336	153,437	153,437
Consumption based	377,555	475,238	520,757	654,743
Energy cycle	409,639	511,270	566,758	709,205

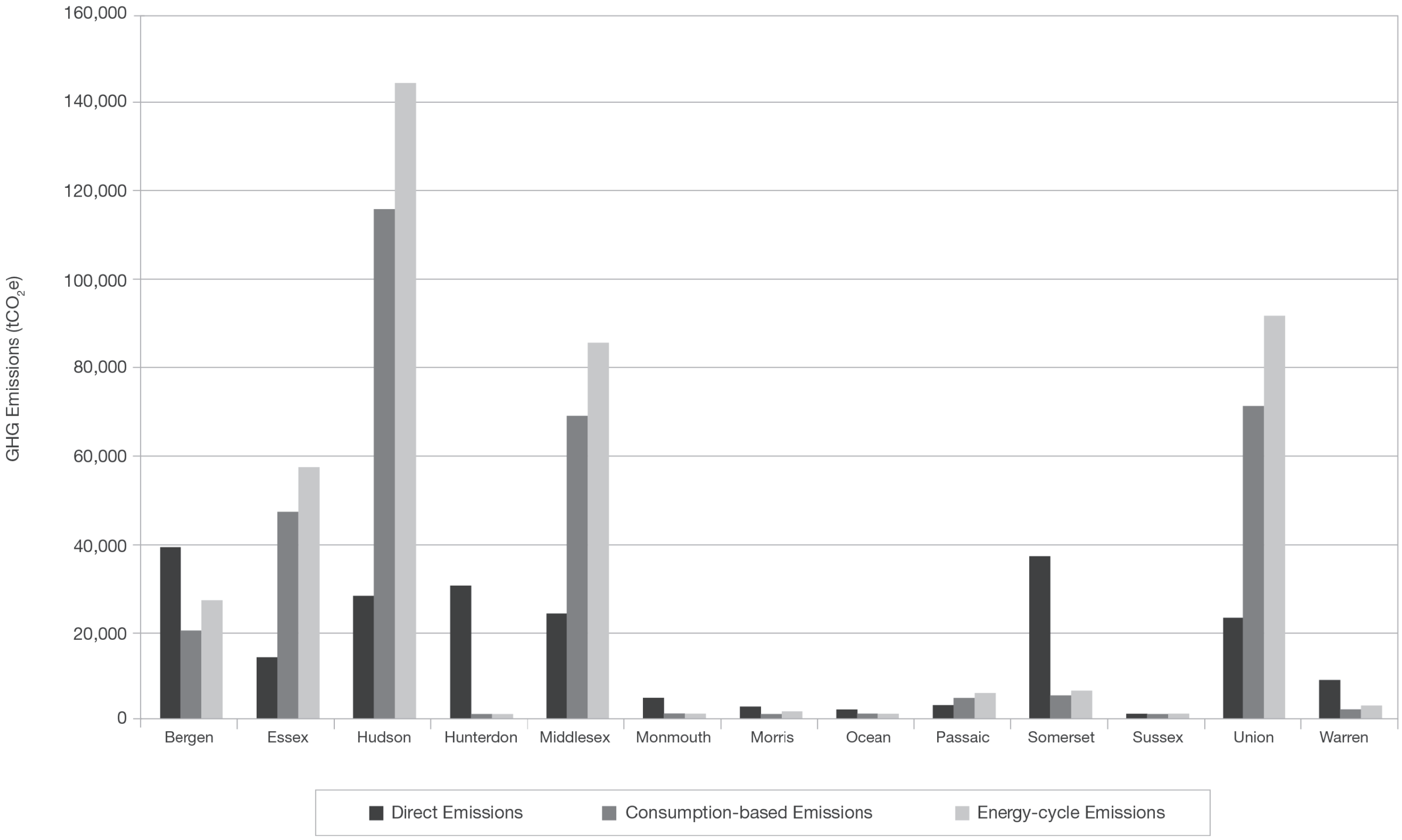


Figure 5.7. Direct, consumption-based, and energy-cycle freight railway emissions by NJTPA county in 2006.

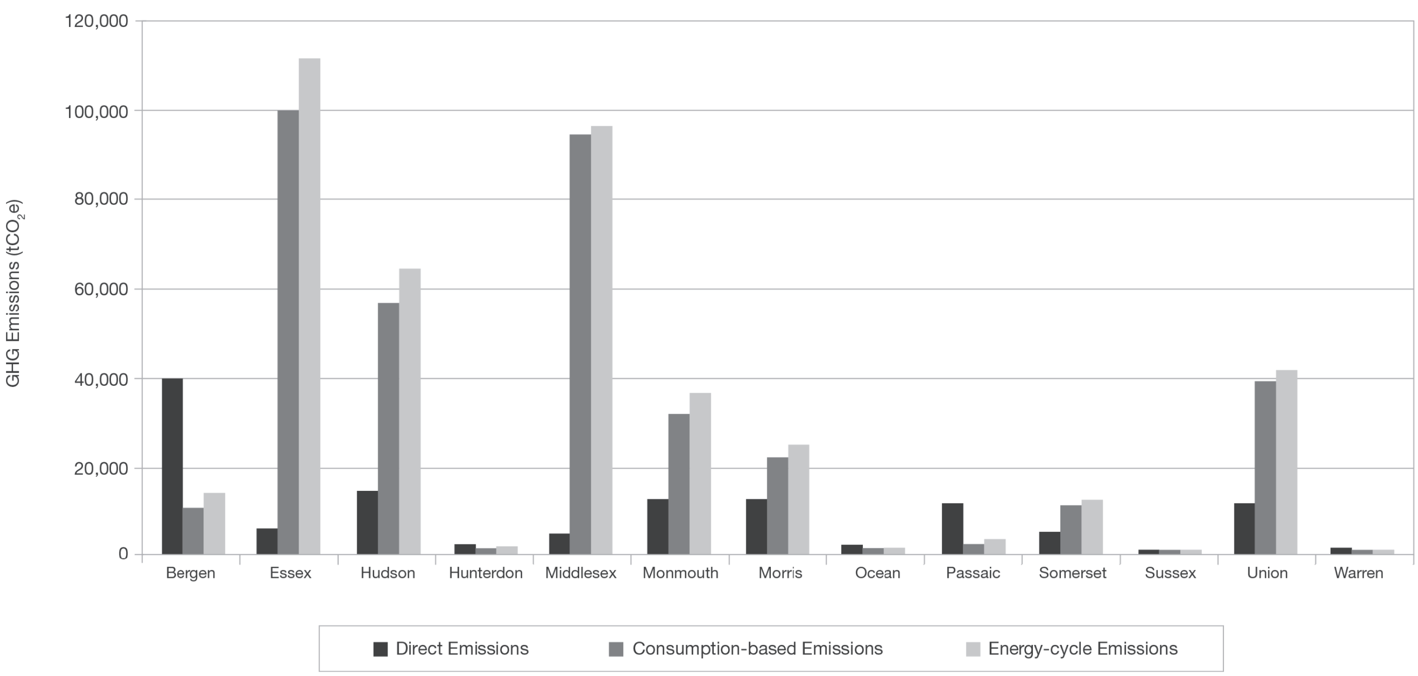


Figure 5.8. Direct, consumption-based, and energy-cycle passenger railway emissions by NJTPA county in 2006.

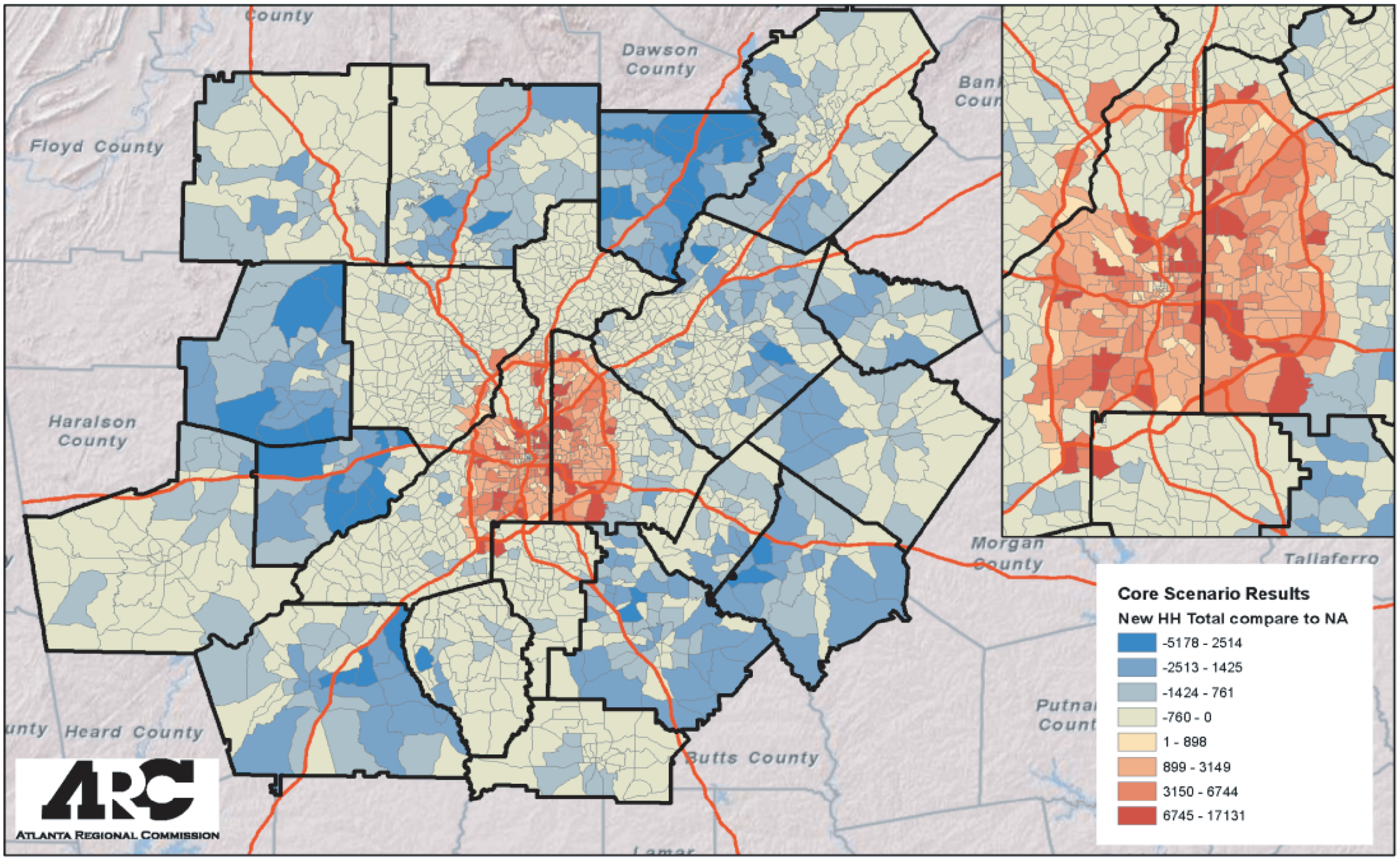


Figure 5.9. Total households by traffic analysis zone, core scenario versus base case in 2040, Atlanta Regional Commission.

scenarios. Since the analysis was conducted before the release of the MOVES model, speed-based emission factors from MOVES could not be used, and thus the CO_2 emission rates varied only by vehicle type.

To account for the effects of federal fuel efficiency standards not reflected in the MOBILE6 emissions rates, ARC interpolated regional fuel economy (in miles per gallon) for both the EISA (2011 to 2020) and 2009 CAFE (2012 to 2016) standards for light-duty vehicles. Adjustments were made in the MOBILE6 run to get emission factors that were then applied to the ARC model results. The overall analysis process is shown in Figure 5.10.

Transit emissions were not calculated separately. Bus emissions would be implicitly included in the highway inventory (since buses are included in highway traffic counts), but emissions from the electrically powered Metropolitan Atlanta Regional Transit Authority rail system were not included. However, since transit service levels were not varied across the four scenarios, the calculation of these emissions was not important for this particular analysis.

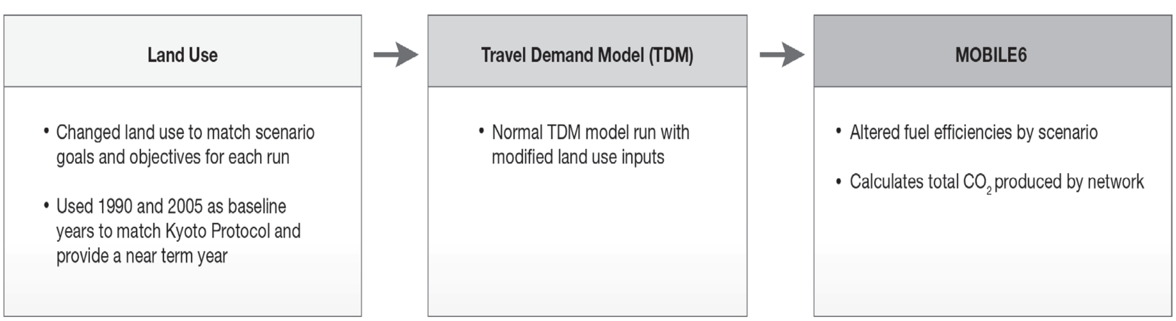


Figure 5.10. Atlanta Regional Commission GHG scenario analysis procedure.

Results

The Atlanta region has experienced rapid growth, with population, VMT, and on-road GHG emissions all growing by about 60% between 1990 and 2005. These strong regional growth trends are expected to continue. Prior to adoption of the EISA federal fuel efficiency standards, and continuing land use patterns based on current local plans, CO_2 emissions were forecast to increase by 170% over 1990 levels by the year 2030. The EISA fuel efficiency standards were expected to virtually eliminate the *growth* in emissions after 2010, but 2030 emissions would still be 90% higher than 1990 levels (Figure 5.11).

ARC found that changes to land use patterns could make a meaningful difference in the future growth of CO_2 emissions. The Envision6 land use plan would keep CO_2 emissions flat at 2010 levels, or about 80% higher than 1990. More aggressive changes to land use would begin to decrease emissions, reducing them to 60% to 70% above 1990 emissions. This is still a substantial increase, but much less than expected if no action were taken.

Accounting for the harmonized federal–California standards adopted in 2010 primarily had the effect of further reducing GHG emissions in the interim years (2015 through 2025), as the primary effect compared with the EISA standards was to accelerate the introduction of more fuel-efficient vehicles.

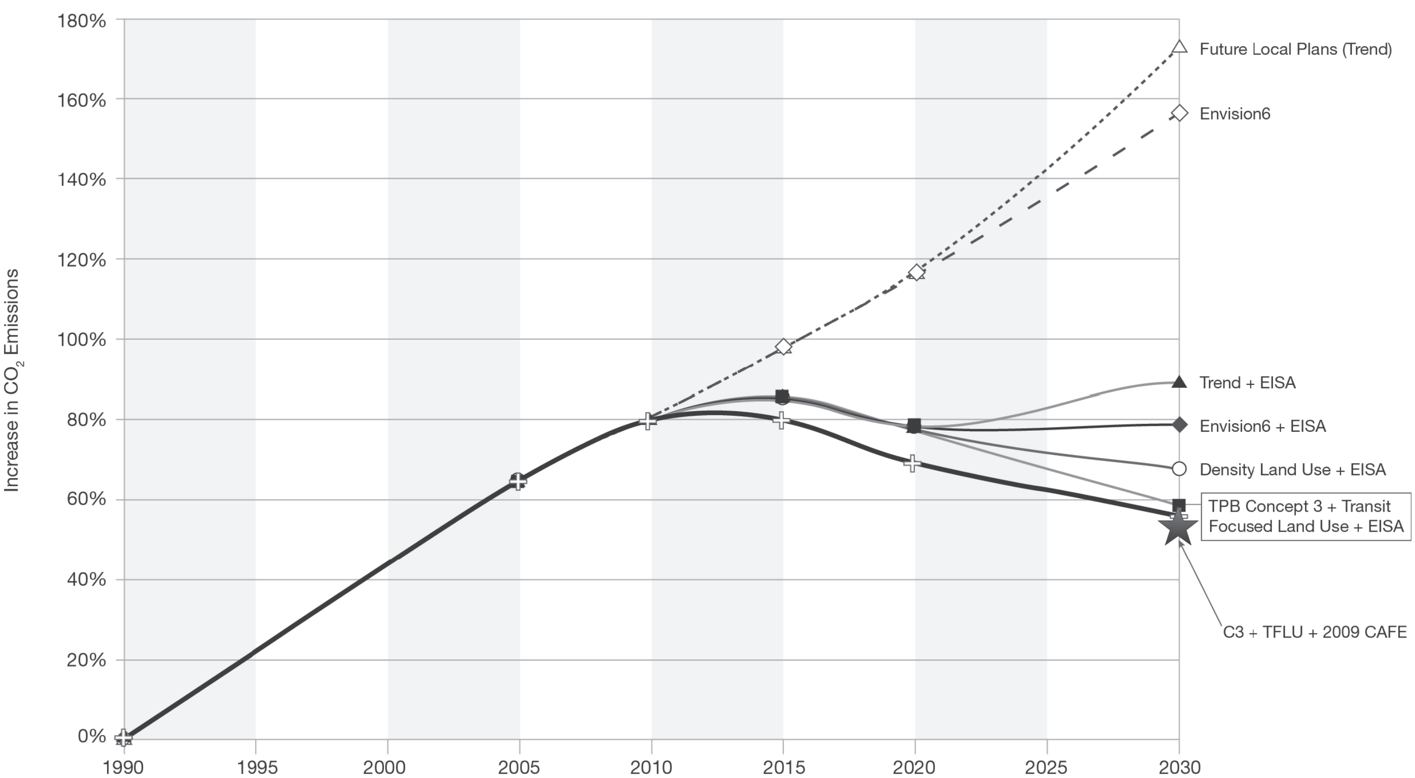
Realizing that regional population and job growth are driving the growth in emissions, ARC also looked at future emissions on a per capita basis (Figure 5.12). The results showed that the EISA federal fuel economy standards will begin to reduce CO_2 emissions per capita, declining to about 16% below 1990 levels under trend land use conditions and 21% with adopted Envision6 actions. More dense land use patterns would further reduce emissions per capita to as much as 30% below 1990 levels.

Conclusion

Once regional land use scenarios were defined, and the travel effects of these scenarios were modeled using the regional travel demand model, estimating CO_2 emissions was relatively straightforward. The analysis demonstrates the potentially significant impact of changes in land use patterns on GHG emissions, at least in a high-growth region. The analysis also demonstrates the added value of combining technology improvements (vehicle fuel efficiency) with strategies that reduce travel demand.

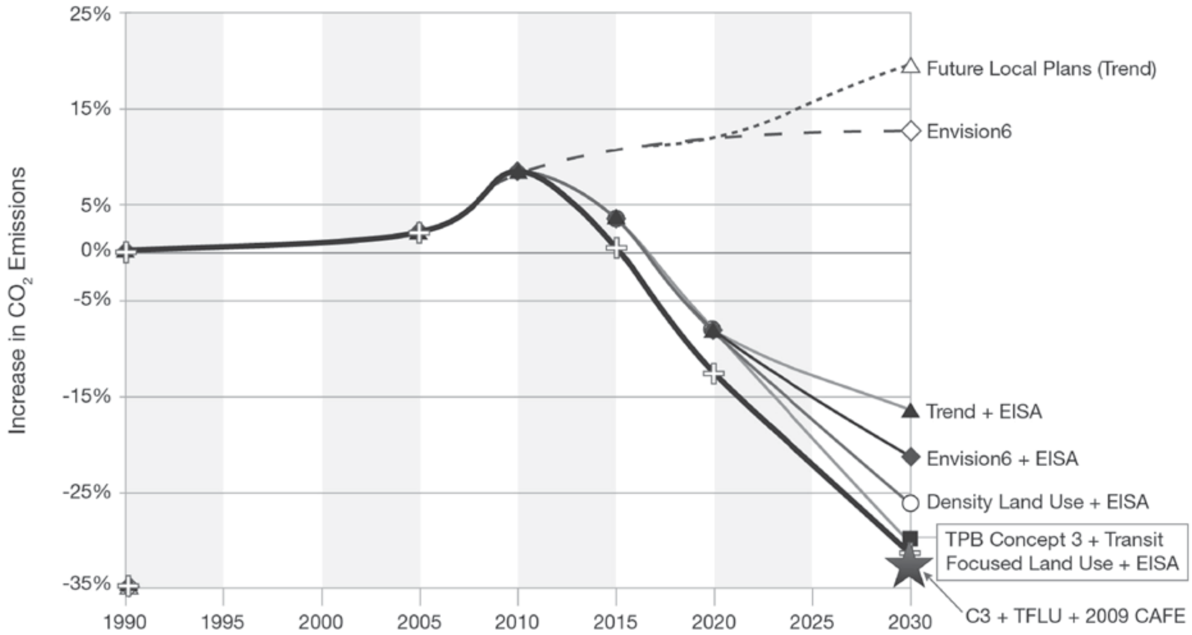
Although the information in this analysis was useful for informing development of the next update of the transportation plan, enhancements could be made in the future to improve the analysis:

- ARC is moving from MOBILE6 to the MOVES model for emissions modeling. Once this migration is complete,



Source: Atlanta Regional Commission

Figure 5.11. Composite Atlanta Regional Commission CO_2 modeling results.



Source: Atlanta Regional Commission

Figure 5.12. Composite Atlanta Regional Commission CO_2 modeling results, per capita.

GHG estimates would account for changes in travel speeds and congestion on the regional highway network under different scenarios. MOVES will also allow inclusion of CH_4 and N_2O for a more complete inventory.

- Life-cycle emissions, including emissions associated with fuel production and distribution, could also be included for a more complete inventory. (See the North Jersey case study for an example of how this can be done.)
- Transit emissions (including rail) could be explicitly included to account for scenarios that combine different levels of transit investment and service with different land use patterns.
- Because the regional travel demand model has limited sensitivity to the effects of microscale land use design factors (e.g., pedestrian design, mixed use), the primary land use effects that are modeled result from shifts in the regional distribution of population and jobs. Enhancements to the regional model could allow for greater sensitivity to land use design factors.
- Regional land use patterns are assumed not to affect freight (truck) travel. The potential impact of compact land use on freight (e.g., through shorter delivery trips or the development of freight villages to reduce truck hauls) requires further research.

Hillsborough County, Florida, Long-Range Transportation Plan Analysis

Goal: Compare future GHG emissions among several alternative plan scenarios

Level of analysis: Regional

Methods and/or models used: Draft MOVES 2009, *Annual Energy Outlook* reference case, Tampa Bay regional planning model

Emissions analyzed: CO_2 equivalent (CO_2, CH_4, N_2O)

Summary

The Hillsborough MPO is the designated MPO for Hillsborough County, Florida, in the Tampa Bay region. In 2009, the MPO included GHG considerations as part of its Long-Range Transportation Plan 2035 Update. As part of the plan development process, the MPO compared future GHG emissions among several alternative plan scenarios. The scenarios for which GHGs were evaluated included cost-affordable scenarios for 2035 with and without transportation funding from a proposed sales tax, as well as a transit-oriented development scenario that included a shift of some population and jobs into transit station areas for a proposed high-capacity regional transit system. These scenarios were compared with the 2006 base year and a 2035 future year with existing plus committed projects.

Background

The Hillsborough County MPO maintains a regional travel demand model known as the Tampa Bay Regional Planning Model (TBRPM). This model was used to calculate emissions for the Hillsborough County regional transportation system (highways and transit) in 2006 and 2035. GHG emissions were initially calculated for four scenarios:

- 2006 Base: The existing (2006) transportation network and travel conditions;
- 2013 E+C: Projected travel conditions in 2035 on the existing plus committed (E+C) roadway network (which stops growing in 2013);
- Cost-affordable A: 2035 travel conditions and transportation network with no new sales tax for Hillsborough County; and
- Cost-affordable B: 2035 travel conditions and transportation network with additional funding from a sales tax for Hillsborough County. The sales tax would support additional roadway improvements, as well as a new fixed-guideway transit system.

Two more scenarios were added to understand the effect of transit-oriented development on travel and GHG emissions:

- Cost-affordable C: 2035 travel conditions and transportation network with additional funding from a sales tax adopted for Hillsborough County. This scenario was similar to cost-affordable Scenario B, but with some adjustments to the model; and
- Cost-affordable D: 2035 travel conditions and network from cost-affordable Scenario C, but with different socioeconomic data to represent transit-oriented development.

The analysis reflected the GHG impacts of roadway and transit investments and the resulting changes in travel demand patterns (e.g., mode shares and trip lengths), as well as travel speeds and congestion on the roadway network. Lower levels of congestion should reduce GHG emissions since vehicles operate most efficiently at moderate speeds (approximately 35 to 60 mph). The analysis did not reflect any impacts from other programs or policies (such as travel demand management programs or pedestrian-friendly land use design) that could not be directly analyzed using TBRPM.

The three 2035 scenarios with funding available from a regional sales tax (cost-affordable Scenarios B, C, and D) included a significantly higher level of transit service. The transit-oriented development scenario (cost-affordable D) altered the socioeconomic data inputs to the travel demand model by moving half of the growth in population and jobs from donor zones to transit-oriented development zones around rail transit stations.

Methodology

GHG emissions from general roadway traffic (automobiles and trucks) were estimated separately from transit vehicle emissions due to different sources of emission factors and VMT. Emission factors for general traffic came from the EPA's draft MOVES 2009 model and were adjusted based on *Annual Energy Outlook* data to account for future fuel efficiency improvements. Emission factors for transit vehicles were based on data from the National Transit Database, again adjusted for future efficiency improvements. VMT for general traffic came directly from the travel demand model, and VMT for transit vehicles was calculated based on route miles and frequency information in the travel demand model. The next sections discuss the calculation methodologies for both general roadway traffic and transit vehicles.

GHG Emissions from General Roadway Traffic

The approach to modeling GHG emissions from roadway vehicles (automobiles and trucks) was as follows. Draft MOVES 2009, the EPA's best available model for GHG emissions at the time of the analysis, was run to obtain GHG emission rates in grams per mile for 2006 for a variety of combinations of vehicle type, fuel type, road type, area type, and speeds. GHGs included carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), which were combined into one emission rate reported in grams of CO_2 equivalent (CO_2e). MOVES was run based on local meteorological data (built into the model) for Hillsborough County, along with national defaults for other factors.

The 2035 GHG emission rates were created based on 2006 rates by using fuel efficiency predictions for 2030 from the April 2009 *Annual Energy Outlook* reference case, a nationally accepted forecast of fuel economy and other energy factors (Energy Information Administration 2009). MOVES produces future year as well as base year emission rates, but the draft 2009 version of the model did not reflect the effects of federal fuel economy standards adopted in 2009 and updated in 2010. The 2009 *Annual Energy Outlook* forecasts accounted for improvements in light-duty vehicle fuel efficiency standards established under the Energy Independence and Security Act (EISA) of 2007 that would have achieved a fleet average fuel efficiency of 35 mpg by 2020; however, they did not account for the new standards established in May 2010, which will accelerate this efficiency to 35.5 mpg in 2016. The difference in 2035 emission rates was expected to be minor since most vehicles meeting the 35.5 mpg standards would be phased in by 2035 under either case. Similarly, although the 2009 *Annual Energy Outlook* only includes forecasts through 2030, the difference between fleet average fuel economies in 2035 and 2030 should be modest under the current policy scenario. Future increases in vehicle fuel efficiency beyond current standards, such as the heavy-duty vehicle standards proposed in October 2010, would result in lower GHG emissions than those projected here.

The following factors were developed from the *Annual Energy Outlook* to adjust 2006 GHG emission rates to 2035 rates for different vehicle types:

- Light-duty vehicles (passenger cars, light passenger trucks): 0.66;
- Light commercial trucks: 0.74; and
- Heavy-duty vehicles (buses, single-unit truck, combination truck): 0.88.

The proportion of VMT for light-duty versus heavy-duty vehicles was determined for local conditions from the TBRPM, and MOVES default VMT fractions for the proportion of VMT by vehicle types within these two categories were applied. A lookup table of VMT fractions based on VMT activity data from MOVES for 2006 and 2035 was created. These fractions were adjusted for every integer percentage of trucks between 0 and 100, based on link-specific truck percentages from the regional model.

Consolidated emission rates were calculated by weighting the emission rates for each vehicle and fuel type by their appropriate VMT fraction and summing together all vehicle and fuel types. Rates were maintained in a lookup table by year, MOVES road type, speed, and percentage trucks.

Travel activity results (congested speed and VMT) were taken from link-level data for Hillsborough County from the TBRPM for each of the first four scenarios identified above (2006, 2013 E+C, and 2035 cost-affordable Scenarios A and B).

Emission rates were matched to individual links from the TBRPM using year, road type, area type, speeds, and percentage trucks. A conversion map was created to help match TBRPM road and area types to MOVES road types. Speeds were grouped into the nearest 5 mph MOVES speed bin, and percentage trucks was rounded to the nearest integer percentage (1% bins). Emission rates were multiplied by VMT to calculate grams of CO_2e for each link, which were summed for all links in each scenario.

For cost-affordable Scenarios C and D the same method described above was used, except 2035 emission rates were used.

GHG Emissions from Transit Vehicles

Current average transit GHG emission rates for the Hillsborough area were calculated using 2006 data from the National Transit Database for Hillsborough Area Regional Transit. These data were used to obtain gallons of diesel and compressed natural gas usage for buses and kilowatt hours of electricity usage for the streetcar (light rail). Fuel usage was multiplied by industry standard GHG emission rates (grams per gallon) for diesel and compressed natural gas to obtain total bus GHG emissions. Electricity usage was multiplied by the GHG emission rate for electricity (grams per kilowatt hour) in the Florida region from the EPA's eGrid database. Total emissions were divided by vehicle revenue miles for each mode using data from the National Transit Database. This provided the GHG emission rate in grams per vehicle mile.

The 2035 GHG emission rates were estimated by adjusting the 2006 rates downward using percent per year reduction estimates due to projected vehicle technology improvements and reductions in the GHG intensity of electricity generation. These percent per year reductions were based on a recent national study of GHG emissions reduction strategies and assume aggressive improvements in vehicle efficiency, as well as reductions in the carbon intensity of the electricity generation grid (Cambridge Systematics 2009). The assumed annual carbon intensity improvements were 0.54% per year for buses and 1.25% per year for light rail.

VMT estimates based on spreadsheet calculations using route miles and headways for transit vehicles were obtained from the TBRPM for Hillsborough County. They were divided into VMT by scenario and mode. Emission rates for each mode and scenario were multiplied by the VMT for that mode and scenario to obtain total GHG emissions. Emissions were summed across modes in each scenario to obtain total scenario GHG emissions from transit. For cost-affordable Scenarios C and D the same method described above was used, except only 2035 emission rates were used. These two scenarios have the same VMT estimates by mode since only socioeconomic data were changed to model transit-oriented development.

Results

Table 5.13 shows combined GHG emissions from roadway and transit vehicles under the various scenarios. The first four scenarios are comparable to each other and the last two scenarios are comparable to each other, but scenarios from the two sets should not be compared due to changes in the travel demand model.

For the first four scenarios, emissions under all 2035 scenarios increase compared with 2006 due to higher levels of VMT (75% to 85% above 2006 levels) and increased congestion (reflected in lower average travel speeds, as shown in Table 5.14). These increases in VMT and congestion more than outpace projected fuel economy improvements over this time period by 13% to 19%. The existing plus committed scenario shows the largest increase in emissions (56%) due to its high VMT and high emissions rate (due to low speed), and cost-affordable Scenarios A and B show increases of 44% and 42%, respectively. Cost-affordable Scenario B (with sales tax) results in the lowest 2035 GHG emissions of the three scenarios. Although transit emissions are higher due to the expanded transit investment (Table 5.14), the difference is smaller than the lower roadway emissions, which is due to

Table 5.13. Total Daily GHG Emissions from Roadway and Transit Vehicles, Hillsborough County

Item	Year	Scenario	GHG Emissions (metric tons CO_2e)			Change versus Item 1 (%)	Change versus Item 2 (%)
			Roadways	Transit	Total		
Scenarios A and B							
1	2006	2006 Base	16,501	96	16,597	—	
2	2035	2013 E+C	25,790	82	25,872	56%	—
3	2035	Cost-affordable A	23,743	104	23,847	44%	–8%
4	2035	Cost-affordable B	23,326	299	23,626	42%	–9%
Scenarios C and D							
1	2035	Cost-affordable C	20,199	316	20,515		
2	2035	Cost-affordable D	20,129	316	20,444	–0.35%	

reduced VMT and congestion when compared with the cost-affordable Scenario A (no sales tax) scenario.

For the last two scenarios (C and D) that analyze the effects of transit-oriented development, GHG emissions decreased slightly when including transit-oriented development (0.35% reduction for Scenario D versus Scenario C). This is due to slightly less VMT (about 50 million VMT per year) and slightly lower levels of congestion (indicated by a slightly higher average travel speed), as shown in Table 5.14. The emissions of GHGs from transit are the same for both scenarios because the model run assumed no changes to the transit network. Details on emission factors, vehicle miles, and GHGs are provided in Table 5.15 for both the bus and light rail mode.

Conclusion

This analysis showed that the travel demand model results, in combination with GHG emission rates from MOVES and the National Transit Database, can show the relative differences in GHG emissions among transportation plan scenarios that reflect varying levels of investment in roadway and transit networks. These tools are appropriate to use for this analysis because the change in investment results in changes in travel demand patterns (e.g., mode shares and trip lengths) and in travel speeds and/or congestion on the roadway network to which the travel demand model is sensitive.

It is interesting to note the small changes in GHG emissions between the transit-oriented development scenario and

Table 5.14. Roadway Daily Travel and GHG Emissions, Hillsborough County

Item	Year	Scenario	Total Daily VMT (millions)	Average Speed (mph)	Average CO_2e Emission Rate (g/mi)	Equivalent Fuel Efficiency (mi/gal)[a]	GHG Emissions		
							Total (metric tons CO_2e)	Change versus Item 1 (%)	Change versus Item 2 (%)
Scenarios A and B									
1	2006	2006 Base	34.0	32.4	485	19.4	16,501	—	
2	2035	2013 E+C	61.7	23.2	418	22.6	25,790	56%	—
3	2035	Cost-affordable A	60.0	25.0	395	23.9	23,743	44%	–8%
4	2035	Cost-affordable B	59.6	25.4	391	24.1	23,326	41%	–10%
Scenarios C and D									
1	2035	Cost-affordable C	60.3	28.4	335.1	28.1	20,199		
2	2035	Cost-affordable D	60.1	28.5	334.7	28.2	20,129	–0.35%	

[a] The much lower fuel efficiency shown here compared with the 35 mpg light-duty standard cited above is a result of (1) the inclusion of heavy-duty vehicles in the mix and (2) the fact that on-road fuel efficiency tends to be lower in practice than standards. The higher speeds and fuel efficiency for cost-affordable Scenarios C and D compared with A and B are due to changes to the model runs for C and D, which were completed several months after A and B. For example, the truck-trip model was adjusted, and Scenarios C and D show much lower truck percentages (5.5% versus 12% to 13%). Due to these differences Scenarios C and D should not be compared with the other scenarios.

Table 5.15. Transit Vehicle Daily Travel and GHG Emissions, Hillsborough County

		Motor Bus (local and express)			Light Rail (includes streetcar)			All Transit
Year	Scenario	Emission Factor (g CO_2e/mi)	VMT	GHG (metric tons CO_2e)	Emission Factor (g CO_2e/mi)	VMT	GHG (metric tons CO_2e)	Total GHG (metric tons CO_2e)
2006	2006 Base	3,000	31,200	93.7	4,440	559	2.5	96.2
2035	2013 E+C	2,530	31,700	80.1	2,830	559	1.6	81.7
2035	Cost-affordable A	2,530	40,300	102.0	2,830	592	1.7	103.7
2035	Cost-affordable B	2,530	106,300	268.9	2,830	10,800	30.5	299.4
2035	Cost-affordable C	2,530	110,700	279.9	2,830	12,600	35.6	315.6
2035	Cost-affordable D	2,530	110,700	279.9	2,830	12,600	35.6	315.6

its comparison scenario, and contrast this modest difference with the much larger impact of development patterns shown in the Atlanta region case study. This is partly the result of the much smaller level of land use change assumed in the Tampa Bay transit-oriented development scenario compared with the Atlanta Regional Commission future land use scenarios. The travel demand model is also limited in its ability to assess the impacts of transit-oriented development. For example, the model (like most models in use by MPOs today) is sensitive only to the location of jobs and housing, and not to microscale land use changes, such as pedestrian improvements and mixed-use development, that may result in more trips being taken by transit or walking rather than driving.

New York State Department of Environmental Conservation

Goal: Assessing GHG emissions in an environmental impact statement
Level of analysis: Regional and project
Methods and/or models used: Various recommended
Emissions analyzed: CO_2, N_2O, CH_4, hydrofluoro-carbons, perfluorocarbons, sulfur hexafluoride (SF_6)

Summary

The New York State Department of Environmental Conservation (NYDEC) has drafted a guide for assessing energy use and GHG emissions in an environmental impact statement (EIS). Although this policy addresses transportation emissions (particularly project-generated VMT), it also provides guidance on how GHG emissions and energy consumption in other sectors can be measured and incorporated into decision systems. This guide, which must be used by NYDEC staff when they review each project, identifies the methods and boundaries for the assessment of energy use, GHG emissions, and mitigation measures for an EIS. The guide is applicable to large-scale projects, such as electricity-generating facilities, solid waste facilities, very large-scale resorts, and residential, industrial, or commercial development projects that generate thousands of vehicle trips or use significant amounts of electricity. All project or activity proponents must provide total projected GHG emissions.

Background

Part of New York State's Climate Action Plan requires state agencies to

- Inventory GHG emissions within the state, including the relative contribution of each type of emission source;
- Identify and assess short-term and long-term actions to reduce GHG emissions and adapt to climate change across all economic sectors, including industry, transportation, agriculture, building construction, and energy production;
- Identify and analyze the anticipated reductions of each action and the economic implications of such reductions; and
- Identify the anticipated life-cycle implications, consequences, benefits, and costs of implementing each action and option to the state government, local governments, business, and residents.

In response to the requirements of the Climate Action Plan, in July 2009 NYDEC issued a *Guide for Assessing Energy Use and Greenhouse Gas Emissions in an Environmental Impact Statement.* This guide identifies the methods and boundaries of analysis when energy consumption or GHG emissions are identified as a significant issue or have been included in the scoping process. The policy underlying the NYDEC guide did not establish a threshold for when such issues were to be considered significant nor when they should be included in a scoping process.

The NYDEC guide notes that the consideration of GHG emissions recognizes the limitations of models to quantify exact estimates of what is likely to occur: "as long as the relative levels of energy use and GHG emissions are compared with respect to project alternatives, and the outcome of the comparison is used in the decision-making process, an important goal will have been achieved even if the quantification of total annual GHG emissions is not precise" (NY Department of Environmental Conservation 2009). The intent of such an approach, similar to Transportation for Communities: Advancing Projects Through Partnerships (TCAPP), is to consider energy consumption and GHG emissions as early in project development as possible.

Methodology

Some key aspects of the recommended practice include the following:

- Total annual GHG emissions should be presented as short tons of CO_2, and other types of GHGs should be presented as both short tons and equivalent short tons of CO_2, using the most up-to-date Intergovernmental Panel on Climate Change global warming potential factors;
- When GHG emissions are analyzed in an EIS, both direct and indirect GHG emissions from both stationary and mobile sources should be assessed;
- Direct GHG mobile emissions will include emissions from fleet vehicles owned (or leased) and operated by the project proponent and emissions associated with the project. Fleet vehicles include freight trucks; delivery trucks; on-site mobile equipment such as forklifts, tractors, maintenance, and security vehicles; and other nonstationary equipment used on-site whose operation involves combustion of carbon containing fuels;
- Indirect mobile source GHG emissions will include emissions generated from vehicle trips to or from the project site during its operation from vehicles that are not owned or operated by the project proponent (e.g., freight deliveries, employee commuting, customer visits). Another source of indirect emissions is the generation, transportation, treatment, and disposal of wastes generated at the site. If NYDEC staff have determined that the project proponent has demonstrated efforts to minimize emissions to the maximum extent possible, the EIS may include a qualitative discussion of the emissions from such sources;
- Indirect GHG mobile emissions come from employee commute trips, residents, suppliers and vendors, and customers and users of the project, as well as the transportation of waste generated at the site. The most recent edition of the Institute of Transportation Engineers' *Trip Generation Handbook* should be used to estimate the number of trips generated by the proposed project;
- The first step to quantify indirect mobile emissions is to estimate net new trips generated by the proposed project. Such trips should be estimated separately for different trip purposes and categories (e.g., commuting employees, residents, suppliers and vendors, customers and users, and waste transportation). New net trips should then be expressed as the annual VMT for each category, using reasonable assumptions about distances traveled based on existing community patterns. Converting annual VMT to CO_2 emissions involves using appropriate CO_2 emissions factors such as those found in EPA MOBILE6.2 (which is expressed as grams per mile) and converting it to tons per year by dividing by 907,185 g/ton. This model does not take vehicle speeds into account at this time, although speed does influence total GHG emissions from VMT. Future EPA models that account for speed may be used; and
- If GHG emissions resulting from the construction phase cannot be quantified, a qualitative discussion that includes the manufacture or transport of the construction materials should be included in an EIS. This qualitative review can compare emissions attributed to design and construction choices and activities without quantifying the emissions.

The NYDEC guide explains that the state's environmental regulation also requires the consideration of alternatives in an EIS. If GHG emissions are considered to be significant, the EIS should examine the ability of each alternative to reduce GHG emissions generated by the project, including a description and evaluation of the range of reasonable alternatives with respect to sites, technology, scale, design, or use. An explanation should be provided of which design alternatives were rejected, and the reasons for the rejection.

The EIS is also to include a review and assessment of mitigation measures applicable to the proposed action, including calculations of the projected reduction in GHG emissions that would result from each mitigation measure. When practicable, the EIS should include a quantification of reductions in GHG emissions that would result from mitigation measures that were considered and rejected (i.e., not incorporated into the proposed action.) If models do not allow reasonable quantitative analyses, the EIS should still provide qualitative comparisons of GHG emissions of various measures.

For transportation emissions, transportation demand management measures should be identified and assessed using models available for estimating the potential emissions reductions for such measures, such as the EPA COMMUTER model and the Work Trip Reduction Model. Transportation mitigation measures that might be considered include

- Locating new buildings in or near areas designated for transit-oriented development;
- Incorporating transit-oriented development principles in employee and customer activity patterns;
- Purchasing alternative fuel and/or fuel-efficient fleet vehicles, including the maintenance and operation vehicles used on-site;
- Incorporating idling reduction policies;

- Joining or forming a transportation management association;
- Providing new transit service or supporting extension and/or expansion of existing transit (buses, trains, shuttles, water transportation);
- Supporting expansion of parking at park-and-ride lots and/or transit stations;
- Developing or supporting multiuse paths to and through sites;
- Sizing parking capacity to meet, but not exceed, local parking requirements and, when possible, seeking reductions in parking supply through special permits or waivers;
- Pursuing opportunities to minimize parking supply through shared or banked parking;
- Developing a parking management program to minimize parking requirements, such as parking cash-out, parking charges, preferential carpool or vanpool parking, and limiting parking available to employees;
- Developing and implementing a marketing and information program that includes posting and distribution of ridesharing transit information;
- Subsidizing transit passes;
- Providing for the use of pretax dollars for nonsingle-occupancy vehicle commuting costs;
- Reducing employee trips during peak periods through alternative work schedules, telecommuting, and/or flextime;
- Providing a guaranteed ride home program;
- Providing on-site amenities such as banks, dry cleaning, food service, and childcare;
- Providing bicycle storage and showers and/or changing rooms;
- Conducting roadway improvements to improve traffic flow; and
- Optimizing traffic signalization and coordination to improve traffic flow and improve pedestrian and bicycle safety.

Conclusion

The New York State guidance on considering GHG emissions in an EIS presents a reasoned approach to conducting GHG analyses. It recognizes that the level of sophistication of GHG emissions modeling is not always at a level that allows credible quantification of GHG estimates. It also recognizes the need to incorporate emissions associated with construction activities into the analysis, even if these emissions are considered qualitatively.

Columbia River Crossing

Goal: Assessing GHG emissions in a draft environmental impact statement
Level of analysis: Project
Methods and/or models used: Various recommended
Emissions analyzed: CO_2, N_2O, CH_4, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride (SF_6)

Summary

The Columbia River Crossing project is a complex transportation project to improve safety and mobility for 5 miles of I-5 between Portland, Oregon, and Vancouver, Washington. The existing bridge is expected to be replaced, light rail extended from Portland to Vancouver, seven interchanges improved, and existing pedestrian and bicycle paths widened.

This project was one of the first such projects in the United States to undergo a GHG emissions analysis as part of the alternatives assessment. The analysis included the long-term effects on GHG emissions of the different alternatives; the temporary effects, such as those due to construction activities; and the effects of highway and transit GHG emissions.

Background

State transportation agencies and local governments in the Vancouver and Portland region joined together to develop a comprehensive strategy for addressing highway, freight, transit, bicycle, and pedestrian needs within the study area. This corridor had been extensively studied in prior years for highway improvements, as well as enhancements to transit and pedestrian and bicycle services. The project statement noted that a potential project in this corridor was to address six problems:

- Growing travel demand and road congestion;
- Impaired freight movement;
- Limited public transportation operation, connectivity, and reliability;
- Safety and vulnerability to incidents;
- Substandard bicycle and pedestrian facilities; and
- Seismic vulnerability.

Four build alternatives were assessed in the draft EIS, in addition to a no-build alternative. Each alternative consisted of several components that, when combined, created a multimodal alternative. These components included

- Multimodal river crossing and highway improvements, such as bridges over the Columbia River carrying transit, highway, and bicycle and pedestrian traffic; bicycle and pedestrian improvements between north Portland and downtown Vancouver; and highway and interchange improvements;

- High-capacity transit modes;
- Transit terminus and alignment options, including end-point and alignment options;
- Transit operations (frequency of train or bus rapid transit service);
- Bridge tolls; and
- Transportation system and demand management measures.

Both Oregon and Washington State have laws and environmental regulations that require an assessment of energy and GHG emissions for projects of this significance.

Methodology

The overall analysis addresses four primary issues:

- Energy consumed during construction of the I-5 Columbia River Crossing;
- Energy consumed during operation of the I-5 Columbia River Crossing;
- Potential measures to reduce or offset operational and construction effects on energy; and
- CO_2 equivalent (CO_2e) emissions resulting from use of electricity, gasoline, and diesel.

Energy Analysis

The methodologies used in the energy analysis were intended to reflect the relative levels of energy use that would be required in the future with and without the project. The estimated GHG emissions were based on emission factors from EPA that identified the amount of CO_2 and other GHGs produced from combusting gasoline or diesel in a motor vehicle. For petroleum-based fuels, the amount of fuel consumed by the project was multiplied by the applicable emission factor to estimate CO_2 emissions, then multiplied by another conversion factor to account for the global warming potential of other GHGs emitted by vehicles. The amount of GHG emissions was estimated for the purpose of comparing alternatives and system-level choices. Interestingly, the analysis included long-term effects, such as land use and travel behavior changes that are included in the regional travel demand model, and short-term effects related to construction activities.

Personal Vehicles

The Oregon DOT (ODOT) has adopted a methodology for estimating operational energy usage by personal automobiles that accounts for factors such as the daily volume of vehicles, length of roadway segment, types of vehicles, average vehicle speed, fuel consumption rates, and the type of fuels used (Oregon DOT 2006). The following equation represents the relationships between these factors and the general formula for calculating vehicle fuel energy use:

$$E = V \times L \times \text{FCR} \times \text{CF}$$

where

E = energy consumed (Btu),
V = daily volume of traffic,
L = length of the roadway (0.9 mi),
FCR = fuel consumption rate based on vehicle type and speed (gal/mi), and
CF = fuel conversion factor (Btu/gal gasoline or diesel).

Note the 0.9-mile length of roadway. The energy analysis was based on the change in travel demand over 0.9-mile segments, as opposed to total VMT, for the following reasons:

- Travel demand forecasts are relative, and emphasis should be put on changes in travel demand as opposed to absolute nominal values;
- The most pronounced change in travel demand, which identifies differences in project alternatives, was the difference across the I-5 and I-205 bridge crossings;
- The differences in total VMT for each alternative were miniscule, and therefore did not adequately illustrate the effects of each project alternative; and
- Estimating energy consumption as a function of VMT does not appropriately account for the operational benefits (i.e., increased speeds) of the project alternatives, which affect the amount of energy consumed.

Using this approach, the estimates associated with personal automobile use are not intended to be representative of the total amount of energy used or CO_2 emitted by the project. Rather, these estimates should be considered in concert with each other; the value of these estimates lies in their relative differences.

The data needs for these estimates included the composition of the types of vehicles in the traffic stream, fuel economies for each type of vehicle over a range of speeds, temporal changes, and emission factors for each type of fuel used.

Average daily traffic volumes were obtained from the region's traffic database and the regional travel demand model. Vehicle classification data were used to determine the traffic stream composition by vehicle type (automobiles, medium-duty trucks, heavy-duty trucks, and buses). The relative proportions of these vehicle types in the corridor flow were analyzed because of the difference in fuel consumption rates and fuel type used. Fuel consumption rates over a range of speeds for each vehicle class were based on data obtained by using revised fuel correction factors from the California Department of Transportation (Caltrans), as predicted by ODOT's Motor Fuel Consumption Model (Oregon DOT 1997) and from the 2007 *Monthly Energy Review* (Energy Information Administration 2007a). The ODOT data provided both historic fuel consumption rates and forecasts. A linear growth rate was estimated from these data and used to extrapolate fuel consumption rates to 2030.

All personal automobiles, light-duty trucks, and motorcycles were assumed to use gasoline, and heavy-duty trucks were assumed to use diesel. The fuel conversion factors vary depending on the fuel type: 123,976 Btu/gal for gasoline and 138,691 Btu/gal for diesel (National Biodiesel Board 2007).

Bus Transit

The amount of energy consumed by bus transit operations was also based on the ODOT methodology for personal automobiles, but a different variation for the volume input was used. VMT for each bus transit line was estimated based on assumed future service plans. Bus VMT was used to estimate energy consumption, as opposed to change in travel demand across the I-5 and I-205 bridges, for the following reasons:

- Both transit systems serving the corridor are well-defined, and therefore future projections can be appropriately evaluated on the absolute nominal values in addition to the relative differences;
- Differences in bus VMT between alternatives were more pronounced than the differences in VMT for personal passenger vehicles; and
- The effects of operating speed on I-5 and I-205 on bus fuel efficiency were expected to be small since the majority of operating time would be either on local streets or within exclusive rights-of-way.

This approach provided complete estimates of energy use and CO_2 emissions associated with project alternatives. Existing bus fuel consumption rates were provided by the transit agencies. Historic bus fuel consumption rates, which were used to develop a linear growth rate and extrapolate 2030 bus fuel efficiency, were also provided by the agencies. Interestingly, fuel consumption rates varied slightly by transit agency and by route type (local, express, or bus rapid transit).

Light Rail Transit

Energy consumed in the operation of the existing light rail line was determined using the same equation used for automobiles, but with slightly different units. In this case, *V* was the daily volume of light rail cars; *L* was the length of the rail segment (miles); FCR was the fuel consumption rate based on average operating speed (kW-h/mile); and CF was a conversion factor (Btu/kW-h). The fuel consumption rate for this analysis was based on Portland's MAX light rail system, which averages approximately 6 kW-h/car mile (or 12 kW-h/train mile for two-car trains). The fuel conversion factor for electricity was 3,412 Btu/kW-h (U.S. Department of Energy 2005). Similar to the bus transit methodology, this methodology for light rail provides a complete estimate of energy use and CO_2 emissions associated with the project because the rail transit system is well-defined.

GHG Emissions Analysis

The GHG emissions analysis considered both short-term, construction-related effects and long-term effects from the operations of the highway and the transit system. The equation was

$$EM = FC \times EF \times CDE$$

where

EM = emissions of CO_2 (in lbs CO_2e),
FC = fuel (energy) consumed during construction or operations (gal or kW-h),
EF = emissions conversion factor by fuel type (19.4 lb CO_2/gal gas; 22.2 lb CO_2/gal diesel; 2.095 lb CO_2/kW-h coal; 1.321 lb CO_2/kW-h natural gas), and
CDE = CO_2e (in a 100:95 ratio to represent the approximate proportions of CO_2 and other GHGs emitted during fuel combustion).

The emission factor for biodiesel can vary slightly depending on the blend, but was assumed to be equal to diesel (i.e., 22.2 lb CO_2/gal biodiesel), which is consistent with EPA conclusions that biodiesel emits the same amount of CO_2 as diesel.

Light rail transit would use electricity supplied by electrical substations. Based on the assumed geographical locations of the substations, 40% of the electricity was assumed to be provided by one utility and 60% from another. Of the 40% portion, 42% was assumed to be generated from coal and 13.9% was assumed from natural gas; this split was consistent with that utility's breakdown of primary energy sources used to generate electricity. The remaining 44.1% of the energy comes from other sources (e.g., hydropower, nuclear, biomass) that do not emit CO_2 when used to generate electricity.

Of the 60% of electricity assumed to be provided by the other utility, 28% was assumed to come from natural gas combustion and 7% from coal firing. The remaining 65% of the electricity is generated from renewable, non-CO_2 emitting sources (e.g., hydropower, nuclear, biomass).

The generation of electricity from natural gas and coal emits CO_2. According to the U.S. Department of Energy, approximately 2.095 lb CO_2 are emitted to produce 1 kW-h of electricity from coal, and 1.321 lb CO_2 are emitted to produce 1 kW-h of electricity from natural gas. These emission factors were used to estimate the amount of CO_2 emissions associated with the electricity needed to operate light rail transit.

In order to fairly reflect the operational energy requirements for all modes (e.g., bus, rail, personal automobiles, trucks), it was necessary to include the amount of energy required to generate electricity, even though the end use of electricity does not emit CO_2. In this approach, CO_2 emission estimates associated with light rail transit account for both the generation of electricity and the end use. Conversely, CO_2 emission estimates for personal and bus transit vehicles are limited to end-use emissions and do not account for the amount of CO_2 emitted during the extraction of crude oil and refinement processes.

Construction Impacts

The project's temporary effects on energy supply and GHG emissions are solely associated with the construction of the project. The approach for determining energy use during construction was based on an input–output method developed by Caltrans (Caltrans 1983). This method estimates energy requirements using energy factors that were developed for a variety of construction activities (e.g., construction of structures, electrical substations, and site work). These energy factors relate project costs to the amount of energy required to manufacture, process, and place construction materials and structures. The general equation for estimating energy consumed during construction can be represented as

$$E = C \times \text{EF} \times \text{DC}$$

where

E = energy consumed (Btu),
C = cost of a particular construction activity (2007$),
EF = energy factor (Btu/1973$), and
DC = dollar conversion (1973$/2007$).

The dollar conversion is necessary because the project's cost estimates are in 2007 dollars, but the Caltrans energy factors were based on construction cost estimates in 1973 dollars. Although the construction cost estimates and dollar conversion factor will change depending on the year of construction, the estimated amount of energy consumed will not.

Of the total energy used for construction, 70% was assumed to come from diesel and 30% from gasoline. Electricity would likely be needed for some construction purposes (e.g., lighting), but would likely be derived from gas and/or diesel generators. This breakdown of energy sources was used to estimate the gallons of diesel and gasoline needed to construct the project, and was then used to estimate CO_2e emissions. The estimated amount of energy consumed by the construction of the project was based on preliminary construction cost estimates.

Results

The alternatives assessment represented specific combinations of system- and segment-level choices. Table 5.16 shows how each alternative affected energy consumption and GHG emissions. In addition to the long-term energy and GHG emissions effects associated with each alternative, the analysis included the temporary effects of construction activities. Table 5.17 shows the results of this analysis.

The project team also conducted sensitivity analyses on key project elements that might affect the analysis results. In addition to these choices and options, other project elements were identified that could potentially affect short-term energy use and CO_2e emissions. These elements included such things as the choice of the minimum operable segment for high-capacity transit, choice of mode for high-capacity transit, the location of a transit maintenance base, and use of tolls. Tables 5.18, 5.19, and 5.20 show the results of analyses examining the impact on energy and GHG emissions from high-capacity

Table 5.16. Alternatives Assessment of Daily Energy Use and CO_2e Emissions, Columbia River Crossing

Alternative	Energy (mBtu)	Electricity (kW-h)	Gasoline (gal)	Biodiesel/Diesel (gal)	CO_2e Emissions (ton)
Existing	4,014	77,355	8,343	19,585	342
Alternative 1 no build	5,384	152,628	10,661	25,536	463
Alternative 2 replacement, BRT	5,248	152,628	9,598	25,520	452
Alternative 3 replacement, LRT	5,242	162,063	9,598	25,231	452
Alternative 4 supplemental bridge, BRT	5,729	160,645	9,622	28,790	493
Alternative 5 supplemental bridge, LRT	5,687	172,053	9,622	28,172	490

Note: BRT = bus rapid transit; LRT = light rail transit.

Table 5.17. Temporary Effects on Energy Use and CO_2e Emissions Relating to Construction of Columbia River Crossing Project

	Alternative 2		Alternative 3		Alternative 4		Alternative 5	
Alternative Construction Element	**Energy (mBtu)**	**CO_2e Emissions (ton)**	**Energy (mBtu)**	**CO_2e Emissions (ton)**	**Energy (mBtu)**	**CO_2e Emissions (ton)**	**Energy (mBtu)**	**CO_2e Emissions (ton)**
Project cost ($2007)	$2,641,666,596		$2,781,200,598		$2,446,698,968		$2,564,108,066	
South highway approach	1,785,754	149,432	1,785,754	149,227	1,894,597	158,540	1,894,597	158,540
North highway approach	1,386,874	116,054	1,386,874	115,894	1,024,308	85,714	1,022,312	85,547
Columbia River Bridge	2,698,291	225,793	2,698,290	225,484	2,349,097	196,573	2,349,097	196,573
Transit	1,125,337	94,168	1,348,181	112,661	635,550	53,183	818,727	68,511
Subtotal	6,996,256	585,447	7,219,100	603,267	5,903,553	494,010	6,084,734	509,171
16th Street Tunnel cost	$14,662,600		$15,450,400		$0		$0	
16th Street Tunnel	59,611	4,731	62,449	4,956	0	0	0	0
McLoughlin Tunnel cost	$383,000		$787,000		$0		$0	
McLoughlin Tunnel	1,116	88	2,571	204	0	0	0	0
Total (with 16th Street Tunnel)	7,055,867	590,178	7,281,549	608,224	5,903,553	494,010	6,084,734	509,171
Total (with McLoughlin Tunnel)	6,007,372	585,536	7,221,671	603,472	5,903,553	494,010	6,084,734	509,171

Table 5.18. Long-Term Effects of High-Capacity Transit Alignment on Daily Energy Use and CO_2e Emissions

	Vancouver Alignment				I-5 Alignment			
Vehicle Type/Roadway	**Energy (mBtu)**	**Electricity (kWh)**	**Biodiesel/ Diesel (gal)**	**CO_2e Emissions (ton)**	**Energy (mBtu)**	**Electricity (kWh)**	**Biodiesel/ Diesel (gal)**	**CO_2e Emissions (ton)**
Conventional bus	3,218	0	23,201	271	3,243	0	23,383	273
BRT bus	0	0	0	0	0	0	0	0
Light rail	553	162,063	0	60	555	162,713	0	60
Transit total	3,771	162,063	23,201	331	3,798	162,713	23,383	333

Table 5.19. Long-Term Effects of High-Capacity Transit Mode on Daily Energy Use and CO_2e Emissions

	Bus Rapid Transit				Light Rail Transit			
Vehicle Type/Roadway	**Energy (mBtu)**	**Electricity (kWh)**	**Biodiesel/ Diesel (gal)**	**CO_2e Emissions (ton)**	**Energy (mBtu)**	**Electricity (kWh)**	**Biodiesel/ Diesel (gal)**	**CO_2e Emissions (ton)**
Conventional bus	3,232	0	23,301	272	3,218	0	23,201	271
BRT bus	24	0	189	2	0	0	0	0
Light rail	521	152,628	0	56	553	152,063	0	60
Transit total	3,777	152,628	23,490	330	3,771	152,063	23,201	331

Table 5.20. Long-Term Effects of Tolling on Daily Energy Use and CO_2e Emissions

	No Toll on I-5				Standard Toll on I-5				Standard Toll on I-205			
	Energy (mBtu)	Gas (gal)	Biodiesel/ Diesel (gal)	CO_2e (ton)	Energy (mBtu)	Gas (gal)	Biodiesel/ Diesel (gal)	CO_2e (ton)	Energy (mBtu)	Gas (gal)	Biodiesel/ Diesel (gal)	CO_2e (ton)
I-5												
Auto	616	4,970	0	51	522	4,213	0	43	575	4,639	0	47
Medium truck	8	69	0	1	7	58	0	1	8	64	0	1
Heavy truck	203	0	1,462	17	172	0	1,239	14	189	0	1,365	16
Motorcycle	1	11	0	0	1	10	0	0	1	11	0	0
I-5 Subtotal	828	5,050	1,462	69	702	4,281	1,239	58	773	4,714	1,365	64
I-205												
Auto	632	5,099	0	52	651	5,251	0	54	520	4,191	0	43
Medium truck	7	53	0	0	7	54	0	1	5	43	0	0
Heavy truck	105	0	755	9	110	0	792	9	88	0	632	7
Motorcycle	1	11	0	0	1	12	0	0	1	9	0	0
I-205 Subtotal	745	5,163	755	61	769	5,317	792	64	6,114	4,243	632	50
Transit												
Bus	3,232	0	23,301	272	3,232	0	23,301	272	3,232	0	23,301	272
BRT	24	0	189	2	24	0	189	2	24	0	189	2
Light rail	521	0	0	56	521	0	0	56	521	0	0	56
Transit Subtotal	3,777	0	23,490	331	3,777	0	23,490	330	3,777	0	23,490	331
Total	5,350	10,213	25,707	461	5,248	9,598	25,521	452	5,164	8,957	25,487	445

transit alignment, the choice of high-capacity transit mode, and use of tolls, respectively.

The draft EIS also suggested mitigation measures that might be considered as part of the project development process:

- Implementing programs to further encourage use of public transit;
- Promoting compact and transit-oriented development to encourage walking;
- Providing safe and well-lighted sidewalks to encourage walking;
- Providing safe and more accessible connections to paths for bicyclists and pedestrians;
- Offering rideshare and commute choice programs;
- Constructing with materials and building systems that meet efficiency standards for equipment and lighting design;
- Recycling building materials, such as concrete, from the project;
- Using sustainable energy to provide electricity for lighting and other operational demands;
- Planting vegetation to absorb or offset carbon emissions;
- Promoting fuel efficiency improvements, such as a low-carbon fuel standard;
- Promoting diesel engine emissions reductions; and
- Considering clean energy certificates or other carbon offsets for energy used.

Additional construction-related mitigation measures were suggested that encouraged conservation of construction materials and best management practices:

- Reusing and recycling construction materials;
- Encouraging workers to carpool;
- Turning off equipment when not in use to reduce energy consumed during idling;
- Maintaining equipment in good working order to maximize fuel efficiency;
- As practical, routing truck traffic through areas where the number of stops and delay would be minimized and using off-peak travel times to maximize fuel efficiency;
- As practical, scheduling construction activities during daytime hours or during summer months when daylight

hours are the longest to minimize the need for artificial light;

- As practical, implementing emission-control technologies for construction equipment; and
- As practical, using ultra-low-sulfur diesel (for air quality purposes) and biodiesel in construction equipment.

Conclusion

This project was one of the first and certainly one of the most complex multimodal projects to undergo an energy and GHG emissions analysis. The analysis showed state-of-the-art approaches for assessing transit energy consumption and GHG emissions, considered the energy and GHG emissions impacts of construction-related activities for different alternatives, and conducted sensitivity analyses on key system design factors that might have important impacts on overall GHG emissions. In addition, the analysis suggested mitigation measures that could be considered as part of the long-term facility design and operation, as well as for the construction period. This case probably represents the most complete GHG emissions analysis of a highway project in the United States at this time.

CHAPTER 6

Knowledge Gaps and Research Needs

This research lays out a technical framework that can be used to develop a baseline analysis, as well as an assessment of likely GHG emissions given the use of different mitigation strategies. As government agencies, communities, and the public itself become more concerned about the role that GHG emissions play in climate change, the need for credible and transparent analysis tools will become even more apparent. As found in this research, there are still many gaps in analysts' knowledge that limit their ability to measure and project future GHG emissions and estimate potential reductions from transportation strategies. In a 2010 workshop and conference on environmental research needs organized by the Transportation Research Board (Transportation Research Circular 2010), workshop participants ranked climate change and GHG analysis models and methodologies as second in a list of the 10 top-ranked research needs, and a larger set of conference participants ranked this issue as fifth.

Many of the key knowledge gaps identified by the research team during this project can be classified in three categories:

- Data and methodological limitations for the development of inventories and baseline forecasts;
- Limitations on basic knowledge regarding strategy effectiveness; and
- Limitations in tools and methods for analyzing strategy effectiveness.

Each of these areas is discussed in the following sections.

Data and Methodological Limitations for Development of Inventories and Baseline Forecasts

Data and credible methods are almost always two critical constraints of any problem-solving exercise. In the context of GHG emissions analysis, they can be the difference between a believable forecast of impact to one that is considered implausible. Insufficient data and inadequate methodologies can limit an understanding of the amount and sources of transportation GHG emissions currently emitted, as well as expected emissions in the future if current trends continue and no actions are taken to alter these trends. Key research topics are detailed below.

Mismatch between fuel-based and activity-based inventories. Fuel sales data provide the most accurate baseline emissions inventory, but they cannot easily be disaggregated by mode or substate region. They also are unsuitable for forecasting given that future emissions forecasts would have to rely on future fuel sales, something that presents its own forecasting challenge. However, inventories developed using travel activity and emissions factor data typically show discrepancies (usually a shortfall, and often significant) in estimated emissions compared with inventories based on fuel sales. These discrepancies illustrate that lab-measured fuel efficiency data and models are far from perfect.

Limited knowledge of how travel conditions and characteristics (e.g., VMT per capita) will change. Although some factors (such as economic growth or population growth at a regional level) are forecast with potentially high levels of uncertainty, analysts' ability to understand and model factors such as how changing demographics, communications technology, logistics trends, consumption habits, and urban form are likely to affect passenger and freight travel patterns in the future need improvement.

Differing assumptions about potential changes in future year motor vehicle fuel economy. This can be a large source of uncertainty in fuel use and GHG forecasts. Analysts often have substantial inconsistencies in how they incorporate the influence of future fuel economy standards. These differences in assumptions can result from not understanding the difference between fuel economy standards and in-use fuel economy; confusing new vehicle fuel economy standards with existing vehicle fuel economy; not understanding the new fuel economy standards from the perspective of how they align with model years; and not knowing what the fuel economy standards will be beyond the adopted time frame.

Limited data on travel activity by nonpassenger modes, especially trucks, freight rail, and marine. Freight travel is a significant part of a region's GHG emissions inventory and could become even more important in the future. Similar to the GHG emissions estimating process for passenger vehicles, emissions estimation for freight modes depends on the level of activity that each freight mode actually incurs. Obtaining this data has traditionally been challenging, although surrogate values such as cargo value can be used to reverse estimate the number of rail cars or fleet trucks actually on the move. Major improvements in estimating freight flow (e.g., the Freight Analysis Framework 2) are underway, and when completed they should improve the reliability of travel activity input into the GHG emissions analysis process.

Intercity travel activity. Although the Freight Analysis Framework allows planners to obtain some estimate (albeit at a high level) of intercity freight flows, nothing similar exists for intercity passenger transportation (although FHWA has research underway currently to produce a similar approach). Thus, analysts interested in developing GHG emissions inventories for intercity travel have to rely on airline, rail, and bus schedules for activity data and gross estimates for intercity automobile flows. In addition, estimating passenger origin–destination pairs can be a challenge; Amtrak, for example, knows how many passengers board and alight at each station, but does not know the actual origin–destination pair for each traveler. This becomes an important constraint when undertaking policy studies that examine the feasibility of alternative, GHG-reducing modes (such as high-speed rail). Improved data collection and models for intercity travel are an important research need.

Uncertainty over life-cycle emissions. This is a particular problem for biofuels, for which land use and other indirect impacts are highly uncertain. However, it is also true for other fuel types, especially since life-cycle emissions can vary by the specific production process, which is not typically accounted for in today's inventories.

Lack of knowledge regarding noninventoried GHGs. A number of other gases are known to have climate change effects, either through their direct warming potential or because they influence the formation or destruction of other GHGs. These gases include ozone, nonmethane volatile organic compounds, particulate matter, and aerosols. The contribution of the transportation sector to some of these gases is significant. However, there is no agreed-on method to estimate the global warming potential of gases that are short-lived, spatially variable, or have only indirect effects on radiative forcing.

Limitations on Basic Knowledge Regarding Strategy Effectiveness

One of the most important products of GHG analyses is producing a set of strategies that will reduce GHG emissions in a cost-effective way. Inherent to developing such methods or analysis tools is an understanding of the underlying relationships between human and firm behavior and the incentives or disincentives used to influence travel-related behavior. Transportation researchers have been studying these relationships for decades and have developed a strong foundation of understanding of what influences household and individual travel decisions. However, strategies for reducing GHG emissions could include fundamentally different responses to strategies than what has been seen before (e.g., a heavy reliance on pricing strategies might result in significantly different responses than simply focusing on a single facility toll).

The major gaps in fundamental understanding are listed below according to whether they relate to travel activity strategies, system efficiency improvements, vehicle and fuel technologies, or cross-cutting issues. The reader will recognize many of these gaps from other research in the transportation field. They are listed here as gaps and needed research simply because of the unique circumstances surrounding the implementation of GHG emission strategies. Clearly, many areas among travel behavior research and GHG emissions research will overlap.

Travel Activity Strategies

Synergies among pricing, land use, transit, transportation demand management (TDM), and nonmotorized improvements. These strategies are believed to be more effective when applied in combination, but little quantitative evidence exists to support this belief or to show how synergies vary for different combinations of these strategies in different contexts. This gap in knowledge is particularly important in that a state or regional GHG emissions reduction strategy will likely have to use multiple initiatives and actions to produce any noticeable impact on the level of GHG emissions. Most of the research and studies to date on combined strategies to reduce GHG emissions have made assumptions of how individual strategies might affect the GHG emissions reduction potential of other strategies. Research on this topic is an important first step in identifying feasible approaches to GHG emissions reduction programs.

Potential for vehicle travel reduction in smaller or low-density regions with limited congestion, limited transit, and/or slow growth. By far, and not surprisingly, most of the research on GHG emissions reduction strategies has focused on metropolitan areas or at the national and state levels. Even here, much of this research has relied on assumptions relating to likely effectiveness of different strategies. Very little attention has been given to nonurban areas. Aside from pricing, do any strategies to reduce travel activity (such as transit, TDM, nonmotorized travel, and land use change) have significant potential in such regions? Will this change in the future if energy prices increase substantially? If there is to be a national transportation-related strategy for reducing GHG emissions, and if some portion of this strategy focuses on reducing VMT, what role will medium- to small-sized MPOs have in planning and assessing the effectiveness of metropolitan GHG programs?

Effects of land use patterns and smart growth on freight and commercial vehicle travel, particularly urban and local freight distribution. The freight industry responds to changing market pressures and government requirements concerning environmental issues. And given that freight-related GHG emissions will continue to be an important part of a GHG emissions inventory, how will the dynamic nature of the freight industry affect the effectiveness of GHG emissions reduction strategies? Can reductions in local goods movement and commercial vehicle movement be obtained proportionate to similar reductions in passenger travel? To what extent will freight villages tend to reduce GHG emissions from freight flows?

Potential of new information systems and communications technologies (telematics) to change travel habits. One of the most important characteristics of future transportation systems will be the application of network and vehicle technologies to make the system more efficient and safer. Large-scale implementation of intelligent transportation systems (ITS) technologies has occurred in most major U.S. metropolitan areas. Research on such technologies has shown that they can reduce levels of congestion, make pathfinding much more efficient, and promote multimodal coordination. To what extent might technology-based strategies such as neighborhood vehicles, dynamic ridesharing, real-time multimodal wireless information, and demand-responsive (intelligent) transit assist in mode shifting or other carbon-intensive travel reduction in different contexts? How could such technologies be used to promote a GHG emissions reduction strategy for a metropolitan area?

Potential for eco-driving in the United States. European GHG-reduction strategies have included a strong emphasis on eco-driving. Although the evidence suggests that continual reinforcement to individual drivers of the eco-driving ethic could result in notable reductions in GHG vehicle emissions, it is not clear how such a strategy would work in the United States. Some research on eco-driving is taking place through the U.S. DOT ITS Joint Program Office's Applications for the Environment: Real-Time Information Synthesis program. This 5-year program, initiated in 2010, is examining how applications of vehicle–infrastructure integration can benefit the environment (ITS Joint Program Office 2012). This research will provide important insights on what will work in the U.S. context. Important questions include, what fraction of the population can realistically be reached with comprehensive eco-driving training? How might this fraction vary based on the cost of fuel, vehicle technology, and other factors?

System Efficiency Strategies

Short- and long-term induced demand effects of strategies that improve traffic flow. This issue is not limited to GHG emissions reduction efforts; it has been studied for a variety of reasons over the past several decades. However, in the context of GHG emissions strategies, additional questions need to be considered as part of such research. To what extent are the fuel efficiency benefits of congestion-relief improvements such as bottleneck removal, signal coordination, and incident management offset by long-term increases in travel in response to improved travel conditions? How does this trade-off vary for capacity versus operational strategies, for strategies affecting recurring versus nonrecurring congestion, and for passenger versus freight travel?

Effect of new and/or emerging vehicle technologies on the effectiveness of system efficiency improvements. The introduction of new technologies into the vehicle fleet will have a potentially significant impact on both travel behavior and vehicle emissions. In addition, as noted above, ITS technologies have been employed for many years as a strategy for improving system efficiency. One of the key issues with respect to vehicle technology relates to the ability of electric-drive vehicles to reduce the fuel efficiency losses of low-speed travel. To what extent will full or partial electric-drive vehicles (including hybrid electric, plug-in hybrid, battery-powered electric, and fuel cell) reduce or even eliminate the fuel efficiency and GHG benefits of congestion relief?

Potential for freight mode shifting to rail. Rail is approximately three times more energy efficient than truck transport on an energy per ton-mile basis. Yet much of these efficiencies are lost for short trips (which still require truck transport at either end), and it is widely assumed that movement by rail is most cost-effective only for longer-distance and/or lower-value goods movement. Yet, given the large contribution of the nation's truck fleet to GHG emissions, it would be worthwhile to examine different strategies for reducing GHG emissions from this component of the vehicle fleet. This raises several issues: how much cargo could be shifted to rail as a result of widespread investment in freight rail and intermodal facilities? What realistic reduction in GHG emissions would result? How does this potential depend on the price of fuel, roadway congestion, and other influencing factors?

Benefits of emerging ITS strategies, advanced traffic management, integrated corridor management, and vehicle–infrastructure *integration.* Concepts such as eco-adaptive cruise control, eco-routing, and green platooning, as well as system operations, may potentially transform travel. As these types of concepts take hold in the U.S. environment, transportation professionals need to have a better understanding of their effects on system management, and thus cumulatively what their effect is with respect to GHG emissions reduction.

Vehicle and Fuel Technology Strategies

Research on vehicle and fuel technologies occurs in a variety of settings, with orders of magnitude levels of investment over what is invested by transportation agencies in GHG reduction strategies. It is clear from numerous studies that changes in vehicle and fuel technologies will have by far the most significant impact on reducing GHG emissions from the transportation sector. However, from the perspective of GHG emissions analysis, one important issue stands out: *the effect of government interventions (e.g., pricing, infrastructure deployment) on technology advancement.* In addition to federal investments in research and deployment, many local and state governments are interested in how they can provide incentives to help accelerate the adoption of new vehicle technologies. What are the most important interventions that local governments can make? What critical mass of action across areas is needed to make local government incentives meaningful? There is no certain answer to these questions without understanding fundamentally what technologies will progress fastest and at what rate. However, through techniques such as system dynamics modeling, different scenarios can be examined to illustrate which interventions might be most likely to be effective, and what levels of subsidy (and for how long) might be needed under different energy price assumptions.

Cross-Cutting Issues

Ability to adopt new vehicle technologies in different land use and transit contexts. For example, densely populated urban environments may lend themselves more to electric vehicle and neighborhood vehicle technology, because trips are shorter and street space is constrained. However, the barriers to deployment of recharging infrastructure may be greater in environments where opportunities for in-home charging are limited. Are there significant variations in the most effective vehicle technology across urban contexts?

Mechanisms through which pricing leads to GHG reductions in different contexts. There is a substantial body of literature on the effects of changes in the cost of fuel on fuel use, as well as the cost of travel on the amount of travel. However, few studies decompose these effects into their components. For example, to what extent would a 5-cents per mile VMT fee lead to greater ridesharing versus transit use versus nonmotorized travel versus trip reduction? How would these effects vary in different geographic contexts? These questions have important implications both for understanding the GHG benefits of pricing strategies and for understanding what types of alternative transportation services might be most needed in different contexts.

Welfare and economic benefits and impacts of different strategies, especially related to mobility and accessibility. Many assessments of GHG reduction potential report vehicle operating cost savings as a benefit, but these represent only one component of consumer welfare and business economic impacts. Travel time savings can be measured with the right tools, but a comprehensive assessment of welfare changes must account for effects on mobility reflected in trips taken or not taken, as well as time and cost changes for existing travelers. Equity—the distribution of benefits and impacts across different population groups—is also important but poorly understood. Finally, as with GHG emissions benefits, better understanding is needed of how welfare and economic impacts vary across different combinations of strategies and in different contexts.

Limitations in Tools and Methods for Analyzing Strategy Effectiveness

These limitations have less to do with basic knowledge of strategy impacts than with the ability to incorporate this knowledge into tools that can be easily applied by practitioners, who often operate under severe time and resource constraints.

Enhancements to current travel demand models. Current travel demand modeling practice is well-suited for examining major highway and sometimes transit investments, broad land use and spatial patterns, and their interactions; it is not well-suited for small-scale interventions such as traffic flow improvements, TMD, or microscale land use and design. Some sketch techniques and models have been developed for strategies such as TDM, transit, and nonmotorized travel. However, there is wide variation in these strategies' effectiveness, depending on how and in what context they are deployed, which cannot easily be captured by sketch modeling.

State-of-practice models in many areas need enhancements for transit, land use, and nonmotorized travel. Enhancements (such as time-of-day models) are also needed to fully examine pricing strategies, including congestion pricing and managed lanes. In addition, few areas have models capable of capturing feedback between transportation and land use. Induced demand may only be partially accounted for even in regional models, and is not accounted for at all in most project- and corridor-level models.

Most cost-effective use of simulation models. Traffic simulation models are good tools for capturing the effects of capacity and operations improvements on traffic flow and emissions, especially if used in conjunction with modal emissions models such as MOVES. However, such applications are labor-intensive to develop and therefore feasible only for large projects. Furthermore, travel demand is an external input to these models, and therefore taken as a given.

Modeling of freight movements. Regional and statewide transportation models are limited in their ability to predict future freight flows and the impacts of freight emissions reduction strategies. Few areas have well-developed freight models at the level of detail that allows a credible analysis of GHG emissions reduction strategies. There is a need to provide analysts with better models, analysis tools, and methods that accurately assesses the contribution of different freight strategies to reduced GHG emissions.

Lack of intercity passenger models. Similar to the concept discussed above with respect to data, few intercity passenger models are available for use in GHG emissions analysis. When the intercity passenger equivalent of the Freight Analysis Framework is available, this observation may no longer be true, but as it stands today, intercity alternatives (e.g., high-speed rail) represent a choice that does not currently exist for many people, and therefore the possibility of their use as a future option is poorly understood.

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A Framework for Collaborative Decision Making on Additions to Highway Capacity (C01)

Partnership to Develop an Integrated, Advanced Travel Demand Model and a Fine-grained, Time-Sensitive Network (C10A)

Partnership to Develop an Integrated Advanced Travel Demand Model with Mode Choice Capability and Fine-Grained, Time-Sensitive Networks (C10B)