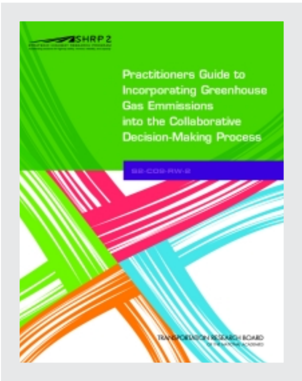

Practitioners Guide to Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process

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

Practitioners Guide to Incorporating Greenhouse Gas Emmissions into the Collaborative Decision-Making Process

S2-C09-RW-2

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

THE SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM

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SHRP 2 Report S2-C09-RW-2

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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.

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

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The research reported in this guide was performed by PB Americas, Inc., supported by Cambridge Systematics, Inc., E.H. Pechan & Associates, Inc., and EuQuant, Inc. Dr. Michael Meyer was the Principal Investigator. Other contributors 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.

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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 *Practitioners Guide* and the associated report 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. The report will be particularly useful for areas that are not using complex transportation planning and air quality models at the present time. The findings are also available on a 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 80% of U.S. greenhouse gas emissions. Carbon dioxide emissions are directly linked to the amount of fuel consumed and its carbon intensity. Therefore, carbon emission reductions can be achieved by increasing the use of low-carbon fuels, improving fuel economy, reducing vehicle miles of travel, or reducing congestion. The job of a transportation analyst is to determine the cost-effectiveness of various strategies at their disposal.

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.

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 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.

CONTENTS

1

INCORPORATING GHG EMISSIONS INTO COLLABORATIVE DECISION MAKING: A PRACTITIONERS GUIDE

INTRODUCTION

Most climate scientists agree that climate change has been occurring in scientifically measurable ways since the first stages of industrialization and that it will likely become even more pronounced in future years. In the past several years, an ever-increasing number of state and local officials have begun to examine how activities in their jurisdictions can contribute to greenhouse gas (GHG) emissions. Hundreds of U.S. cities have joined national consortia whose aim is to take action with respect to climate change. Many states have formed regional climate initiatives and have developed individual statewide climate action plans (often with little or no input from state transportation officials). Most of these state, regional, and local plans have identified specific GHG reduction targets for the transportation sector and specific strategies to achieve these targets.

Almost all these efforts identify the transportation sector as an important area in which GHG reductions can be achieved. National inventories suggest that the transportation sector contributes approximately 28% of the U.S. GHG emissions, with roadway vehicles constituting 82% of transportation GHG emissions. These are national percentages, with significantly higher transportation shares in states that rely heavily on hydropower and other low-carbon electricity. Most importantly, the GHG emissions from the transportation sector have been growing at a much faster rate than emissions from other sectors.

As owners, operators, and regulators of much of the nation's transportation system, transportation agencies are well-positioned in the public policy arena and in public infrastructure decision making to contribute to efforts at reducing GHG emissions. Although many of the most effective strategies for achieving such emissions reductions will likely come from national vehicle and fuel standards, many agencies and groups are looking at the use and performance of the transportation system as another opportunity for emissions reductions.

This *Practitioners Guide* presents suggested approaches for considering GHG emissions in transportation planning and decision making. The material is structured around the decision guide that was developed for the Strategic Highway Research Program 2 (SHRP 2) series of projects aimed at incorporating a collaborative decision-making approach throughout the entire transportation decision process or targeted on specific issues. The decision guide and corresponding information on a variety of topical issues for transportation officials are available on the Transportation for Communities: Advancing Projects Through Partnerships (TCAPP) website.

It is important to recognize the different settings and institutional environments within which decision making occurs. At the level of state government, there are wide variations in public awareness of climate change, transportation program size, financial capacity, mix of urban and rural areas, and transportation planning experience. In urban areas, many small metropolitan planning organizations (MPOs) lack experience in extensive planning, and a multifaceted decision-making process often does not occur. Rural areas are another context in which institutional capacity and decision-making options differ markedly from those found at the state or large urban level. Similarly, analysts and transportation officials who have not been engaged in the air quality analysis mandated by conformity requirements usually have very different capabilities in such efforts than those who have. Hence, users of this guide should view the information on data, methods, and strategies as being appropriate for varying levels of analysis, some applicable to their circumstance, and some not.

The SHRP 2 decision guide focuses on four major decision-making contexts: long-range transportation planning, programming, corridor planning, and National Environmental Policy Act (NEPA) project development and permitting. Most transportation agencies are involved with many more types of decisions, such as system and operations management, congestion management, and modal planning. Although such planning and decision making are not explicitly considered in this guide, many of the methods and approaches discussed are appropriate for assessing the GHG emissions impacts and benefits of different types of strategies.

This guide benefited greatly from the participation of many transportation practitioners who reviewed the material. In particular, state department of transportation (DOT)–sponsored workshops were held in Colorado, Massachusetts, Minnesota, and Washington State that provided important feedback on the usefulness and presentation of the material.

ORGANIZATION

Chapter 2 presents the overall decision framework for guiding the reader to an understanding of when and how GHG emissions can be considered in planning and decision making. Users should determine which decision context—long-range planning, programming, corridor planning, or project development and permitting—is most relevant to their situation and use the information from the appropriate parts of this section.

Each decision point uses the following template in presenting useful information to the user. The specific consideration of GHG emissions in that particular decision point is explained. The linkage between the GHG role in that decision point and how it relates to other decision points in the framework are described, and key questions that analysts should ask themselves are presented. Finally, the type of information that will be necessary to answer these questions is provided.

Users of this guide can thus focus on a particular decision point and obtain information on how GHG emissions can be considered in that decision; alternatively, they can trace the role of GHG emissions analysis through different decision-making processes.

Key Question Template

GHG Consideration

Integration of GHG considerations into …?

Information Transfer Among Key Decision Points

The decisions made at LRP-1 are transferred to LRP-2 to support …?

Questions

What is the scope of GHG emissions to be …?

Technical Information Needed to Answer Questions

Technical information needed at this key decision point involves a review of existing or readily available tools and data resources available to the agency to support the preferred mechanism and scope for integrating GHGs into the long-range plan.

- Emissions source(s) to …?
- Transportation mode(s) to …?
- Analysis results that …?

Chapter 3 describes methods and approaches that can be used for considering GHG emissions in different decision-making contexts. The section is organized in a way that allows users to identify how GHG emissions can be considered through the planning process or pinpoint specific approaches for individual planning tasks.

The annotated bibliography that follows Chapter 3 provides a description of useful references for those researching more specific approaches and methods for analyzing GHG emissions.

Appendix A serves as a reference document for users who wish to have more information on different technical aspects of GHG emissions analysis.

2 TRANSPORTATION FOR COMMUNITIES: ADVANCING PROJECTS THROUGH PARTNERSHIPS DECISION-MAKING FRAMEWORK

INTRODUCTION

This section outlines a framework for decision making that is used throughout this guide as a reference for how greenhouse gas (GHG) emissions analysis can support the types of decisions facing transportation officials. This framework, called Transportation for Communities: Advancing Projects Through Partnerships (TCAPP), has been developed by SHRP 2 as a defining structure for linking different planning issues and capabilities to the decision-making process. TCAPP is structured around four levels of decision making:

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

These key decision points are examined to determine whether there is an opportunity for including some form of GHG consideration as part of the information supporting a particular type of decision. Although the information provided in this guide relates to the key decision points associated with the decision levels above, many other types of decision contexts, such as operations analysis and congestion management planning, would use very similar approaches and methods to those described in this guide.

COLLABORATIVE DECISION-MAKING PROCESS

Most of the steps that make up the transportation decision-making process are work activities that take place in the technical decision-making process. Key decisions are those points in the process at which the general work activities need review and approval from higher levels of authority or at which consensus needs to be reached among diverse decision makers before the project can advance further. Figure 2.1 shows what is called the practitioner-level collaborative decision-making framework that serves as the organizing structure for this guide. The four major phases shown in this figure and the associated steps are described below.

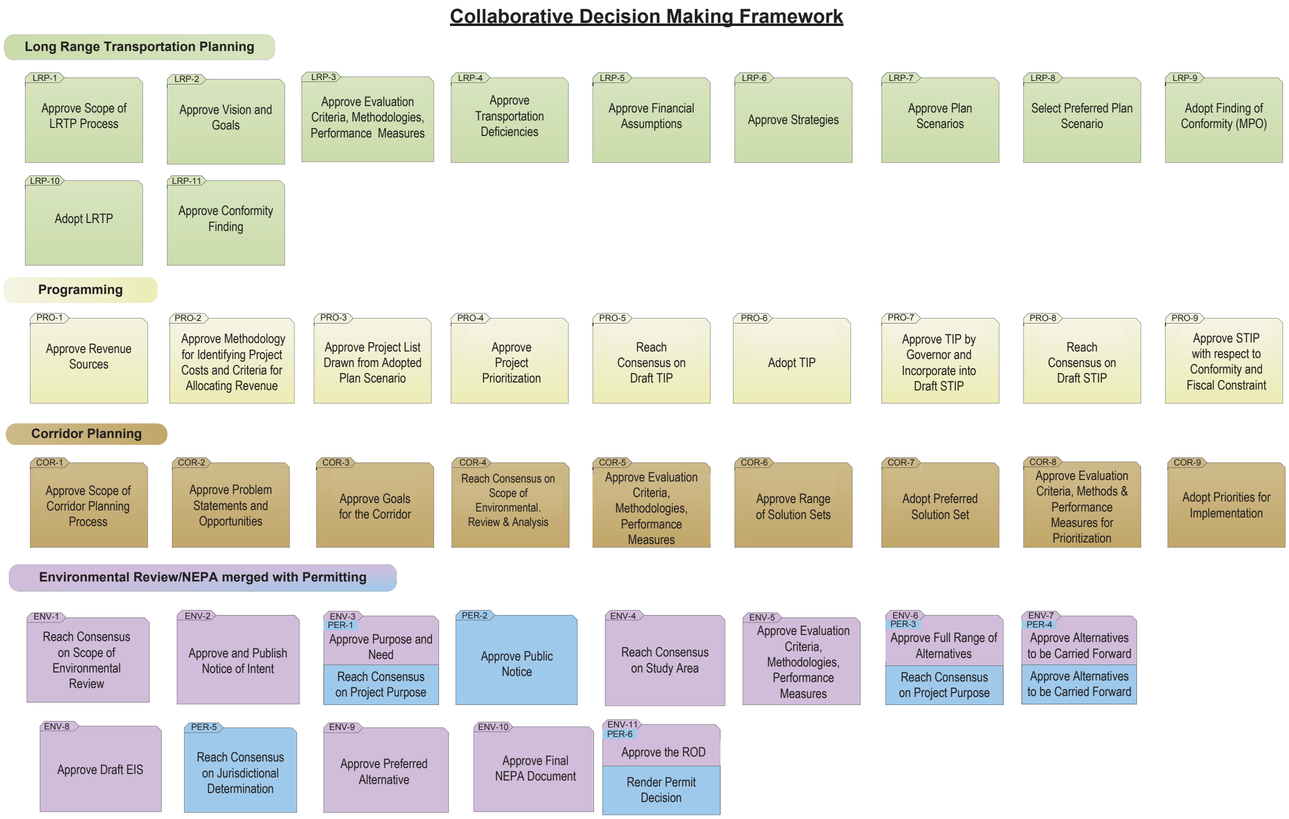

Figure 2.1. *Collaborative decision-making framework.*

LONG-RANGE TRANSPORTATION PLANNING

This phase constitutes the early steps in the decision-making framework and relates to the actions undertaken to develop long-range transportation plans (LRTPs). The long-range transportation planning process in Figure 2.1 describes primarily the process followed by metropolitan planning organizations (MPOs); a similar process or framework applies to city and county processes. The state planning process, however, differs from the metropolitan planning process; it is carried out by different entities, with different federal requirements. The key decision points in the long-range planning process and how GHG emissions might be considered include the processes discussed below.

Approve Scoping Process

This step (LRP-1) represents a consensus-building process among key stakeholders in defining what the LRTP process should include and the issues facing a study area. The identification of key stakeholders is a critical part of this early step.

Approve Scoping Process (LRP-1)

GHG Consideration

Integration of GHG considerations into the scoping decision point involves determining to what extent GHG emissions will be considered as part of long-range plan development.

Information Transfer Among Key Decision Points

The decisions made at LRP-1 are transferred to LRP-2 to support integration of GHG considerations into the long-range plan vision and goal statements. The vision and goal statements are critical in that they serve as the foundation for how potential transportation investment strategies will be evaluated at LRP-3 (in the context of how well they support attaining long-term goals) and how investments will be prioritized in the final approved plan scenario (LRP-8).

Decisions made at LRP-1 can also be transferred to COR-1 and ENV-1 to maintain consistency between the scope of the long-range plan and the scope reflected in subsequent project development activities.

Questions

What is the scope of GHG emissions analysis as part of the long-range planning process (e.g., boundaries, methods, data, feasible solution strategies)?

Does the consideration of GHG emissions have bearing on other objectives (e.g., energy, congestion, smart growth)?

Will GHG considerations be treated in a qualitative or quantitative manner?

Are there requirements that will influence how GHG emissions will be considered (e.g., a state climate action plan, federal GHG inventory, or reduction requirements)?

(continued on next page)

Approve Scoping Process (LRP-1) (continued)

Are existing tools and data resources sufficient to support the proposed method of GHG analysis?

What additional coordination efforts (data or resources) will be needed to support the desired method of GHG analysis in long-range planning?

Technical Information Needed to Answer Questions

- Technical information needed at this key decision point involves a review of existing or readily available tools and data resources to support the preferred mechanism and scope for incorporating GHG analysis into the long-range planning process.
- Emissions source(s) to include in analysis.
- Transportation mode(s) to include in analysis.
- Analysis years.
- Tools to estimate travel activity and network performance: macro (travel model), micro (simulation model), sketch analysis.
- Tools to estimate emissions rates.
- Data availability by emissions source, by travel mode, and by data format.

Approve Vision and Goals

Defining the vision and goals (LRP-2) is often the first public effort in a transportation planning process. This step includes the process of developing a vision for the study area and goals for the transportation planning process that follows. The vision and goals statement is approved by a state department of transportation (DOT), an MPO's decision-making body, or a county or city council. The vision and goals often extend beyond transportation system performance and include such things as maintaining quality of life and enhancing the environment.

Approve Vision and Goals (LRP-2)

GHG Consideration

Integrating GHG considerations into the vision and goals decision point involves defining, through high-level statements of purpose, what the agency GHG goals are for the long-range plan. Inclusion of GHG considerations at this point signals that it is a priority planning consideration and will influence resource allocation decisions.

Information Transfer Among Key Decision Points

The goal statements are directly transferred to LRP-3 in that they provide the context for how proposed transportation investment strategies will be evaluated; in other words, goal statements define the primary planning emphasis areas to be considered as part of project evaluation and plan development. Inclusion of GHG considerations at this point also signals that GHGs will be a factor in identifying transportation deficiencies that should be addressed with the long-range plan (LRP-4); selecting types of investment strategies for the plan (LRP-6); and approving and adopting the final plan scenario (LRP-8, LRP-9).

Goal statements defined at LRP-2 can also be transferred to COR-3 and ENV-3/PER-1 to maintain consistency between the goals of the long-range plan and the goals of subsequent planning and project development activities.

Questions

How will GHG considerations be reflected in the long-range plan vision and goal statements?

What type of GHG information should be available to stakeholders and the general public to inform the visioning and goal-setting process?

How specific should GHG goal statements be (e.g., integrated into a broader environmental goal or emphasized in their own GHG reduction statement)?

Technical Information Needed to Answer Questions

- Data might be needed to illustrate the extent to which GHG emissions are a significant concern to the nation, state, and/or region.
- Consistency with the results of LRP-1 is important in terms of the scoping of the GHG issues.

Approve Evaluation Criteria, Methodology, and Performance Measures

This step (LRP-3) identifies different types of evaluation criteria, the methodology for analyzing plans and projects with these criteria, and the system measures that can be used to assess overall system performance and its impacts on the environment.

Approve Evaluation Criteria, Methodology, and Performance Measures (LRP-3)

GHG Consideration

Evaluation criteria and methods defined at this point are transferred to LRP-4, in which transportation deficiencies are defined and evaluated (e.g., congestion issues, safety needs, environmental impacts). The criteria also transfer to LRP-6, where strategies are defined to address deficiencies; LRP-7, where investment scenarios (packages of strategies) are evaluated in terms of how well they address deficiencies; and at LRP-8 and LRP-9, where preferred investment scenarios are adopted using this information.

Information Transfer Among Key Decision Points

This stage is a critical point of departure for the analysis that follows. If evaluation criteria and performance measures have been adopted for the planning process, then it is incumbent on the analysis and evaluation efforts that follow to produce the required information. Evaluation criteria and performance measures dictate what type of data needs to be collected and the types of necessary analysis capabilities. Assuming that decision makers consider GHG-related criteria and performance measures when adopting the plan and program, identifying evaluation criteria in this early stage of the framework could ultimately result in GHG-related strategies being considered at the end of the process.

Evaluation criteria and methods defined at LRP-3 can be transferred to PRO-4, COR-5, and ENV-5 if LRP-3 methods involve GHG analysis at a project or corridor level. If methods defined at LRP-3 are defined for systems-level analysis only, then they may need to be modified for project- or corridor-level analysis.

Questions

What GHG evaluation measures will be used to evaluate transportation investment strategies and scenarios (e.g., carbon dioxide [CO_2], carbon dioxide equivalent [CO_2e], or, as a proxy, vehicle miles traveled [VMT])?

What is the capability of the agency's analysis methods of producing this information?

To what extent does the agency have control over the factors that influence the measure outcome?

Is a target GHG emissions reduction established externally (e.g., by a state or federal requirement)? Will one be established internally?

Technical Information Needed to Answer Questions

- Output of model or sketch analysis tools, such as travel data only (speeds and VMT), emissions data, other activity data.
- Ability to convert model or sketch analysis output to GHG baseline measures of interest.
- Ability to forecast measure for target years.

Approve Transportation Deficiencies

Using the evaluation criteria and performance measures from the previous step (LRP-3), the planning process next identifies current and expected deficiencies (LRP-4) in system performance. These deficiencies become the focus of strategies and actions aimed at improving system performance.

Approve Transportation Deficiencies (LRP-4)

GHG Consideration

Integration of GHG considerations at this point assumes that the production of GHG emissions is a deficiency (negative impact) of transportation performance. Potential investments for the long-range plan can be evaluated in terms of how well they address the deficiency; that is, the extent to which they reduce GHG emissions along with other identified deficiencies (e.g., congestion and safety).

Information Transfer Among Key Decision Points

Transportation-related GHG system concerns identified at this point link directly to LRP-6, where strategies are defined to address deficiencies; LRP-7, where investment scenarios (packages of strategies) are evaluated in terms of how well they address deficiencies; and at LRP-8 and LRP-9, where preferred investment scenarios are adopted.

Deficiencies defined at LRP-4 can be transferred to PRO-3, COR-2/4, and ENV-3/PER-1 if project- or corridor-level operations contribute to the GHG emissions inventory.

Questions

What are the key social, demographic, and technological factors influencing future GHG emissions levels?

What is the GHG emissions inventory for the base year and planning horizon year(s) corresponding to the existing plus committed (E+C) transportation network?

What is the gap between the baseline GHG emissions and the target GHG emissions levels (if applicable)?

Technical Information Needed to Answer Questions

Inventory and projection method (from LRP-3).

E+C project list for baseline and planning horizon year(s).

Estimates of travel activity and transportation network performance for baseline and planning horizon year(s) that reflect all factors that will affect travel levels.

GHG emissions rates that reflect state and federal policies (current and future) affecting GHG emissions.

Target GHG reductions (if applicable).

Approve Financial Assumptions

Federal law requires LRTPs and short-range transportation improvement programs (TIPs) developed by MPOs to be fiscally constrained. Identifying the likely revenue resources (LRP-5) that will be available over the life of the plan and providing for reasonable project cost estimates are essential components of demonstrating fiscal constraint. This step produces an approved set of financial assumptions that serve as the basis for meeting the fiscal constraint requirement.

Approve Financial Assumptions (LRP-5)

GHG Consideration

Two possible financial assumptions could be affected by GHG considerations at this point in the process. If dedicated GHG reduction funding is available, then the finance strategy for the overall transportation program should include the expected level of funding and eligibility criteria. The other financial consideration relates to the impact on the financial strategy if funding will be allocated to strategies aimed at reducing GHG emissions.

Information Transfer Among Key Decision Points

Information on financial capability feeds into the next step (LRP-6), where different types of strategies to be considered in the long-range planning process are approved. This process ultimately leads to step LRP-10, where a fiscally constrained long-range plan is approved.

Financial assumptions considered as part of the long-range planning process will feed into PRO-1, Approval of Revenue Sources; and PRO-4, where programming priorities are established.

Questions

Are there funding programs that target GHG reduction strategies?

Are there other funding programs that can support GHG reduction strategies?

Technical Information Needed to Answer Questions

Listing of funding sources and eligibility criteria.

Approve Strategies

This step (LRP-6) identifies and selects those strategies that will be considered as part of the transportation plan, ranging from changes to the transportation system to land use and pricing strategies aimed at changing travel behavior.

Approve Strategies (LRP-6)

GHG Consideration

Integration of GHG considerations at this point involves defining possible transportation solutions for GHG reduction.

Information Transfer Among Key Decision Points

Approved transportation strategies that contribute to GHG reduction identified at this decision point link directly to LRP-7, where investment scenarios (packages of strategies) are evaluated in terms of how well they address deficiencies; and to LRP-8 and LRP-10, where preferred investment scenarios are adopted using this information.

Questions

What transportation-related strategies may have GHG emissions implications (increasing or decreasing) (e.g., system management and operations, demand management, construction and maintenance practices, land use integration)?

What type of analysis is required to support the evaluation of particular strategies (in line with the general methods defined in LRP-3)?

Which GHG reduction strategies would provide the most benefit and be most cost-effective in meeting GHG goals?

Technical Information Needed to Answer Questions

List of potential strategies that can provide GHG reduction benefits, refined based on agency review of those potentially applicable in the region of interest.

Analysis results to support effective review of individual and packaged transportation strategies (e.g., screening-level assessment based on research applied in other areas, sketch-level analysis, and model analysis).

Approve Plan Scenarios for Analysis

Transportation planning often uses different "what if?" scenarios to take into account the inherent uncertainty associated with predicting the future (LRP-7). Scenarios often test different levels of investment by mode in order to compare a range of potential futures. Such scenarios can also be proactive in that they articulate a possible desired vision (e.g., what types of investment will be necessary to produce a compact development pattern in our region?). This step results in an approved set of scenarios that will be evaluated by the planning process.

Approve Plan Scenarios for Analysis (LRP-7)

GHG Consideration

GHG consideration at this decision point requires GHG emissions–reducing transportation strategies or packages of strategies that can be incorporated into one or more plan scenarios.

Information Transfer Among Key Decision Points

Scenarios approved at this step, inclusive of strategies that contribute to GHG reduction, directly transfer to LRP-8 and LRP-10, where preferred investment scenarios are adopted using this information.

Questions

What GHG-reduction transportation strategies should be included as part of scenario analysis?

What is the combined effect of such strategies?

Are there interactive effects that should be considered (e.g., strategies that work better in combination, or alternatively, that work against each other)?

To what extent are such strategies politically feasible?

Technical Information Needed to Answer Questions

Level of GHG reduction and cost-effectiveness for each strategy.

Relative importance (weight) of GHG reduction benefits compared with other planning factors.

Sketch-level planning cost for strategies included in scenarios.

Select Preferred Plan Scenario

After different alternative scenarios have been evaluated, one scenario (i.e., an assumed future with associated transportation investments) is selected by the decision-making body (LRP-8). The recommended plan scenario may evolve from, or be a hybrid of, one or more of the initial scenarios evaluated. This final recommended scenario in essence becomes the long-range plan for the metropolitan area or region.

Select Preferred Plan Scenario (LRP-8)

GHG Consideration

The consideration of GHG emissions at this decision point involves estimating the impact of various plan scenarios on GHG emissions levels and using this information as part of the selection and adoption of the preferred long-range investment scenario.

Information Transfer Among Key Decision Points

The preferred investment scenario adopted at this point is directly linked to LRP-10, in which the preferred scenario is finalized to become the adopted long-range transportation plan.

Questions

How important are GHG reduction benefits compared with other transportation benefits (i.e., what is the trade-off if scenarios improve some planning factors, but not others)?

What are the GHG impacts of various scenarios compared with the baseline and applicable targets?

What is the public and stakeholder response to the results of scenario analysis?

What is the cost of implementing various scenarios?

Technical Information Needed to Answer Questions

Technical information will vary according to the level of analysis needed to support a review of the planning scenarios, such as model analysis supplemented with off-model enhancements as needed. Most important information would include

- Level of GHG reduction for each scenario compared with baseline and target (if applicable) from LRP-7.
- Non-GHG-related transportation benefits of each scenario (in line with other evaluation criteria defined in LRP-3).
- Relative importance (weight) of GHG reduction benefits compared with other transportation benefits.
- Cost to implement scenarios.

Adopt Finding of Conformity by MPO

For those metropolitan areas or regions not in attainment of national air quality standards and/or areas that come into attainment but must maintain that status, the MPO decision-making body must find, based on analyses of proposed projects and strategies, that the plan will not result in increased emissions of target pollutant(s) nor pollutant precursors (LRP-9). A formal technical process has been defined by federal regulation as to the methodology that must be followed for such a determination.

Adopt Finding of Conformity by MPO (LRP-9)

GHG Consideration

At this time, there is no requirement for GHG emissions to be included in a conformity analysis.

Adopt Long-Range Transportation Plan by MPO

This step is the formal approval of the LRTP by the MPO decision-making body. A transportation plan must be updated and adopted on a periodic basis: every 4 years in air quality nonattainment areas, every 5 years otherwise (LRP-10).

Adopt LRTP by MPO (LRP-10)

GHG Consideration

Specific GHG considerations at this stage are contingent on the extent to which plan approval hinges on a GHG inventory or reduction assessment. GHG integration at this point also focuses on what should be communicated to various planning partners and stakeholder groups about the GHG implications of the adopted plan.

Information Transfer Among Key Decision Points

The decision to adopt a long-range plan transfers directly to PRO-1/2/3, with the adopted plan providing the framework for the types of projects to be programmed in the TIP, the revenue available for programming, and the general methods and criteria to be used for project evaluation.

Questions

To what extent are GHG emissions considerations important in the review?

Who is responsible for reviewing and approving the plan?

What needs to be communicated with respect to GHG reduction as part of plan adoption?

Technical Information Needed to Respond to Questions

Impact of long-range plan on all evaluation criteria and planning areas in line with long-term transportation goals, including GHG goals.

Cost-effectiveness of GHG strategies.

Obtain U.S. DOT Conformity Determination

The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) must make a conformity determination on the LRTP (LRP-11). This is an important step because the plan is not valid until FHWA and FTA have made this determination.

Approve Conformity Finding (LRP-11)

GHG Consideration

At this time, there is no requirement for GHG emissions to be included in a conformity analysis.

PROGRAMMING

This decision-making phase includes identifying the projects in the adopted plan that will be forwarded into a capital program, as well as the process of approving the state TIP (STIP). This process involves extra steps if a metropolitan area is in nonattainment of national air quality standards.

Approve Revenue Sources

This step identifies and approves the revenue sources that will be used in the STIP (PRO-1). In many cases, an analysis must be undertaken to estimate the level of funding that will be available in future years based on a range of assumptions (e.g., revenues collected from a transportation-dedicated sales tax that depends on an assumed state of the economy).

Approve Revenue Sources (PRO-1)

GHG Consideration

Revenue sources are largely determined at LRP-5 as part of the development of long-range plan financial plan assumptions, inclusive of the TIP period. Revenue sources defined at LRP-5 primarily comprise dedicated fund sources that can be reasonably projected to be available over the life of the plan.

LRP-5 assumptions may be reviewed again at this step, but they should not be disconnected from the results of LRP-5 because the TIP and long-range plan financial assumptions must be consistent. Specific TIP-related GHG revenue sources identified at this step could reflect some combination of committed local, state, or federal funding specific to GHG reduction that is available for programming a project in the TIP, such as grant programs for projects aimed at reducing GHG emissions.

Information Transfer Among Key Decision Points

Revenue sources identified here should be consistent with those identified in LRP-5, unless the fund source is specific to the TIP time horizon (e.g., grant funding for project and/or program implementation).

Questions

Are there any additional revenue sources specific to the TIP time horizon that are available to program projects that reduce GHG emissions?

Technical Information Needed to Answer Questions

NA.

Approve Methodology for Project Costs and Criteria for Allocating Revenue

The most important product of the programming process is a document that indicates the timing and costs associated with the transportation projects and strategies that the metropolitan area is implementing over the following 4 to 5 years (PRO-2). Basic to this process is a set of criteria and a method for their use that allow transportation officials to establish priorities for project selection.

Approve Methodology for Project Costs and Criteria for Allocating Revenue (PRO-2)

GHG Consideration

This key decision point involves defining methods to estimate project costs, at a minimum for the three federally funded project phases (preliminary engineering, right-of-way, and construction), and determining the evaluation criteria and process for allocating funding and revenue across potential TIP investments.

Integrating GHG at this step can occur at two levels. First, GHG emissions mitigation costs may be included in project costs (e.g., via short-term construction cost or long-term operations cost). Second, the project evaluation methods defined at this step can be used to estimate the effect of potential transportation investment in relation to GHG reduction goals, consistent with the LRP process.

Information Transfer Among Key Decision Points

Project evaluation methods defined at this point are transferred to PRO-4, where the approved project list defined at PRO-3 is prioritized using the methodologies defined at this step. Project costs are transferred to PRO-5, where priority projects are mapped to various funding programs, and costs are compared with available revenue for each program as part of the financial balancing element of fiscal constraint.

Project costing and project evaluation methods defined at PRO-2 can be transferred to COR-5 and ENV-5 to ensure consistency between project-level assessment conducted for the TIP and subsequent corridor study and/or environmental review.

Questions

What, if any, GHG goals must the TIP or individual projects be consistent with?

How will projects be evaluated and prioritized for funding in the TIP (consistent with LRP analysis)?

What GHG evaluation criteria or measures will be used to evaluate projects (e.g., CO_2, CO_2e, VMT [as proxy])?

Is a TIP-level GHG assessment required?

What is the scope of GHG emissions impacts to be considered?

How will GHG impacts be evaluated? *Note: Preliminary scoping of evaluation methods is done in LRP-3. Specific methods are likely to depend on individual projects.*

What weight will be given to GHG criteria in relation to other project evaluation criteria?

Will GHG emissions mitigation measures be reflected in project costs (e.g., via construction or design)?

(continued on next page)

Approve Methodology for Project Costs and Criteria for Allocating Revenue (PRO-2) (continued)

Will long-term operations and maintenance of individual projects that may reduce or increase GHG emissions be factored into the costing methodology?

Technical Information Needed to Answer Questions

For costing:

- Cost of various GHG emissions mitigation measures that can be applied during project construction and development.
- Factors for operations and maintenance relevant to each project or program type if long-term operations and maintenance costs will be applied at the project level.

Additional evaluation methods:

- Output of model or sketch analysis tools, such as travel data (speeds and VMT), emissions data, other activity data.
- Ability to convert model or sketch analysis output to a GHG baseline measure of interest.

Approve Project List Drawn from Adopted Plan Scenario

The programming process usually begins with a preliminary listing of projects (PRO-3) that surface from the LRTP and/or newly identified projects resulting from completed corridor or subarea studies (see step below in corridor planning on adopting priorities). After more careful analysis, a project priority list is approved for advancement into the TIP based on a set of project prioritization criteria.

Approve Project List Drawn from Adopted Plan Scenario (PRO-3)

GHG Consideration

This key decision point establishes the pool of projects drawn from the long-range plan (or parallel corridor planning activities) that will be considered for funding in the TIP. Integration of GHG considerations at this point involves including in the list of projects a subset of projects that directly contributes to GHG reduction, consistent with the GHG reduction strategies identified as part of the long-range plan process and incorporated into the preferred long-range plan scenario.

Information Transfer Among Key Decision Points

Decisions made at this step are transferred directly to PRO-4, where the approved project list is prioritized using the methodologies defined in PRO-2.

Questions

What is the relative importance of GHG reduction compared with achieving other transportation goals and objectives?

Are there programmed projects in the current long-range plan or in corridor studies that have GHG emissions reduction benefits?

Are there additional projects that reduce GHG emissions that might be considered?

What projects, inconsistent with GHG reduction goals, may need to be removed?

Are there GHG reduction projects that may be advanced into the TIP that also address non-GHG goals?

Technical Information Needed to Answer Questions

There is no additional technical information needed (beyond what is defined for PRO-2) to address these questions. The decisions made at this point are largely policy related.

Approve Project Prioritization

This step takes the project list developed as part of the adopted plan scenario and develops an approved list of projects based on the application of prioritization criteria (PRO-4).

Approve Project Prioritization (PRO-4)

GHG Consideration

The list of projects to be evaluated for possible inclusion in the TIP is evaluated and prioritized using the methods defined in PRO-2. Integrating GHG at this point is not a new statement of GHG considerations, but rather a reflection of the GHG analysis defined in previous steps.

Information Transfer Among Key Decision Points

Priority projects identified at this step are directly transferred to PRO-5, where projects are mapped to available revenue sources and levels to support (draft) TIP programming decisions.

Questions

With respect to the criteria established in PRO-2, what is the direction and/or magnitude of GHG impact for each project?

Do the results of the project evaluation process yield a list of priority projects that support GHG-related goals and objectives or meet established targets? If not, does the list of projects defined at PRO-3 need to be expanded?

Are there key GHG-related results of the project prioritization process that need to be communicated to stakeholders and decision makers to inform decision making?

Technical Information Needed to Answer Questions

Project-level results; this could include modeled results of project performance across evaluation criteria defined in PRO-2, aggregate project scores calculated across evaluation criteria defined in PRO-2, and/or project-level benefit–cost analysis.

Reach Consensus on Draft TIP

A draft TIP (PRO-5), developed as part of the programming process, represents an important indication of regional transportation investment priorities. MPO staff often spend considerable time developing the draft TIP for referral to the MPO decision-making body.

Reach Consensus on Draft TIP (PRO-5)

GHG Consideration

At this key decision point, project priorities are aligned with available funding within program restrictions to select those projects to be included in the TIP. The draft TIP is then presented for public and planning-partner review and discussion to build consensus around the TIP prior to formal adoption.

Integrating GHG considerations at this step involves including strategies and/or projects that reduce GHG emissions in the TIP project list; estimating the impact of TIP projects on GHG emissions levels to determine if the package of projects addresses GHG-related goals and/or objectives; and communicating the GHG implications of the proposed TIP to stakeholders and the public.

Information Transfer Among Key Decision Points

The decisions made at this point link directly to PRO-6, where the draft TIP is formally adopted by the MPO. Decisions made at this step should align with the long-range planning phase (LRP-10), in that project-level programming decisions made as part of the TIP must be consistent with assumed funding in the long-range plan.

Questions

What are the combined GHG effects of the projects proposed in the TIP?

Does the recommended TIP meet GHG reduction goals or provide a trajectory for meeting longer-term goals beyond the TIP time frame?

How will funding and revenue projections for each funding program and for each fund source (federal, state, and local) affect the selection of priority projects and what, specifically, are the impacts to GHG-related projects?

Will the results of the project prioritization process be directly reflected in the TIP (consistent with fund program requirements) or will other policy and/or qualitative factors affect final project selection (e.g., project readiness, geographic equity)?

Technical Information Needed to Answer Questions

- Revenue projections for project programming by fund program and source (federal, state, local).
- Legal restrictions (if any) for programming funds for each fund program and source.
- Total GHG emissions impact of TIP projects in relation to GHG-related goals and/or objectives.

Adopt TIP by MPO

This step (PRO-6) is an important decision point in the transportation planning process in that it is a legal prerequisite for federal transportation project funding.

Adopt TIP by MPO (PRO-6)

GHG Consideration

At this key decision point, the MPO adopts the TIP. By adopting the final TIP, the MPO and the partner agencies agree that the TIP has been developed appropriately and addresses the MPO's transportation goals and objectives. Specific GHG considerations at this stage are contingent on the extent to which TIP approval hinges on a GHG inventory or reduction assessment, if at all.

Information Transfer Among Key Decision Points

The decision to formally adopt a TIP transfers directly to PRO-7, where the adopted TIP is reviewed and approved by the governor (or designee) and incorporated into the draft STIP.

Questions

Who is responsible for reviewing and approving the TIP?

What information needs to be communicated to support TIP adoption (outside of what is presented during PRO-5)?

Technical Information Needed to Answer Questions

- Impact of the TIP across all evaluation criteria and/or planning areas in line with long-term transportation goals and/or objectives, including GHG-related considerations.
- Cost of the TIP.
- Detail related to delivering the TIP (e.g., phasing of high-priority projects in the TIP).

Approve TIP by Governor and Incorporate into Draft STIP

Federal law states that the state governor or governor designee and the MPO have the final say on the adoption of the TIP (PRO-7). In addition to approving a region's TIP, it is the state's responsibility to adopt the TIPs of all state MPOs as part of the STIP.

Approve TIP by Governor and Incorporate into Draft STIP (PRO-7)

GHG Consideration

At this point, the MPO-adopted TIP is reviewed against federal and state requirements and approved by the state governor or governor designee for incorporation into the STIP. Specific GHG considerations at this point are contingent on state-level GHG requirements, if applicable (e.g., the TIP approval may hinge on a state-required GHG inventory or reduction assessment).

Information Transfer Among Key Decision Points

The decision to incorporate the TIP into the STIP is transferred to PRO-8 and PRO-9, where the STIP is reviewed by the general public and approved by the U.S. DOT with respect to federal requirements.

Questions

Does the state require a GHG inventory or demonstration of GHG reduction for TIP approval and incorporation into the STIP? If so, does the TIP address GHG requirements?

Are there additional, state-level GHG-related requirements affecting areas outside of MPO boundaries that need to be reflected in the STIP? If so, will these requirements affect MPO TIP incorporation into the STIP if they are not addressed properly?

Technical Information Needed to Answer Questions

- GHG-related requirements of STIP, if applicable.
- Impact of TIP in relation to GHG-related requirements.

Reach Consensus on Draft STIP

This step represents a consensus-building effort on the part of the state DOT in developing a draft STIP (PRO-8) that includes the TIPs from all of the state's MPOs, as well as other state projects. Depending on the state and the requirements and history of developing the STIP, the consensus-building process could be very straightforward and accomplished in a short time frame, or it could be subject to many meetings and public outreach efforts.

Reach Consensus on Draft STIP (PRO-8)

GHG Consideration

At this key decision point, the draft STIP is released for public comment. GHG integration at this point focuses on what needs to be communicated to the public about the GHG implications of the proposed STIP.

Information Transfer Among Key Decision Points

Decisions made here transfer to PRO-9, where the STIP (revised as needed based on public feedback) is reviewed and formally approved by the U.S. DOT.

Questions

Was there any feedback from the public that requires a reconsideration of TIP and/or STIP programming decisions?

Technical Information Needed to Answer Questions

NA.

Approve STIP with Respect to Conformity and Fiscal Constraint

This final step in the programming process requires FHWA and FTA to determine that the metropolitan TIPs that constitute the STIP meet the fiscal constraint requirement (PRO-9). FHWA and FTA do not make a conformity determination on the STIP, but they do make conformity determinations on individual metropolitan TIPs. This conformity determination on the individual TIPs is made before the incorporation of the TIP into the STIP.

Approve STIP with Respect to Conformity and Fiscal Constraint (PRO-9)

GHG Consideration

This step relates specifically to reviewing the STIP with respect to federal transportation planning regulations to include fiscal constraint and transportation and air quality conformity requirements in air quality nonattainment and maintenance areas. Regulations do not currently require GHG considerations.

Information Transfer Among Key Decision Points

Once the STIP, inclusive of MPO TIPs, is formally approved, projects can proceed to project development and/or be the focus of more detailed analysis in corridor planning (COR-1 to COR-3).

Questions

NA.

Technical Information Needed to Answer Questions

NA.

CORRIDOR PLANNING

Many state DOTs, MPOs, and transit agencies conduct corridor or subarea studies to provide a finer level of detail on the strategies and projects that help achieve the vision and goals of the transportation plan. Although the steps that follow focus on corridor planning as it relates to highway projects, these steps are also relevant to multimodal corridor planning that includes transit strategies and land use options.

Approve Scope of Corridor Planning Process

Corridor studies can be undertaken for variety of reasons and help focus attention on numerous challenges facing a particular corridor's transportation system (e.g., safety, congestion, economic development) (COR-1). This initial step represents an effort to define a scope of the corridor planning study in terms of geographic extent, types of problems to be examined, time frame, and level of analysis.

Approve Scope of Corridor Planning Process (COR-1)

GHG Consideration

This initial key decision point involves assessing what data, decisions, and relationships need to be considered as part of the corridor study process. The corridor planning scope is often informed by long-range transportation planning in that the long-range plan identifies transportation needs and issues that warrant more detailed study and review. This step also serves to inform the scope of subsequent environmental review activities.

Integration of GHG considerations into this scoping decision point involves defining to what extent GHG emissions will be considered as part of the corridor planning process, specifically how GHG emissions reduction will be included in the broader study process.

Information Transfer Among Key Decision Points

The decisions made at COR-1 are transferred to COR-2, where GHG considerations are defined in more technical detail, and to COR-3, where the scope of the study is refined into more specific study goals.

Decisions made at COR-1 are directly informed by LRP-1. They also serve to inform ENV-1 to maintain consistency between the scope of corridor planning activities and subsequent (more detailed) project development activities.

Questions

What is the scope of GHG emissions analysis as part of the long-range planning process (boundaries, methods, data, and feasible solution strategies)?

Will GHG considerations be treated in a qualitative or quantitative manner?

Are there requirements that will influence how GHG emissions will be considered (e.g., a state climate action plan, federal GHG inventory, or reduction requirements)?

Are existing tools and data resources sufficient to support the proposed method of GHG analysis?

What additional coordination efforts (data and/or resources) will be needed to support the desired method of GHG analysis in long-range planning?

(continued on next page)

Approve Scope of Corridor Planning Process (COR-1) (continued)

Technical Information Needed to Answer Questions

- Technical information needed at this key decision point involves a review of existing or readily available tools and data resources to support the preferred mechanism and scope for incorporating GHG analysis into the long-range planning process.
- Emissions source(s) to include in analysis.
- Transportation mode(s) to include in analysis.
- Analysis years.
- Tools to estimate travel activity and network performance: macro (travel model), micro (simulation model), sketch analysis.
- Tools to estimate emissions rates.
- Data availability by emissions source, by travel mode, and by data format.

Approve Problem Statements and Opportunities

Once a scope has been determined for the study, the corridor management team in cooperation with corridor stakeholders defines more specific problem statements and identifies opportunities for improving corridor system performance (COR-2). These problem and opportunity statements become the basis for analysis and evaluation during the study.

Approve Problem Statements and Opportunities (COR-2)

GHG Consideration

The full range of deficiencies and opportunities within a corridor are defined at this key decision. Deficiencies and opportunities can extend beyond transportation, as defined by the scope of the study in COR-1. The problem statements and opportunities resulting from this key decision are informed by the transportation deficiencies identified in long-range planning and inform the purpose and need during environmental review.

Integrating GHG considerations at this step involves defining GHG emissions as a deficiency (investment need) to address through the study, and defining potential opportunities for addressing GHG emissions in the study process.

Information Transfer Among Key Decision Points

Decisions made at COR-2 transfer to COR-3, where the full range of corridor deficiencies and opportunities are packaged into more specific study goals.

Decisions made at this point are informed by the transportation deficiencies identified in LRP-4. They also serve to inform the purpose and need statement developed as part of ENV-3/PER-1.

Questions

How is transportation performance in the corridor affecting or benefiting GHG emissions levels?

How can these effects be mitigated or enhanced?

Are there potential solutions beyond traditional transportation investment, such as land use or demand management?

Technical Information Needed to Answer Questions

- Results from long-range plan analysis that are applicable to corridor study area; for example, corridor travel data (current and projected travel volume, speeds, congestion levels); corridor land use data (current and projected population and employment characteristics); and/or corridor-specific GHG emissions data as available.
- Range of potential GHG emissions reduction solutions identified in long-range planning process, supplemented with new information as available.

Approve Goals for the Corridor

Similar to identifying goals for a long-range planning process, this step defines planning goals that will reflect the desires and needs of the major stakeholders in the corridor (COR-3). The goals also provide input into the selection of evaluation criteria and performance measures (COR-5).

Approve Goals for the Corridor (COR-3)

GHG Consideration

At this key decision point, a broad range of corridor-specific transportation, community, and environmental goals are considered. The study goals defined at this step should align with the scope of the study process defined in COR-1. The key decision is informed by the goals approved during long-range transportation planning, and it informs the purpose and need for projects in environmental review.

Integration of GHG considerations into the COR-3 key decision point involves defining, through high-level statements of purpose, the GHG-related goals of the study. Inclusion of GHG considerations at this point signals that it is a priority study consideration and will influence study recommendations on some level.

Information Transfer Among Key Decision Points

The study goals for the corridor are directly transferred to COR-5 in that they provide the context for how potential investment options will be evaluated.

Decisions made at this point can be informed by the goal statements identified in LRP-2. They also serve to inform the purpose and need statement developed as part of ENV-3/PER-1.

Questions

How will GHG considerations be reflected in the corridor study goal statements?

How specific should GHG goal statements be; for example, should they be integrated into a broader environmental goal? Or emphasized in their own GHG reduction statement?

Technical Information Needed to Answer Questions

No technical information is needed to respond to the policy questions identified at this point, but goal statements should not conflict with the (technical) scope of GHG consideration defined in COR-1.

Reach Consensus on Scope of Environmental Review and Analysis

A corridor study could be an important context for environmental analysis. Thus, for example, a corridor study could be combined with an environmental impact statement effort that results in a recommended transportation alternative. It is very important at the early stages of any corridor study, but in particular those aligned with environmental analysis, that the scope of the environmental effort be defined (COR-4): What impacts are expected? What data should be collected? What types of analysis tools will be used? What permitting agencies need to be involved?

Reach Consensus on Scope of Environmental Review and Analysis (COR-4)

GHG Consideration

In order to provide a clear linkage to the subsequent environmental review process, this key decision point defines the acceptable level of detail for the corridor study analysis. Completion of this step establishes a common understanding among planning partners (primarily transportation and resource agencies) about what decisions and analyses will be transferable to the merged environmental review and permitting process.

Integrating GHG at this step involves clarifying whether GHG emissions analysis conducted as part of the corridor study will be needed and/or required for subsequent environmental review. And, if included as part of environmental review, what acceptable level of detail will be needed to transfer GHG-related analysis?

Information Transfer Among Key Decision Points

Decisions made at this step will translate directly to COR-5 and ENV-5, where specific GHG evaluation methods are defined to support corridor evaluation and subsequent environmental review activities.

Questions

What are environmental review requirements for subsequent project development activities?

Will GHG emissions be included as an element of environmental review?

What is the acceptable level of detail for analysis to be transferred between the corridor study and environmental review?

Technical Information Needed to Answer Questions

Analysis requirements for environmental review.

Approve Evaluation Criteria, Methodology, and Performance Measures

Project evaluation is based on a set of criteria and performance measures that reflect the concerns raised in earlier steps of the corridor study (COR-5). These criteria and performance measures are likely to be at a much finer level of disaggregation than those used for the long-range planning process, primarily because of the much smaller geographic scale of analysis. Thus, a safety measure might be generally defined in a long-range plan as fatalities per 100 million vehicle miles traveled; in a corridor study, safety might be defined in more specific terms, such as truck-related, pedestrian or bike, or driveway crashes. This decision step approves the set of criteria and performance measures that will be used to assess the relative effectiveness of different strategies.

Approve Evaluation Criteria, Methodology, and Performance Measures (COR-5)

GHG Consideration

At this key decision point, evaluation criteria, evaluation methodology, and performance measures are approved to support corridor analysis. Corridor analysis is conducted for base or current conditions and on a variety of potential solutions to allow decision makers to compare solutions that best address corridor needs within the context of the study goals. The evaluation criteria, methodology, and performance measures are informed by the evaluation criteria, methodology, and performance measures used in long-range transportation planning and are considered during environmental review to ensure consistency across the entire transportation decision-making process.

Integration of GHG considerations at this point involves defining GHG-related evaluation criteria and methods to estimate the effect of potential investment strategies in relation to GHG-related study goals.

Information Transfer Among Key Decision Points

Evaluation criteria and methods defined at this point are transferred to COR-7, where a preferred solution set is adopted based on the results of the corridor evaluation using methods defined in this guide. Decisions are also transferred to COR-8, in that evaluation methods used to evaluate potential solution sets should be consistent with methods used to prioritize investment strategies.

Questions

What GHG evaluation measures will be used to evaluate transportation investment strategies and scenarios (e.g., CO_2, CO_2e, VMT [as proxy])?

What is the capability of the agency's analysis methods of producing this information?

To what extent does the agency have control over the factors that influence the measure outcome?

How will the GHG impacts of potential corridor solutions be evaluated? *Note: Preliminary scoping of evaluation methods will be done in COR-1/LRP-3, but specific methods are likely to depend on strategies and solution sets identified in COR-6.*

Technical Information Needed to Answer Questions

- Types of output of model or sketch analysis tools (e.g., travel data only [speeds and VMT], emissions data, other activity data).
- Ability to convert model or sketch analysis output to GHG baseline measure of interest.
- Ability to forecast.

Approve Range of Solution Sets

The evaluation process examines a variety of strategies and projects that can improve the performance of the corridor transportation system (COR-6). As part of this process, this step identifies a candidate set of strategies that will be part of the analysis.

Approve Range of Solution Sets (COR-6)

GHG Consideration

A range of approved solution sets for the corridor results from this key decision. These solution sets are influenced by the preferred plan scenario adopted as part of the long-range transportation plan, and they help to define the full range of alternatives to be evaluated during environmental review.

Integrating GHG at this step involves including GHG reduction strategies in the approved solution sets for the corridor study.

Information Transfer Among Key Decision Points

The range of solution sets approved at this step is influenced by the preferred plan scenario approved in LRP-10 and helps to define the full range of alternatives to be evaluated during environmental review in ENV-6/PER-3.

Decisions transfer directly to COR-7, where a preferred solution set is adopted based on the results of corridor evaluation using methods defined in COR-5.

Questions

What corridor investment strategies or other actions that contribute to GHG emissions reduction should be included as part of the solution sets?

How cost-feasible are these strategies when combined or when treated separately?

Are there interactive effects that should be considered? That is, do some strategies work better in combination, or alternatively, work against each other?

Are there potential strategies that extend beyond the traditional transportation realm, and if so, do they require more refined analysis or study?

Technical Information Needed to Answer Questions

- Relative importance (weight) of GHG reduction benefits compared with benefits of other potential corridor solutions.
- Level of GHG reduction and cost-effectiveness for each strategy or combination of strategies evaluated in COR-6.
- Sketch-level planning cost for strategies potentially included in scenarios.

Adopt Preferred Solution Set

The corridor study recommends a package of actions and projects to meet study goals (COR-7). This package can range from new capacity expansion projects to transportation demand management or transportation system management, as well as land use and urban design strategies. The corridor study decision-making body adopts a preferred set of strategies and projects informed by analysis undertaken during the study.

Adopt Preferred Solution Set (COR-7)

GHG Consideration

At this key decision point, a preferred solution set is adopted for the corridor study. An evaluation of the preferred solution set using the approved evaluation criteria, methodology, and performance measures from COR-5 are the basis for selection.

Integrating GHG at this point is not a new statement of GHG considerations, but rather a reflection of the GHG integration defined in previous steps.

Information Transfer Among Key Decision Points

The preferred solution set is typically influenced by the preferred plan scenario adopted in long-range planning, so potential investment strategies need to be consistent between the long-range plan and the more detailed corridor study. The preferred solution set should also feed into the range of alternatives considered in subsequent project-level environmental review.

Decisions made here directly inform COR-8 because the preferred solution set will shape individual investment strategies that will be defined and prioritized to support final study recommendations (i.e., specific project recommendations for scope and schedule).

Questions

What are the results of the corridor scenario and solution set analysis?

How well does each solution set address study goals?

What is the preferred solution based on the analysis results?

What is the public feedback on the different solution sets?

Technical Information Needed to Answer Questions

- Results of solution set technical analysis (strategies combined).
- Aggregate cost (and/or cost-effectiveness) of solution sets.

Approve Evaluation Criteria, Methodology, and Performance Measures for Prioritization

The number of projects that results from a corridor study usually surpasses the level of funding available for their implementation. This situation requires a set of criteria and performance measures to establish priorities among the different recommended projects (COR-8). Those projects receiving high priorities are often placed in the STIP or regional TIP. This decision step represents the approval of the criteria that will be used for assigning these priorities. In most cases, these criteria will be the same from one corridor study to another, or at least some subset will be common across all corridor studies in a state.

Approve Evaluation Criteria, Methodology, and Performance Measures for Prioritization (COR-8)

GHG Consideration

At this key decision point, priorities for implementation of the preferred solution set are established. A second set of evaluation criteria, methodology, and performance measures can be used for prioritization purposes, if needed, but the criteria and method should not conflict with the evaluation conducted in previous steps.

Integrating GHG considerations at this point includes using GHG-related criteria as one of the criteria to prioritize corridor investment strategies.

Information Transfer Among Key Decision Points

Decisions made at this step directly influence the final study recommendations provided at COR-9.

Questions

Are more specific evaluation criteria and methods needed to define and prioritize investments strategies for the corridor (i.e., beyond those established in COR-5 to support evaluation of solution sets)?

How will the results of technical analysis affect the prioritization process in the context of other study considerations such as cost, public support, and project feasibility?

What factors will play a role in project prioritization, and how will these factors be weighted and considered in the prioritization process?

Technical Information Needed to Answer Questions

NA.

Adopt Priorities for Implementation

This decision step represents the actual selection of projects and strategies that are recommended for future funding consideration (COR-9). The recommended improvements for the corridor may need to be adopted into the regional long-range transportation plan. Although the corridor planning process, including goals and objectives, should be consistent with the regional LRTP, some major projects that come out of corridor planning may not be explicitly included in the regional plan. In this sense, the process is iterative—the development of the regional LRTP may identify the need for more detailed planning at the corridor level, and the corridor-level planning may inform or feed back into the regional plan.

Adopt Priorities for Implementation (COR-9)

GHG Consideration

At this step, individual projects within the adopted preferred solution set are evaluated and prioritized to identify an appropriate sequencing for implementation. The prioritized list of projects becomes the final study recommendations to address corridor deficiencies. The prioritization of projects supports both programming decisions made as part of the TIP and subsequent project-level environmental review activities.

Integrating GHG at this point is not a new statement of GHG considerations, but rather a reflection of the GHG integration defined in previous steps.

Information Transfer Among Key Decision Points

Priority projects and study recommendations defined at this step directly translate to programming step PRO-3 and the subsequent environmental review steps (ENV-1 through ENV-11) needed for certain types of investment recommendations (e.g., capacity addition).

Questions

How do individual strategies contained in the preferred solution set compare using evaluation methods defined in COR-8?

Does the prioritization process yield a set of priority projects that align with study goals?

What is the appropriate scheduling and phasing for priority projects?

Is there an available project sponsor for study recommendations?

Technical Information Needed to Answer Questions

Results of COR-9 analysis.

ENVIRONMENTAL REVIEW, NEPA, AND PERMITTING MERGED WITH PLANNING

This final decision-making phase focuses on the steps necessary for project environmental review and permitting. This series of steps, many of which are required by national or state environmental laws, represents two aspects of the environmental process: the environmental review (NEPA) process and a typical environmental permitting process. The permitting aspect is identified below in the appropriate steps. Some states require a (programmatic) environmental review of state, regional, county, and city transportation plans prior to plan adoption (e.g., SEPA in the State of Washington). This means that transportation planners need to incorporate environmental factors and considerations early into the planning process. Even without state environmental regulations and requirements, there is an increased emphasis at the federal level on introducing environmental considerations (not only GHG emissions) earlier into the planning process. The decision-making framework described here tends to focus on project environmental review and will likely have to be expanded to include environmental review for plans and programs.

The Council on Environmental Quality has recommended some GHG analysis for certain circumstances. Users of this guide should refer to the latest environmental regulations concerning GHG analysis in environmental review before beginning an environmental analysis.

Reach Consensus on Scope of Environmental Review

This step (ENV-1/PER-1) represents an important part of the environmental review process in that much of what occurs in subsequent steps is initiated by this consensus process. The purpose of this step is to have all agencies potentially concerned with an environmental analysis agree upfront with the scope of the analysis effort. The scope includes the geographic boundaries, types of impacts, needed data, required methodologies, and types of mitigation strategies that should be considered.

Reach Consensus on Scope of Environmental Review (ENV-1/PER-1)

GHG Consideration

This step considers the integration of GHG considerations into project scoping, including determining the extent to which GHG emissions will be considered as part of the impact assessment.

Information Transfer Among Key Decision Points

The decisions made at ENV-1 are transferred to ENV-2 to support integration of GHG into the issues noted in the Notice of Intent.

(continued on next page)

Reach Consensus on Scope of Environmental Review (ENV-1/PER-1) (continued)

ENV-1 decisions also transfer to ENV-3 (project purpose), if desired. The purpose of reducing GHG emissions may already be a part of a larger long-range transportation plan.

ENV-1 decisions could also contribute to ENV-4 to ENV-7, in that scoping comments can include areas of potential effects, suggestions on methods, and potential alternatives.

Questions

What are project characteristics?

- Rehabilitation or restoration.
- Replacement in kind.
- Service improvement.
- New service.

What is the project area of influence?

Is the project part of a larger transportation plan or improvement program for which GHG reduction is an objective?

What were the GHG findings in programming and corridor planning studies?

What project features lend themselves to a potential change in GHG emissions and differences between alternatives from the perspective of traffic and other sources of GHG emissions?

What adopted land development objectives exist in the area of influence that support the reduction of GHGs, and how would the project support those objectives?

What is the lead agency's policy on assessing GHG emissions? What other federal, state, and local policies apply?

Technical Information Needed to Answer Questions

The project definition and objectives as defined in:

- Long-range transportation plans.
- Transportation programming decisions.
- Corridor planning findings.
- Travel forecasts used in previous studies.
- Long-range land use and economic development plans and objectives in the area of project influence.
- Applicable GHG emissions assessment policies.

Approve and Publish Notice of Intent

This step (ENV-2) is an official action on the part of the agency sponsoring a project environmental study. Often, this step involves a public involvement plan for the NEPA document in which the issuance of a Notice of Intent (NOI) is part of the administrative step. The agencies that issue an NOI do so to inform the public about the proposed actions; announce plans to conduct public scoping meetings; invite public participation in the scoping process; and solicit public comments for consideration in establishing the scope and content of the environmental document, alternatives, and environmental issues and impacts.

Approve and Publish Notice of Intent (NOI) (ENV-2)

GHG Consideration

No GHG consideration likely for this decision point.

Approve Purpose and Need and Reach Consensus on Project Purpose

This step (ENV-3/PER-2) represents the approval process of the purpose and need statement. A clear, well-justified purpose and need statement explains to the public and decision makers that the expenditure of funds is necessary and worthwhile and that the priority the project is being given relative to other needed projects is warranted. The project purpose and need also drive the process for alternatives consideration, in-depth analysis, and ultimate selection. For the environmental permitting process, this step often also satisfies a requirement to reach a consensus on project purpose. Permits are required for constructing projects that are disruptive to the environment, and the issuance of a permit must be clearly linked to the purpose of the project.

This step is an official action on the part of the agency sponsoring a project environmental study. Often, this step involves a public involvement plan for the NEPA document, in which the issuance of an NOI is part of the administrative step. The agencies that issue an NOI do so to inform the public about the proposed actions; announce plans to conduct public scoping meetings; invite public participation in the scoping process; and solicit public comments for consideration in establishing the scope and content of the environmental document, alternatives, and environmental issues and impacts.

Approve Purpose and Need and Reach Consensus on Project Purpose (ENV-3/PER-2)

GHG Consideration

Integrating GHG considerations at this step requires first defining if GHG emissions reduction is a project purpose or is simply a factor in deciding among project alternatives.

If GHG emissions reduction is a project purpose, then only alternatives that reduce GHG emissions can be assessed in the environmental assessment or environmental impact statement, regardless of their other benefits. More emphasis would be placed on this benefit over other impacts when selecting the preferred alternative.

If GHG emissions reduction is simply a factor in deciding between alternatives, then it would be one of many positive and negative impact factors considered in the selection of the preferred alternative.

Information Transfer Among Key Decision Points

The scoping comments from ENV-2 will be a factor in this decision.

ENV-3 decisions could contribute to or influence ENV-4 to ENV-9 from the following perspectives:

- ENV-4: Area of project influence on GHG emissions.
- ENV-5: Measurement of impacts.
- ENV-6: Types of alternatives considered.
- ENV-7: Selection of reasonable and feasible alternatives that best meet project purposes.
- ENV-8: Recommended preferred alternative and mitigation strategies.
- ENV-9: Selection of the preferred alternative.

Questions

Is a project purpose defined in long-range transportation plans, programs, and/or corridor studies? Is GHG emissions reduction a motivating factor in such a purpose?

Is a project purpose defined in local land use and economic development plans? Is GHG emissions reduction a motivating factor?

How does the project relate to regional, state, or federal policy or goals?

What are the components of the no-build alternative, including other transportation projects and area plans that could influence future travel demand, movement patterns, and GHG emissions?

Does the project offer the opportunity for more than a marginal reduction of the factors that contribute to transportation-related emissions?

(continued on next page)

Approve Purpose and Need and Reach Consensus on Project Purpose (ENV-3/PER-2) (continued)

What is the GHG emissions reduction need? Does it go beyond "any reduction in GHG emissions is good?"

What level of GHG emissions reduction would meet the need? Is there a target, and if so, how much less in emissions reduction would still achieve the purpose?

How is the need quantified, and how is success at meeting the need quantified? What tools are available? What evaluation measures could be used (e.g., CO_2, CO_2e, VMT [as proxy])?

Technical Information Needed to Answer Questions

The project definition and objectives as defined in:

- Long-range transportation plans.
- Transportation programming decisions.
- Corridor planning findings.
- Local land use and economic development plans.
- State and federal policy.

Traffic forecasts (VMT) and road capacity analyses (vehicle hours traveled, congested VMT, level of service) for the no-build alternative and corridor or sketch-level analyses of potential build alternatives. Changes in development patterns that could be induced by the implementation of the project or plan should be taken into account.

GHG emission factors to apply to travel data to determine no-build GHG emissions (establishes need and baseline) and to test the potential for success and how that might best be expressed for potential build alternatives.

GHG emissions reductions anticipated from federal and state measures such as low-carbon fuel and inspection and maintenance requirements and more stringent certification and corporate average fuel economy (CAFE) standards.

Approve Public Notice

A public notice (PER-3) is necessary for any action in which a permit issuance is being considered. This step approves the content and timing of the public notice.

Approve Public Notice (PER-3)

GHG Consideration

No GHG consideration likely for this decision point.

Reach Consensus on Study Area

As with any planning study, it is important for environmental analyses that the study boundaries be clearly defined (ENV-4). This is particularly important for environmental impact analyses in which some impacts could occur far from the immediate areas bordering the project (e.g., air quality impacts). In some cases, such as wetland impacts, study boundaries are defined through federal regulation and guidance. This step provides the forum and structure for reaching a consensus on the boundaries of the study area.

Reach Consensus on Study Area (ENV-4)

GHG Consideration

This key decision point involves selection of the area over which GHG reductions will be compared between the no-build and build alternatives.

Information Transfer Among Key Decision Points

ENV-4 decisions would define the area over which GHG emissions are calculated under ENV-5.

Questions

What is the area over which GHG reductions will be compared considering

- The area over which the project might influence travel patterns or activity?
- The area, if any, in which the project might influence development patterns?

Are travel data available for the defined study area?

What is the long-range plan's study area relative to the project's area of influence?

What is the availability of data that would permit the estimate of direct, indirect, and cumulative GHG emissions for associated activities such as induced travel, project construction, maintenance and operations activities, motor vehicle manufacturing, and full fuel-cycle emissions?

Technical Information Needed to Answer Questions

Traffic information developed under ENV-3.

Indicators of the potential for induced change in development, including

- Changes in distance and travel time between the project area and major trip attractors such as employment centers.
- Suitability of the project area for development or redevelopment.

Long-range transportation plans.

Local long-range land use and comprehensive development plans.

Approve Evaluation Criteria, Methodology, and Performance Measures

This step (ENV-5) is similar to those in the long-range and corridor planning phases. Environmental analysis produces information on the respective impacts to be considered by decision makers in choosing a preferred alternative. The evaluation criteria used in this evaluation will depend on the types of environmental and community impacts that were identified during the scoping process. The methodologies used for analyzing these impacts and the identification of the performance measures to be used in system performance evaluation are also part of this step. The result of this step is the approval of the criteria, methodologies, and performance measures to be used in the environmental analysis process.

Approve Evaluation Criteria, Methodology, and Performance Measures (ENV-5)

GHG Consideration

This step involves defining the important differentiators between the no-build alternative and the build alternatives associated with GHG emissions, including the ability of alternatives to meet the project purpose and need and to reduce GHG emissions. This step also involves defining the GHG emissions sources to be evaluated; the analysis time frame, including start and ending dates; changes in benefits over time; the methodology for comparing impacts, including direct, indirect, and cumulative impacts; and finalizing performance measures.

Information Transfer Among Key Decision Points

The criteria, methods, and performance measures would be used in the comparison of alternatives under ENV-7 and the assessment of impacts under ENV-8.

Questions

What criteria, methods, and performance measures are appropriate for determining which projects should move forward into environmental analysis? Important information would include emissions sources, time frame, and area of impact. Criteria, methods, and performance measures used for ENV-7 would be simpler than those used for ENV-8, with fewer variables than those for assessing in detail the alternatives to be carried forward.

What criteria, methods, and performance measures are appropriate to use under ENV-8 to differentiate the alternatives carried forward for detailed study and support a decision on a preferred alternative?

(continued on next page)

Approve Evaluation Criteria, Methodology, and Performance Measures (ENV-5) (continued)

Technical Information Needed to Answer Questions

Traffic information developed under ENV-3.

Indicators of the potential for induced change in development, including:

- Changes in distance and travel time between the project area and major trip attractors such as employment centers.
- Suitability of the project area for development or redevelopment.

Long-range transportation plans.

Local long-range land use and comprehensive development plans.

Approve Full Range of Alternatives

Environmental laws and regulations require that all feasible alternatives be considered as part of the analysis (ENV-6/PER-4). For federal law, this includes consideration of the do-nothing alternative. For both the environmental review process and environmental permitting, this step identifies and approves the range of alternatives that will be considered as part of the analysis.

Approve Full Range of Alternatives (ENV-6/PER-4)

GHG Consideration

If GHG emissions reduction was defined as part of the project purpose and need in ENV-3/PER-1, then integrating GHG at this decision step includes identifying alternatives likely to address GHG emissions reduction and, if applicable, support development trends that would aid in the reduction of GHG emissions.

Information Transfer Among Key Decision Points

The results of ENV-6 will be the starting point for the selection of alternatives to be carried forward into detailed study under ENV-7.

Questions

What alternatives are required by regulation, including low capital investment, travel demand management, and mode alternatives?

(continued on next page)

Approve Full Range of Alternatives (ENV-6/PER-4) (continued)

What alternatives were considered under predecessor planning and programming studies, and what conclusions were reached at that time?

What alternatives were suggested of scoping associated with the NOI (ENV-2)?

What additional alternatives might be reasonable with changes in future land use plans and development trends?

Which of these alternatives offer the opportunity to reduce GHG emissions, and if applicable, meet the project's GHG-related purpose and need?

Technical Information Needed to Answer Questions

- Federal and state requirements for the selection of alternatives, including those associated with federal and state goals related to GHG reduction.
- Past planning and programming studies.
- Scoping documentation.
- Traffic studies identifying need.
- Citizen and agency input.

Approve Alternatives to Be Carried Forward

For both environmental review and permitting, this step identifies and approves which alternative or alternatives merit more serious analysis and will be part of further environmental work (ENV-7/PER-5). Regulations specify the desirable characteristics of the alternatives that will be carried forward.

Approve Alternatives to Be Carried Forward (ENV-7/PER-5)

GHG Consideration

If GHG emissions reduction is part of the project purpose and need as defined in ENV-3/PER-1, then integration of GHG at this step requires that alternatives likely to reduce GHG emissions and/or support development trends that would aid in the reduction of GHG emissions be advanced for more detailed analysis.

If GHG emissions are not a part of the purpose and need, then GHG emissions reduction can be one criterion in the selection of alternatives to advance.

Information Transfer Among Key Decision Points

The alternatives approved to be carried forward for detailed study will be assessed in detail under ENV-8.

Questions

Which alternatives developed under ENV-6 will:

- Substantially meet the project purposes and satisfy project needs?
- Minimize potential GHG impacts, or maximize reduction in GHG emissions?
- Support area plans, including those whose goal is to reduce GHG emissions?
- Be affordable?

Technical Information Needed to Answer Questions

- Alternatives descriptions and traffic findings.
- Methods and associated analysis inputs identified under ENV-5 for screening potential alternatives.
- Citizen and agency input.

Approve Draft Environmental Impact Statement

The approval of a draft environmental impact statement (DEIS) (ENV-8) describes the alternatives that were analyzed, the expected impacts on the environment, and recommended mitigation strategies. A preferred alternative is also recommended as part of the DEIS. The DEIS must be approved by both state and federal officials, and the approval process is usually subject to its own public hearing and participation process.

Approve Draft EIS (ENV-8)

GHG Consideration

For the alternatives carried forward, this step assesses the changes in GHG emissions according to the criteria, methods, and performance measures developed under ENV-5, including, as applicable, direct, indirect, and cumulative impacts.

Information Transfer Among Key Decision Points

Assessment findings in combination with public and agency comments on those findings made during the DEIS review will be used in the selection of the preferred alternative under ENV-9.

Questions

What are the direct, indirect, and cumulative impacts on GHG emissions of the alternatives carried forward?

What opportunities exist for mitigating negative GHG emissions changes?

How do the build alternatives compare with each other and with the no-build alternative?

Technical Information Needed to Answer Questions

- Alternatives descriptions and traffic findings.
- Methods and associated analysis inputs identified under ENV-5 for assessment of alternatives carried forward for detailed assessment.

Reach Consensus on Jurisdictional Determination

This decision (PER-5) is a required step in the Section 404 permitting process. It is not integrated with other phases of transportation decision making or other decision-making processes.

Reach Consensus on Jurisdictional Determination (PER-5)

GHG Consideration

No GHG consideration likely for this decision point.

Approve Preferred Alternative

The governor or a designated representative is given the responsibility for approving a preferred alternative that comes out of the federal environmental impact analysis process (ENV-9). This preferred alternative has a level of detail sufficient to give stakeholders a good sense of what impacts are likely to occur.

Approve Preferred Alternative (ENV-9)

GHG Consideration

Integrating GHG considerations at this step involves using the GHG analysis conducted in previous steps to support selection of the preferred alternative from the perspective of GHG emissions reduction.

Information Transfer Among Key Decision Points

GHG-related implementation commitments need to be passed on to the design and construction team. Program of GHG integration into long-range plans needs to be developed and carried forward if applicable.

Questions

What are the GHG-related comments on the DEIS, particularly as it relates to impact findings?

What priority is placed on GHG emissions reduction as a factor in the preferred alternative decision, both in the DEIS and in the comments received?

What are the pros and cons of each alternative relating to GHG emissions and all other impacts?

What implementation commitments are to be incorporated into the project relating to GHG emissions?

What additional coordination efforts (data and/or resources) will be needed to support any desired method of GHG integration into long-range plans?

Technical Information Needed to Answer Questions

- Comments on the DEIS.
- DEIS findings.
- Impact trade-off priorities associated with local, state, and federal law and policy.

Approve Final NEPA Environmental Impact Statement

The final NEPA document is most often an environmental assessment or an environmental impact statement (ENV-10). The sponsoring agency, designated authority, and related federal agencies are part of this approval process.

Approve Final NEPA Environmental Impact Statement (ENV-10)

GHG Consideration

No explicit GHG considerations in this step.

Approve the Record of Decision and Render Permit Decision

For the environmental review process, the Record of Decision is the final action before a project enters more detailed engineering phases (ENV-11/PER-6). For the permitting process, the final step is to actually issue the permit.

Approve the Record of Decision and Render Permit Decision (ENV-11/PER-6)

GHG Consideration

GHG emissions should be included in this document if considered in previous steps.

As these steps of the decision-making framework show, many tasks must be undertaken to progress from a general sense of the transportation problems or opportunities facing a community to the implementation of specific projects. Each step relies on information that comes from both analysis results and public input. In some cases, this information is further refined as a concept goes through the decision-making process, while in other cases information might be new to that particular step. The collaborative decision-making framework is designed to provide this information.

3 ANALYSIS FRAMEWORK FOR CONSIDERING GHG EMISSIONS IN DECISION MAKING

This chapter outlines an analysis framework for considering GHG emissions in transportation planning and project development. The framework assists in answering the questions identified in Chapter 2 for each of the key decision points. The information provided in this chapter is structured around the four levels of decision making identified in the Transportation for Communities: Advancing Projects Through Partnerships (TCAPP) framework:

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

The framework provides checklists, strategy options, options for analytical 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.

The framework is organized around 13 key questions grouped into five basic steps of analysis (Table 3.1).

TABLE 3.1. GHG ANALYSIS FRAMEWORK AND KEY QUESTIONS

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 the GHG emissions analysis?
II. Define goals, measures, and resources	3. What goals, objectives, and policies relate to GHG emissions 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 emissions reduction?
	7. How will GHG considerations affect funding availability and needs?
III. Define range of strategies for consideration	8. What GHG emissions reduction strategies should be considered?
	9. Are strategies and alternatives consistent with a long-range plan and/or other relevant plan that meets GHG emissions 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 emissions reduction 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?

The five analysis steps and 13 key questions are, for the most part, common across all four levels of the TCAPP framework. However, they may be addressed at different decision points in each level, and require somewhat different analysis methods. The 13-question process is presented as an idealized process. There may be iterations among the various questions, and local agencies may consider issues in a different sequence than presented here.

The analysis framework identifies how the 13 key questions map to the TCAPP key decision points. The relationship between GHG analysis steps and the TCAPP steps is diagrammed for each level of the TCAPP framework in Figures 3.1 through 3.4. These figures show where, in each decision process, information on GHG emissions can be incorporated into key decision points.

Appendix A provides much greater detail on GHG emissions analysis and methods that will be of great benefit to *Guide* users.

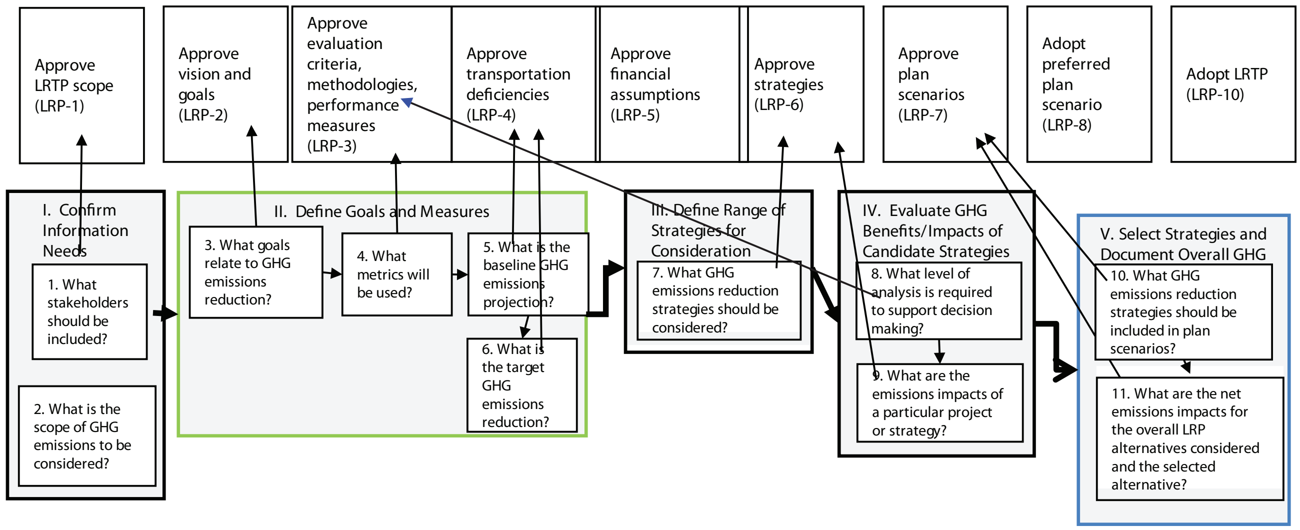

Figure 3.1. *Incorporating GHG emissions into long-range transportation planning.*

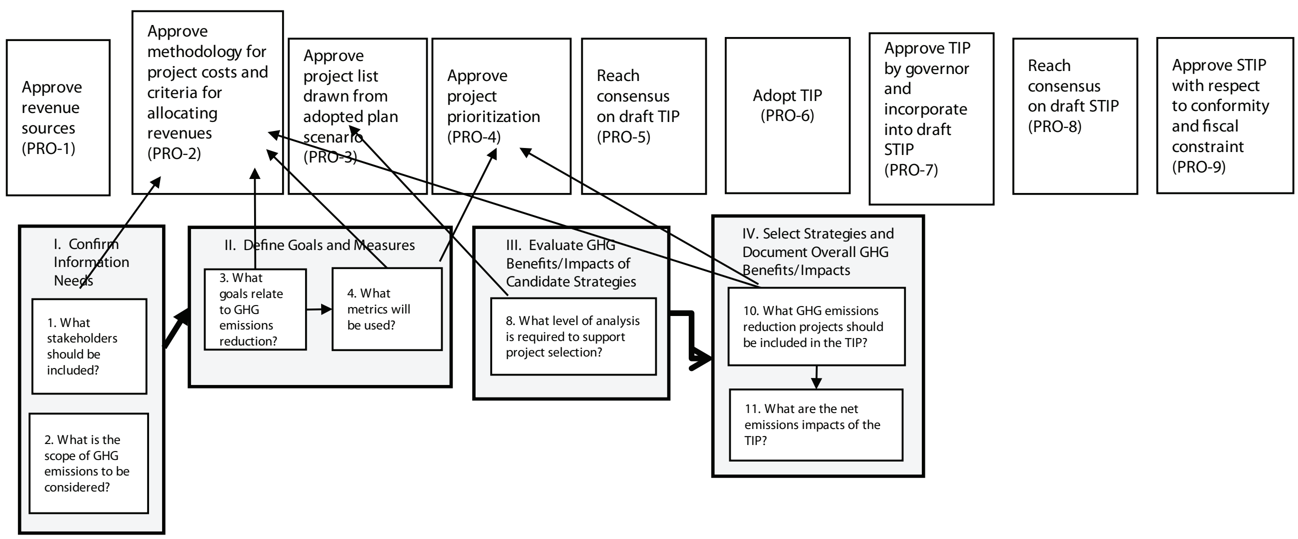

Figure 3.2. *Incorporating GHG emissions into programming.*

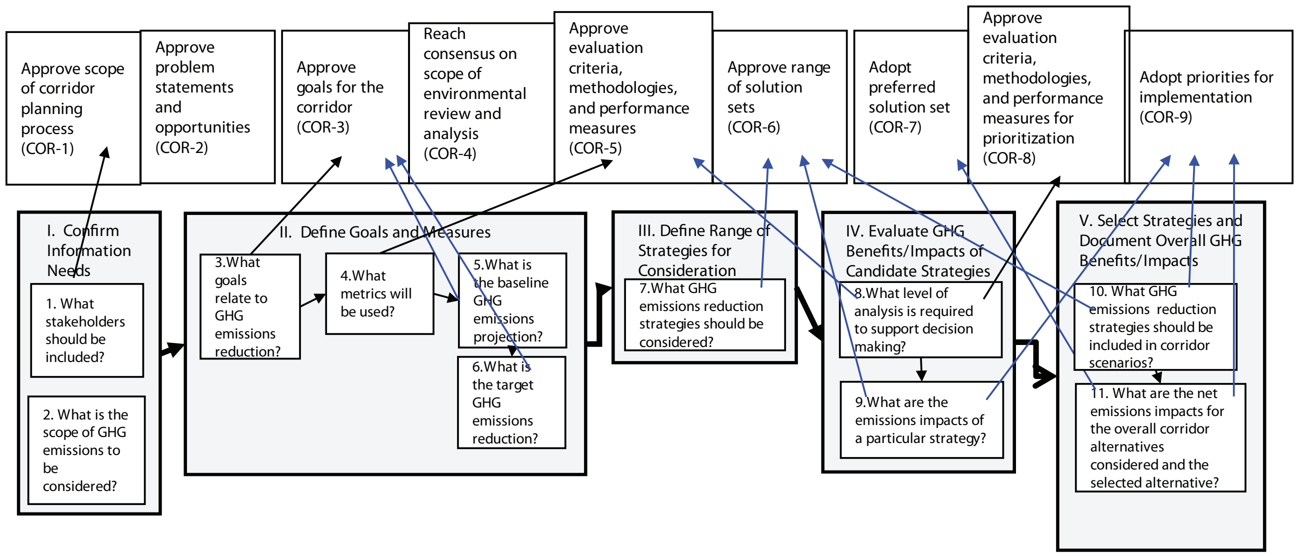

Figure 3.3. *Incorporating GHG emissions into corridor planning.*

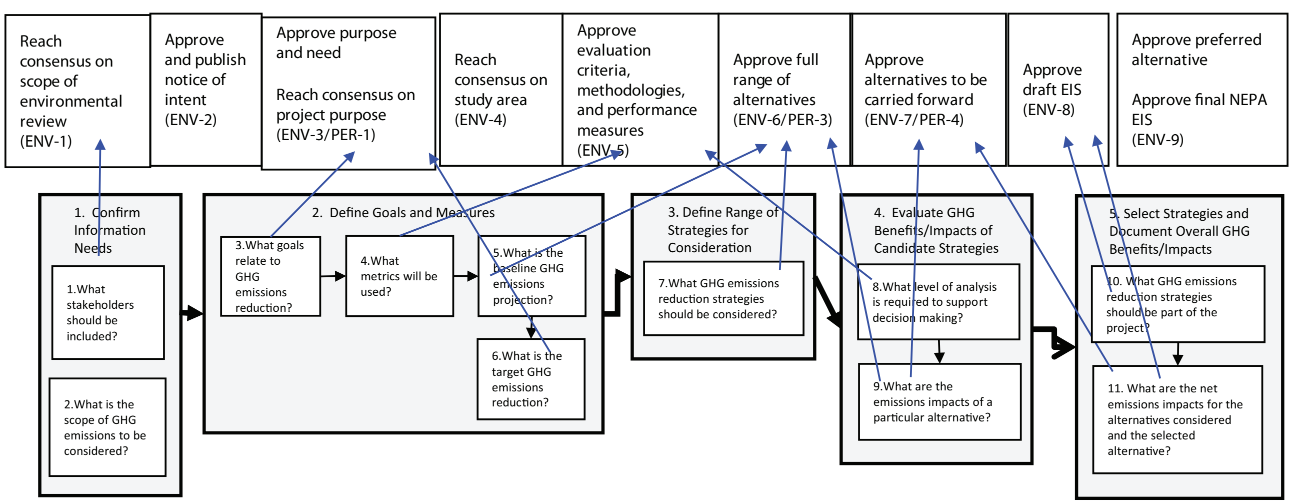

Figure 3.4. *Incorporating GHG emissions into the NEPA process and permitting.*

DETERMINE INFORMATION NEEDS

What Stakeholders Should Be Included in GHG Strategy Development and Evaluation?

Key Decision Points: LRP-1, PRO-2, COR-1, ENV-1

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 the collaborative planning and decision-making process. The TCAPP website provides guidance on stakeholder collaboration. This initial step in GHG planning ensures that key stakeholders with specific interests in GHGs and climate change issues are included in the process. Table 3.2 provides a checklist of key types of stakeholders that should be considered as part of GHG analysis.

TABLE 3.2. KEY STAKEHOLDERS IN GHG PLANNING AND ANALYSIS

____ State DOT
____ Policy & 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/logistics
____ Utilities
____ Construction
____ Advocacy groups
____ Philanthropic organizations
____ Academic/research
____ General public

What Is the Scope of GHG Emissions Analysis?

Key Decision Points: LRP-1, PRO-2, COR-1, ENV-1

Objective

Define the scope of GHG emissions considered as part of LRP or transportation improvement program (TIP) development, corridor planning, or project development and environmental documentation.

Discussion

This step involves determining (1) the emissions sources to be included, (2) the modes to be included, (3) the time frame of analysis, and (4) the geographic boundaries of the analysis. Table 3.3 provides a checklist and explanation of each option. 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 emissions reductions.

See Grant et al. (2010) discussion of target metrics, emissions sources covered, and measurement benchmarks.

TABLE 3.3. 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. See “Vehicle and Fuel Life-Cycle Emissions” in Appendix A.
Construction, maintenance, and operations	May be important for capital-intensive strategies such as new construction, but existing data are limited. See “Emissions from Construction, Maintenance, and Operations” in Appendix A.
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. See “Indirect Effects and Induced Travel” in Appendix A.
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/or interregional analysis.
Air	For statewide and/or interregional analysis.
Freight rail and marine	May be included for comprehensive transportation sector analysis; important if strategies that involve mode shifting from truck to rail are to be analyzed.

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TABLE 3.3. SCOPE OF GHG EMISSIONS CONSIDERED (CONTINUED)

Scope Consideration	Discussion
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 emissions 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 emissions reductions may also be of interest.
Geographic Boundaries	
State MPO planning area Corridor (boundaries defined in corridor study or other studies) Roadway segment (defined endpoints) Other: ____________________	Usually, the geographic analysis area for a state or metropolitan long-range plan or TIP will be the respective state or the 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.

DEFINE GOALS AND MEASURES

What Goals, Objectives, and Policies Relate to GHG Emissions Reduction?

Key Decision Points: LRP-2, PRO-2, COR-3, ENV-3

Objective

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

Discussion

Policies may include external policies and goals (e.g., federal or state); policies, goals, and objectives established by a higher-level planning document, such as a long-range transportation plan (LRTP); 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 GHGs, such as federal requirements or guidance for addressing GHG emissions in transportation planning, state reduction targets, long-range plan goals, or agencywide 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 emissions 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 emissions 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 emissions and include additional GHG reduction and/or mitigation strategies as appropriate. If GHG emissions reductions are not part of the purpose and need, GHGs may still be an important consideration, but this should be determined in consultation with project stakeholders.

Additional resources in Appendix A discuss federal and state guidance and regulations regarding GHG consideration in transportation planning and project development (current as of the fall of 2010).

What GHG-Related Evaluation Criteria and Measures Will Be Used?

Key Decision Points: LRP-3, PRO-2, COR-5, ENV-5

Objective

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

Discussion

This step involves determining what GHG-related measures will be reported, such as carbon dioxide (CO_2), total GHGs, or another proxy or related measure such as vehicle miles traveled (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 3.4 provides a list of potential metrics. The evaluation criteria and metrics selected should be consistent with any higher-level planning documents, such as the LRTP.

TABLE 3.4. GHG-RELATED METRICS

Carbon dioxide (CO_2)
Carbon dioxide equivalents (CO_2e), including: • Methane (CH_4) and nitrous oxide (N_2O) • Refrigerants
VMT (as proxy)
Energy consumption (Btu)
Cost-effectiveness (dollars/ton GHG or VMT)
Other: ___________________________

CO_2 represents about 95% of all mobile-source GHG emissions. A complete accounting of GHGs will also include CH_4, N_2O, and refrigerants, which can collectively be measured in 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 N_2O can be calculated from emission factor models such as MOVES (Motor Vehicle Emission Simulator) and 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). Black carbon is a potential GHG, but existing science and analytic methods are insufficient to support quantifying it in a GHG inventory. Appendix A provides further details on the various types of GHGs and how to calculate them.

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 consumption, which can be 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 to stakeholders for other reasons (e.g., energy security, 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. The cost-effectiveness calculation may 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 and 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. Tables A.6 and A.7 in Appendix A provide evidence from the literature on the cost-effectiveness of different transportation strategies.

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 emissions reductions can actually be achieved;
- **Leakage:** Whether the projected GHG emissions reductions might result in GHG increases outside of the planning area (e.g., a project to apply cordon pricing around a city might reduce GHG emissions within that city, but increase emissions elsewhere if trips are diverted to other locations); 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 information, refer to Grant et al. (2010) for a discussion of target metrics, emissions sources covered, and measurement benchmarks.

What Are the Baseline Emissions for the Region or Study Area?

Key Decision Points: LRP-4, PRO-5, COR-3, ENV-6

Objective

Establish a baseline (no-action) GHG emissions inventory using the selected GHG-related metric(s) and scope of emissions considered for both the base year and any analysis year(s). The baseline inventory should account for any adopted state, multi-state, and federal regulations 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, defined corridor), as well as the adopted baseline land use and socioeconomic forecasts. Different options exist for developing a baseline inventory. The method should be selected by considering factors such as data availability, level of effort, and the accuracy or precision of the 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 emissions 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 the expected change in GHG emissions as a result of a particular project or strategy, either quantitatively or qualitatively.

Two of the methods presented in Table 3.5 are oriented primarily toward a systems- and/or network-level analysis:

- VMT trend extrapolation with VMT-based emissions factors (Method A); and
- Travel demand and emissions factor models (Method B).

Two additional methods are more suited to corridor- or project-level analysis:

- Traffic counts, forecasts, and transit operating data with emissions factors (Method C); and
- Traffic simulation models (Method D).

TABLE 3.5. BASELINE INVENTORY: CALCULATION METHODS AND DATA SOURCES

Method	Comments
Method A: VMT trend extrapolation with VMT-based emissions factors	**Appropriate CDMF levels:** LRP, PRO, COR
	Description: This is the simplest approach available for transportation GHG emissions 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 not available, does not cover all modes, or forecasts for analysis year(s) not yet developed. • Detailed or 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 (see Appendix A) or using a projection already developed by a state or regional agency. — Apply GHG emissions factors (g/mi) appropriate for base and horizon years (see Appendix A). • Transit: — Obtain National Transit Database (NTD) service and fuel consumption data for the past 5 to 10 years and apply GHG emissions factors (see Appendix A). Consult with local transit agencies to project service levels for future years under existing service plans (e.g., continue same level, 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, because buses will be included in vehicle counts.
	Data sources: • HPMS: historic VMT data. • The Climate Registry's *General Reporting Protocol*: Emission rates (g/gal for CO_2, g/mi for CH_4 and N_2O). Emission rates in g/gal can be converted to g/mi using fuel economy estimates as described in Appendix A. • National Transit Database (NTD): Historic transit VMT and fuel consumption by transit mode. • U.S. Environmental Protection Agency (EPA) Emissions and Generation Resource Integrated Database (eGRID): Historic GHG emission rates for electricity (g/mW-h). Grams per megawatt-hour emission rates can be converted to grams per mile using vehicle efficiency estimates, which are commonly expressed in kilowatt-hours per mile (kW-h/mi); 1 megawatt = 1,000 kilowatts. • U.S. Department of Energy's *Annual Energy Outlook*: Projections of fuel efficiency by mode and regional emissions rate (for electricity consumption) through 2030.

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TABLE 3.5. BASELINE INVENTORY: CALCULATION METHODS AND DATA SOURCES (CONTINUED)

Method	Comments
Method B: Travel demand and emissions factor models	**Appropriate CDMF levels:** LRP, PRO, COR
	Description: This approach uses the regional or statewide travel demand model and HPMS data to develop forecasts of VMT by road type and 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: • LRP, PRO: Recommended when travel model is available and a no-build scenario has been developed. • COR: Recommended when travel model has sufficient network detail to represent traffic conditions in 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 (see Appendix A). • Adjust emissions factors for any differences in future year vehicle efficiency and/or carbon content standards not reflected in MOVES (see Appendix A). • Apply adjusted MOVES emissions factors to travel demand model output (see Appendix A). • 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 (see Method A above). • Apply transit emissions factors (see Appendix A).
	Data sources: • HPMS and travel demand model outputs (VMT by speed and vehicle type). • MOVES emissions 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) as shown in Method A above.
Method C: Traffic counts, forecasts, and transit operating data with emissions factors	**Appropriate CDMF levels:** COR, ENV
	Description: Traffic counts and transit vehicle frequencies for the base year are projected to future years using growth factors and multiplied by roadway segment length, 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 the growth trends of the previous 10 years.

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TABLE 3.5. BASELINE INVENTORY: CALCULATION METHODS AND DATA SOURCES (CONTINUED)

Method	Comments
Method C: Traffic counts, forecasts, and transit operating data with emissions factors (continued)	**Calculation methods:** • Identify road network links to be assessed, 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 served by each link 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 the number of congested and uncongested hours or periods per year based on peaking characteristics and road capacity. • 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 broken down by speed (base year and no-build design year) within the GHG study area. • Apply MOVES or EMFAC emissions factors to determine GHG emissions for the base year and design year. If including transit service in the analysis: • Obtain transit vehicle operating data for the current year and expected future year conditions (number of vehicles per day, by vehicle and fuel type, by route length within the study area). • Apply transit vehicle emissions factors from MOVES or EMFAC (diesel, gasoline, or natural gas), or another source for alternative fuel vehicles, to VMT by bus type. • Subtract transit emissions from total on-road emissions (assuming buses are included in traffic counts).
	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. • Transit operating data (current and expected or planned future). • 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.

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TABLE 3.5. BASELINE INVENTORY: CALCULATION METHODS AND DATA SOURCES (CONTINUED)

Method	Comments
Method D: Traffic simulation model	**Appropriate CDMF levels:** COR, ENV
	Description: A traffic simulation model is used in conjunction with operations-based emissions 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 detail 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 affect 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 focused 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. Simulations are generally done to analyze peak travel periods and are often focused on a portion of a road network. Therefore, simulation model results would need to be used with results from Method C to capture all GHG emissions across the links potentially affected by a proposed project.
	Calculation methods: • Standard traffic simulation models can be used (see Appendix A for an overview of these models). • Outputs from simulation models useful to GHG emissions include VMT by vehicle type and 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 as described below. • If the traffic simulation model produces fuel consumption estimates, CO_2 emission factors can be applied directly as shown in Appendix A. • If the traffic simulation model does not produce fuel consumption estimates, either (1) average speeds should be calculated by link and used in conjunction with speed-based emissions factors from MOVES or EMFAC, or preferably, (2) the detailed traffic model output should be postprocessed for use with the MOVES model. Practice in this area is still evolving and is discussed in Appendix A, "Applying MOVES in Project-Level Analyses."
	Data sources: • Traffic forecasts derived from Method C above and intersection and/or interchange turning movement studies. • Design characteristics taken from conceptual or preliminary designs, including lanes, grades, and curves.

Note: CDMF = collaborative decision-making framework.

What Is the Goal or Target for GHG Emissions Reduction?

Key Decision Points: LRP-4, PRO-2, COR-3, ENV-3

Objective

Define a quantitative target or qualitative goal for GHG emissions reductions compared with the baseline inventory or forecast. Goals or targets may be externally determined (e.g., state or federal guidance or requirement) 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 of 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 the 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 2020 from 1990 levels). Options for expressing goals or targets are shown in Table 3.6.

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 emissions 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 project contributes to GHG emissions reductions." Quantitative targets are most likely to be applied at the system level (statewide or regional long-range transportation plan 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 state-level long-range plans that have been developed to meet any applicable GHG reduction goals or targets.

TABLE 3.6. GOAL OR TARGET REDUCTION OPTIONS

Goal or Target
________Percentage 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 _____
________ Other:

How Will GHG Consideration Affect Funding Availability and Needs?

Key Decision Points: LRP-5, PRO-1

Objective

Determine how considering GHG issues in the transportation process may affect (1) available revenue sources and (2) 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.

First, revenue sources (such as federal or state funds) may be available that are specifically dedicated toward GHG emissions reduction or that require such reductions as a condition for funding. As of the fall of 2010 there were no federal aid highway programs specifically directed at GHG emissions 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 (TIGGER) program has explicitly funded GHG emissions reduction projects.

Second, some GHG emissions 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.

Finally, the evaluation of GHG strategies within the planning and project development process may require additional planning funding in order to provide personnel resources to develop inventories, conduct planning for GHG strategies, and analyze emissions reductions. It is also possible that the desire to fund GHG emissions reductions projects may be a significant factor influencing decisions about overall transportation revenue streams.

DEFINE RANGE OF STRATEGIES FOR CONSIDERATION

What GHG Emissions Reduction Strategies Should Be Considered?

Key Decision Points: LRP-6, PRO-3, COR-6, ENV-6

Objective

Identify GHG emissions reduction projects or strategies that should be evaluated for inclusion in the LRTP, TIP, corridor plan, or project design.

Discussion

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

Table 3.7 lists potential GHG emissions reduction projects and strategies and identifies the level(s) of TCAPP application for which each is most suited. Literature providing evidence on the benefits, costs, cost-effectiveness, and cobenefits of various strategies is summarized in Appendix A. It is likely that transportation agencies are already undertaking a number of these strategies. 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.

TABLE 3.7. POTENTIAL GHG REDUCTION PROJECTS AND STRATEGIES

Potential GHG Emissions 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

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TABLE 3.7. POTENTIAL GHG REDUCTION PROJECTS AND STRATEGIES (CONTINUED)

Potential GHG Emissions Reduction Projects and Strategies	Likely Levels of Application			
	LRP	PRO	COR	ENV
____ Congestion pricing	X	X	X	X
____ Speed management (limits, enforcement)	X		X	X
____ 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 low-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
Other ____	X	X	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.

Are Program, Corridor, or Project Alternatives Consistent with a Long-Range Plan and/or Other Relevant Plans That Meet GHG Emssions Reduction Objectives?

Key Decision Points: LRP-6, PRO-3, COR-6, ENV-6

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 LRTP, strategic highway safety plan, state energy plan, or state climate action plan) that has been developed with GHG emissions reduction goals in mind.

Discussion

The LRTP is intended to be an overarching transportation policy document for a state or region. Projects listed in the TIP are expected to be consistent with the goals, objectives, policies, and major projects set forth in the LRTP. Corridor planning processes and projects selected for more detailed development activities should also be consistent with the long-range plan. 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 LRTP or corridor plan will have been developed considering both land use and transportation issues (e.g., as part of a regional or corridor vision for transportation and growth), because land use patterns can significantly affect transportation GHG emissions at this level.

It is generally most practical and effective to set GHG emissions reduction targets at a transportation system or network level (plan or program), rather than for individual corridors or projects. However, an important test of whether the project or corridor plan meets overall GHG emissions reduction goals is whether it is consistent with a broader plan or program. If a statewide or regional transportation plan has been developed with consideration of GHG emissions targets or the state has developed a state energy plan or climate action plan, then the corridor or project concept being evaluated, as well as any specific alternatives or strategies, should be consistent with that plan. Checking for consistency will allow the analyst to determine whether the project and any specific strategies being considered will support GHG emissions reduction objectives. For example, programming a highway capacity expansion project that has not been included in a long-range plan evaluated for GHG emissions impacts may not be consistent with GHG reduction objectives.

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

EVALUATE GHG BENEFITS AND IMPACTS OF PROJECTS AND STRATEGIES

What Calculation Methods and Data Sources Will Be Used to Evaluate the GHG Impacts of Projects and Strategies?

Key Decision Points: LRP-3, PRO-2, COR-5, ENV-5

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 here: order of magnitude assessment, sketch-level analysis, and analysis using network or simulation models. In practice, there may be a continuum of assessment methods from simpler to more complex. Different amounts of effort may be appropriate for different strategies based on the importance of that strategy for GHG emissions 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 3.8 describes different calculation methods and data sources that can be considered for GHG analysis. Table 3.9 shows different types of analysis tools that can be used for GHG analysis.

TABLE 3.8. 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 emissions 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), and — Political climate and effects on feasibility (including public acceptability).

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TABLE 3.8. CALCULATION METHODS AND DATA SOURCES (CONTINUED)

Level of Analysis	Comments
(A) Order of magnitude assessment (continued)	**Data Sources** • A summary of cost-effectiveness by strategy is provided in Appendix A. See also "Strategy Impacts and Cost-Effectiveness" in the annotated bibliography.
(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 American Public Transportation Association methodology for transit GHG benefits. Refer to Table 3.10 for an overview of applicable tools by strategy. More details on analysis tools are provided in Appendix A.
	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 "GHG Analysis Tools" in Appendix A.
(C) Network or simulation model analysis	**Description:** This approach uses 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 emissions reductions and the desire to select the most effective and cost-effective strategies. • 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 Appendix A 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 3.10 for an overview of methods by strategy. See Appendix A for more detail on these methods.
	Data sources: Network model and off-model techniques are not described in detail in this report.

TABLE 3.9. 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 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.	• Center for Clean Air Policy (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

What Are the Emissions Impacts of Specific Projects and Strategies?

Key Decision Points: LRP-6, PRO-4, COR-6, COR-9, ENV-6, ENV-7, ENV-8

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. 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.

Some of the available tools and methods calculate travel impacts but do not directly calculate GHG emissions. 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 applied with emissions factors developed from an emissions factor model or method. "GHG Analysis Tools" in Appendix A describes the analytical tools listed in Table 3.10, which shows how such tools can be used.

TABLE 3.10. GHG EVALUATION TOOLS BY STRATEGY

Tool or Method	GHG Inventory Development	Highway Network Improvements	Urban Transit Expansion	Intercity Rail and Bus	Nonmotorized Improvements	Rail and Marine Improvements	ITS/Operations and Management	Speed Management	Idle Reduction	Transit Service Improvements	Roadway Pricing	Land Use and Smart Growth	TDM and Public Education	Vehicle and 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			

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TABLE 3.10. GHG EVALUATION TOOLS BY STRATEGY (CONTINUED)

Tool or Method	GHG Inventory Development	Highway Network Improvements	Urban Transit Expansion	Intercity Rail and Bus	Nonmotorized Improvements	Rail and Marine Improvements	ITS/Operations and Management	Speed Management	Idle Reduction	Transit Service Improvements	Roadway Pricing	Land Use and Smart Growth	TDM and Public Education	Vehicle and Fuel Policies	Construction and Maintenance Practices
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													
Other tools		Various – see Appendix A for examples													

Notes: TDM = transportation demand management.

[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 Department of Energy's *Annual Energy Outlook*, the Transportation Energy Data Book, and EPA's eGRID database.

SELECT STRATEGIES AND DOCUMENT OVERALL GHG BENEFITS AND IMPACTS OF ALTERNATIVES

What GHG Emissions Reductions Strategies Should Be Part of the Plan or Project?

Key Decision Points: LRP-7, PRO-5, COR-6, COR-9, ENV-8

Objective

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

Discussion

The selection of final strategies will not be done considering GHG impacts in isolation, but rather as part of the larger process of selecting projects or strategies considering the full range of evaluation criteria established. 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 emissions reductions 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 (synergies and antagonisms) to develop plan or project alternatives that include logical groupings of strategies. For example, a regional plan that includes transit as a GHG emissions 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.

What Are the Net Emissions Impacts for the Overall LRP, TIP, Corridor, or Project Alternatives Considered and the Selected Alternative?

Key Decision Points: LRP-8, PRO-5, COR-7, COR-9, ENV-8

Objective

Estimate GHG emissions for draft LRP alternatives and TIP, corridor, or project alternatives compared with baseline emissions and GHG emissions 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 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 shown in Table 3.11 include

- Travel demand and emissions factor models (Method A),
- Travel demand model with enhancements and/or off-model strategy analysis (Method B),
- Traffic forecasts and transit projections with emissions factors (Method C), and
- Traffic simulation models (Method D).

TABLE 3.11. CALCULATION METHODS AND DATA SOURCES FOR GHG ANALYSIS

Method	Comments
(A) Travel demand and emissions factor models	**Appropriate CDMF levels:** LRP, PRO, COR
	Description: This approach uses only the regional or statewide travel demand model and an emissions factor model to assess the GHG emissions associated with 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. • 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 Appendix A. • 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 emissions factors as detailed in Appendix A.
	Data sources: See Methods A and B in Table 3.5.

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TABLE 3.11. CALCULATION METHODS AND DATA SOURCES FOR GHG ANALYSIS (CONTINUED)

Method	Comments
(B) Travel demand model with enhancements and/ or off-model strategy analysis	**Appropriate CDMF levels:** LRP, PRO, COR
	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 GHGs need 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: • Run the travel demand model with the MOVES emissions factor model, incorporating any model enhancements developed for specific strategy analysis (see Appendix A). • Apply adjustments for off-model strategies as described in Appendix A. • Compare total emissions for the plan or TIP to target reductions, if applicable.
	Data sources: See Methods A and B in Table 3.5 and Appendix A.
(C) Traffic forecasts and transit projections with emissions factors	**Appropriate CDMF levels:** COR, ENV
	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 emissions factors.
	Situations in which to apply: • See Method C in Table 3.5. 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 3.5. 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 3.5. • Growth rates from local land use plans.

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TABLE 3.11. CALCULATION METHODS AND DATA SOURCES FOR GHG ANALYSIS (CONTINUED)

Method	Comments
(D) Traffic simulation models	**Appropriate CDMF levels:** COR, ENV
	Description: A traffic simulation model is used in conjunction with operations-based emissions factors to model current and forecast operating conditions and GHG emissions.
	Situations in which to apply: See Method D in Table 3.5. 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 3.5.
	Data sources: See Method D in Table 3.5.

ANNOTATED BIBLIOGRAPHY

GENERAL REFERENCES

Transportation for Communities: Advancing Projects Through Partnership—TCAPP. 2012. ICF International. http://transportationforcommunities.com/. Accessed Oct. 18, 2012.

This website provides a framework for collaborative decision making based on the experience of transportation professionals and stakeholders that lets users develop and prioritize transportation planning at all levels.

U.S. Department of Transportation. 2012. Transportation and Climate Change Clearinghouse: Surface Transportation Planning. Washington, D.C. http://climate.dot.gov/ghg-reduction-strategies/surface-transportation.html. Accessed Sept. 5, 2012.

This website provides resource documents on a wide variety of topics, including an overview of transportation and climate change; GHG inventories, forecasts, and data; methods for analyzing GHG emissions from transportation; GHG emission reduction strategies; climate change impacts and adaptation; state and local actions and policies; and federal actions.

POLICY RESOURCES

Federal Highway Administration. 2012. Office of Planning, Environment, and Realty: Climate Change. U.S. Department of Transportation, Washington, D.C. www.fhwa.dot.gov/environment/climate_change/index.cfm. Accessed Sept. 5, 2012.

This website provides information on FHWA research, publications, and resources related to climate change science, policies, and actions. It also includes some current state and local practices in adapting to climate change and reducing GHG emissions.

Grant, M., J. D'Ignazio, J. Ang-Olson, A. Chavis, F. Gallivan, M. Harris, K. Rooney, T. Silla, E. Wallis, and S. Siwek. 2010. *Assessing Mechanisms for Integrating Transportation-Related Greenhouse Gas Reduction Objectives into Transportation Decision Making*. NCHRP Web-Only Document 152, Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w152.pdf. Accessed Oct. 18, 2012.

This document discusses target metrics, emissions sources covered, and measurement benchmarks; alternative policy mechanisms for reducing GHGs; implications of alternative targets on states and MPOs; and analysis tools to support implementation.

ICF International. 2008. *Integrating Climate Change into the Transportation Planning Process*. Final report. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/integrating_climate_change/climatechange.pdf. Accessed Oct. 18, 2012.

The study advances the practice and application of transportation planning among state, regional, and local transportation planning agencies to successfully meet growing concerns about the relationship between transportation and climate change. The report explores the possibilities for integrating climate change considerations into long-range transportation planning at state DOTs and MPOs. The report reviews the experience of DOTs and MPOs that are already incorporating climate change into their transportation planning processes and identifies the successes and challenges faced by these agencies.

TRANSPORTATION AND EMISSIONS DATA SOURCES

The entries in this section describe some of the recurring data sources cited in this guide.

Bureau of Transportation Statistics. National Transportation Statistics. Published annually. U.S. Department of Transportation, Washington, D.C. www.bts.gov/publications/national_transportation_statistics/. Accessed Sept. 5, 2012.

National Transportation Statistics presents information on the U.S. transportation system, including its physical components, safety record, economic performance, energy use, and environmental impacts. National Transportation Statistics is a companion document to the *Transportation Statistics Annual Report*, which analyzes some of the data presented here, and State Transportation Statistics, which presents state-level data on many of the same topics discussed in the *Guide*.

The Climate Registry. 2012. *General Reporting Protocol*. www.theclimateregistry.org/resources/protocols/general-reporting-protocol/. Accessed Sept. 5, 2012.

The *General Reporting Protocol* outlines the policies of The Climate Registry and required reporting calculation methodologies for the majority of GHG sources. The Climate Registry is a nonprofit collaboration among North American states, provinces,

territories, and Native Sovereign Nations that sets consistent and transparent standards to calculate, verify, and publicly report GHG emissions into a single registry. The Registry supports both voluntary and mandatory reporting programs and provides comprehensive, accurate data to reduce GHG emissions.

Energy Information Administration. 2010. *Annual Energy Outlook 2010: With Projections to 2035*. U.S. Department of Energy, Washington, D.C. www.eia.gov/oiaf/aeo/pdf/0383(2010).pdf. Accessed Sept. 5, 2012.

The *Annual Energy Outlook* presents long-term projections of energy supply, demand, and prices based on results from the National Energy Modeling System of the Energy Information Administration (EIA). *Annual Energy Outlook 2010* projections are based on federal, state, and local laws and regulations in effect as of the end of October 2009. The potential impacts of pending or proposed legislation, regulations, and standards (and sections of existing legislation that require implementing regulations or funds that have not been appropriated) are not reflected in the projections. The *Annual Energy Outlook* is published in accordance with Section 205c of the U.S. Department of Energy Organization Act of 1977 (Public Law 95-91), which requires the EIA Administrator to prepare annual reports on trends and projections for energy use and supply.

Energy Information Administration. 2012. State Energy Data System (SEDS). U.S. Department of Energy, Washington, D.C. www.eia.gov/state/seds/. Accessed Sept. 5, 2012.

SEDS provides state-level data on energy consumption (in Btu) by fuel type for the transportation and other sectors; energy prices (per Btu); and total expenditures. Historic data are provided from 1960 through the most recent year available.

Federal Highway Administration. 2012. Highway Performance Monitoring System. U.S. Department of Transportation, Washington, D.C. www.fhwa.dot.gov/policyinformation/hpms.cfm. Accessed Sept. 5, 2012.

The Highway Performance Monitoring System (HPMS) provides data that reflect the extent, condition, performance, use, and operating characteristics of the nation's highways. It was developed in 1978 as a national highway transportation system database. It includes limited data on all public roads, more detailed data for a sample of the arterial and collector functional systems, and some statewide summary information. HPMS replaced numerous uncoordinated annual state data reports and biennial special studies conducted by each state.

Federal Highway Administration. 2012. Highway Statistics. U.S. Department of Transportation, Washington, D.C. www.fhwa.dot.gov/policy/ohpi/hss/index.cfm. Accessed Sept. 5, 2012.

The Highway Statistics series consists of annual reports published each year since 1945 containing analyzed statistical data on motor fuel, motor vehicles, driver licensing, highway-user taxation, state and local government highway finance, highway mileage, and federal aid for highways. These data are presented in tabular format as

well as selected charts. All highway data are submitted by the states. Each state's contribution is analyzed for consistency against its own past years of data and also against other state and federal data. The finished product is as close as possible to the original submission with only minor adjustments. Major issues are resolved with the help of the data provider. Although the Office of Highway Policy Information is responsible for the preparation of this publication, some of the statistical summaries are prepared by other units within FHWA as indicated by notes on the tables involved.

Federal Transit Administration. National Transit Database. www.ntdprogram.gov/ntdprogram/. U.S. Department of Transportation, Washington, D.C. Accessed Sept. 5, 2012.

The National Transit Database (NTD) was established by Congress to be the primary source for information and statistics on the transit systems of the United States. Recipients or beneficiaries of grants from the Federal Transit Administration (FTA) under the Urbanized Area Formula Program (§5307) or Other Than Urbanized Area (Rural) Formula Program (§5311) are required to submit data to the NTD. More than 660 transit providers in urbanized areas currently report to the NTD through an Internet-based reporting system. Each year, NTD performance data are used to apportion more than $5 billion of FTA funds to transit agencies in urbanized areas. Annual NTD reports summarizing transit service and safety data are submitted to Congress.

Oak Ridge National Laboratory. *Transportation Energy Data Book*. Published annually. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, Washington, D.C. http://cta.ornl.gov/data/. Accessed Sept. 5, 2012.

The *Transportation Energy Data Book* (TEDB) is a compendium of data on transportation with an emphasis on energy. TEDB contains data useful in sketch analysis, such as average energy intensities by mode, fuel economy standards and sales-weighted estimates, fuel economy by speed, household travel characteristics, and GHG emission factors.

U.S. Environmental Protection Agency. 2012. The Emissions & Generation Resource Integrated Database (eGRID). Washington, D.C. www.epa.gov/cleanenergy/energy-resources/egrid/index.html. Accessed Sept. 5, 2012.

EPA's eGRID is a comprehensive inventory of environmental attributes of electric power systems. The preeminent source of air emissions data for the electric power sector, eGRID is based on available plant-specific data for all U.S. electricity-generating plants that provide power to the electric grid and report data to the U.S. government. eGRID integrates many federal data sources on power plants and power companies from three federal agencies: EPA, the Energy Information Administration (EIA), and the Federal Energy Regulatory Commission. Emissions data from EPA are carefully integrated with generation data from EIA to produce useful values such as pounds per megawatt-hour of emissions, which allows direct comparison of the environmental attributes of electricity generation. eGRID also provides aggregated data by state, U.S. total, and company, as well as by three sets of electric grid boundaries.

STRATEGY IMPACTS AND COST-EFFECTIVENESS

Burbank, C. 2009. *Strategies for Reducing the Impacts of Surface Transportation on Global Climate Change: A Synthesis of Policy Research and State and Local Mitigation Strategies*. NCHRP Project 20-24, Task 59. Final report. Transportation Research Board of the National Academies, Washington, D.C. www.ruraltransportation.org/uploads/nchrp20-24(59).pdf. Accessed Sept. 6, 2012.

This report develops scenarios of future transportation GHG emissions based on evidence from the literature on the benefits achievable through different levels of reduced vehicle miles traveled (VMT) growth, enhanced system efficiency, and more aggressive vehicle and fuel CO_2 reductions. 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. 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 GHGs.

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

This report analyzes the nationwide GHG reduction benefits and costs of system efficiency and reduction strategies for travel behavior and VMT. Cumulative benefits and costs from 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.

Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010. *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions*. Report to Congress. U.S. Department of Transportation, Washington, D.C.

This report presents a comprehensive summary of existing literature and some original analysis on the GHG impacts and cost-effectiveness of a full range of transportation strategies. 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 low-to-high summary ranges of nationwide effectiveness (expressed in million metric tonnes of CO_2 equivalents in 2030) and cost-effectiveness (dollars per tonne) are presented for each strategy. For vehicle and fuel strategies, original estimates shown as low-to-high ranges are developed based on data found in the literature for technology effectiveness, market penetration rates, and costs. The report discusses the cobenefits of each strategy, as well as issues affecting feasibility.

Center for Climate Strategies. 2009. *Southern Regional Economic Assessment of Climate Policy Options and Review of Economic Studies of Climate Policy: White Paper Report*. Southern Governors' Association. www.southerngovernors.org/Portals/3/documents/SGA%20Regional%20Report%20in%20Full.pdf. Accessed Sept. 6, 2012.

This report presents an economic assessment of regional climate mitigation policy options in five southern states and the potential GHG impacts and costs associated with 23 strategies, including six transportation strategies.

Federal Highway Administration. 1998. *Transportation and Global Climate Change: A Review and Analysis of the Literature*. U.S. Department of Transportation, Washington, D.C. www.cf.fhwa.dot.gov/environment/glob_cvr.pdf. Accessed Sept. 6, 2012.

This study presents a synthesis of existing literature on travel reduction, fuel economy–focused, and alternative fuel (reduced carbon content) strategies and potential ranges of VMT, fuel savings, and/or GHG impacts. Impacts are not expressed in consistent terms, but rather rely on the information available in the literature. Timing of benefits and implementation issues are discussed.

International Energy Agency. 2005. *Saving Oil in a Hurry*. OECD Publishing, Paris.

This report presents sketch-level estimates of fuel savings for various VMT reduction strategies, as well as speed reduction, eco-driving, and alternative fuels. The study focuses on strategies that could be implemented in the short term to save oil over the next several years, rather than longer-term strategies aimed at reducing GHG emissions. The study is international in its data sources and assumptions; estimates are provided for 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 made.

Lutsey, N. 2008. *Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors*. Research report UCD-ITS-RR-08-15. Institute for Transportation Studies, University of California at Davis.

The author 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 GHG strategies in all sectors in a single cost per ton–reduced metric. 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 level.

McKinsey & Company. 2007. *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* Washington, D.C.

McKinsey & Company. 2009. *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*. Washington, D.C.

These reports (the 2009 report is an update of the 2007 report) 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. 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.

STATE AND METROPOLITAN STUDIES

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. The NCHRP 20-24 Task 59 report identifies 37 states that have plans completed or in progress. The Center for Climate Strategies has facilitated climate action plan development in many of these states, including strategy development and estimation of GHG emissions reductions and cost-effectiveness. However, the methods and assumptions vary greatly from state to state, and some of the estimates are highly aspirational. It is anticipated that in the future, more original analysis will be conducted at the state and metropolitan levels to estimate the potential benefits and costs of GHG emissions reduction strategies in specific local contexts.

Metropolitan Washington Council of Governments. 2008. *National Capital Region Climate Change Report*. Washington, D.C. www.mwcog.org/uploads/pub-documents/zldXXg20081203113034.pdf. Accessed Sept. 6, 2012.

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; it does not attempt to develop regionally specific quantitative estimates. The Metropolitan Washington Council of Governments has since developed a more detailed assessment of a range of GHG emissions reduction strategies. 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 in the future, more original analysis will be conducted at the state and metropolitan levels to estimate the potential benefits and costs of GHG reduction strategies in specific local contexts.

GHG ANALYSIS TOOLS

The references in this section provide information on multiple GHG analysis tools. Additional information and references for specific tools are provided in "GHG Analysis Tools" in Appendix A.

Council on Environmental Quality. 2012. Steps to Modernize and Reinvigorate NEPA. www.whitehouse.gov/administration/eop/ceq/initiatives/nepa. Accessed Oct. 17, 2012.

In 2010, the White House Council on Environmental Quality proposed steps to modernize and reinvigorate the National Environmental Policy Act (NEPA) and establish measures to assist federal agencies to meet the goals of NEPA, enhance the quality of public involvement in governmental decisions relating to the environment, and increase transparency and ease of implementation. This website provides numerous links to current and proposed NEPA changes and clarifications.

ICF Consulting. 2006. *Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects*. NCHRP Project 25-25, Task 17. Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-25(17)_FR.pdf. Accessed Sept. 6, 2012.

This report identifies 17 tools or methods that can be used to analyze the GHG implications of transportation projects and recommends models for transportation project or strategy analysis.

Washington State Department of Commerce, Fehr and Peers, and AECOM. 2009. Assessment of Greenhouse Gas Analysis Tools. Washington State Department of Commerce. www.commerce.wa.gov/DesktopModules/CTEDPublications/CTEDPublicationsView.aspx?tabID=0&ItemID=7797&MId=944&wversion=Staging. Accessed Sept. 6, 2012.

This brochure screens 60 GHG analysis tools and identifies eight as most promising for application by agencies across the state. The focus is on tools that can be used by counties and cities.

A RESOURCE MATERIAL

INTRODUCTION

This appendix provides detailed reference material related to the consideration of greenhouse gases (GHGs) in transportation planning and project development. Topics covered include

- Federal and state requirements and guidance for GHG consideration in planning;
- Surface transportation contribution to GHG emissions;
- Contextual factors influencing GHG emissions;
- Cost-effectiveness of transportation GHG reduction strategies;
- GHG analysis tools;
- Using trend analysis to project future vehicle miles traveled (VMT);
- Converting highway vehicle VMT into emissions;
- GHG emissions from transit vehicles;
- GHG emissions from nonroad vehicles;
- Emissions from construction, maintenance, and operations;
- Vehicle and fuel life-cycle emissions;
- Indirect effects and induced demand; and
- Using the MOVES model to estimate GHG emissions.

FEDERAL AND STATE REQUIREMENTS AND GUIDANCE FOR GHG CONSIDERATION IN TRANSPORTATION PLANNING

Federal Guidance on GHGs in Statewide and Metropolitan Planning

As of January 2011, there is no federal guidance on considering GHG emissions in the statewide and metropolitan transportation planning processes. The most recent surface transportation–authorizing legislation, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005, does not specifically provide for any such consideration. However, states or metropolitan planning organizations (MPOs) that wish to consider them would not find any barriers in the legislation. GHGs could even fit under the general rubric of SAFETEA-LU's fifth planning factor, which includes among its goals to protect and enhance the environment and to promote energy conservation.

Federal Guidance on GHGs in the National Environmental Policy Act

In response to requests by federal agencies and a formal petition under the Administrative Procedure Act, the Council on Environmental Quality (CEQ) released draft guidance in February 2010 on when and how federal agencies must consider GHG emissions and climate change in their proposed actions (Sutley 2010). Final guidance will not be released until sometime after the public comment period. The draft guidance explains how federal agencies should analyze the environmental impacts of GHG emissions and climate change when they describe the environmental impacts of a proposed action under the National Environmental Policy Act (NEPA). It provides practical tools for agency reporting, including a presumptive threshold of 25,000 metric tons of carbon dioxide equivalent (CO_2e) emissions from the proposed action to trigger a quantitative analysis, and instructs agencies how to assess the effects of climate change on the proposed action and their design. The draft guidance does not apply to land and resource management actions, nor does it propose to regulate GHGs. This guidance provides answers to some of the basic questions regarding how GHG analyses might be incorporated into the existing NEPA structure.

Users of this *Guide* are encouraged to identify the latest guidance from CEQ and the U.S. Environmental Protection Agency (EPA) as it relates to considering GHG emissions in the NEPA process.

Although NEPA analyses are specifically focused on impacts, the CEQ guidance recognizes that the global nature of climate change makes it impractical to literally assess the impacts of a given project on the climate. Instead, the level of GHG emissions is identified as a reasonable proxy for assessing potential climate change impacts.

The CEQ guidance identifies a reference point of 25,000 metric tons of direct emissions per year as a useful indicator of significance. Although 25,000 tons is not a hard-line threshold, above that level, agencies should plan to provide an analysis of GHG emissions in their environmental documents. This level is based on Clean Air Act (CAA) requirements that stationary sources emitting 25,000 tons or more of CO_2e emissions annually must report their emissions to the EPA; the idea is that this level provides comprehensive coverage of emissions while limiting reporting requirements to a reasonable number (U.S. Environmental Protection Agency 2009).

The CEQ guidance references several methodologies for quantifying both emissions and carbon sequestration. With regard to mitigation, the proposed guidance says, “CEQ proposes that the agency should also consider mitigation measures and reasonable alternatives to reduce action-related GHG emissions,” and further, “agencies should evaluate GHG emissions associated with energy use and mitigation opportunities and use this as a point of comparison between reasonable alternatives.”

Several other provisions are of interest to transportation practitioners. CEQ notes that some agencies may choose to examine GHG emissions in aggregate, citing transportation programs as lending themselves to this programmatic approach. In that case, subsequent NEPA analyses for actions implementing that program at the project level would tier from the programmatic NEPA analysis, summarizing relevant issues already dealt with at the programmatic level.

Finally, the CEQ guidance identifies the effects of climate change on the proposed project as an impact that should be examined in NEPA. Specifically, climate change effects should be considered in the analysis of projects that are designed for long-term use and located in areas vulnerable to specific climate drivers (such as sea-level rise) within the facility’s lifetime. The project’s effect on the vulnerability of affected ecosystems should also be considered in the context of projected climate changes and resulting implications for that ecosystem’s ability to adapt. Rather than recommending that agencies develop climate projections for each action, the guidance merely recommends summarizing the relevant scientific literature on projected climate changes, particularly the synthesis and assessment products of the U.S. Global Change Research Program. (Although not discussed in the guidance, in the future the development of the National Oceanic and Atmospheric Administration’s National Climate Service may provide a unified federal source of climate projection data.) For adaptation, CEQ notes particularly that monitoring programs can be helpful not just to ensure that decisions are carried out as provided in the Record of Decision, but also because adaptive planning requires constant learning to reduce uncertainties. For example, adaptation is an iterative process in which monitoring is needed to assess how well the adaptations are working in the context of how the climate is actually changing (as compared with projections).

Implications of EPA Authority to Regulate GHGs Under the Clean Air Act

The CAA uses two main strategies for meeting clean air goals: emissions standards and national ambient air quality standards. EPA’s authority to regulate GHGs under the CAA is easily translated into GHG emissions standards for vehicles, and EPA has already shown its willingness to act by mandating new fuel economy and GHG emissions standards (U.S. Environmental Protection Agency 2010b). These new standards, and any that may follow, will contribute to reducing transportation GHG emissions significantly.

State and local planners, however, are much more involved in the other side of the CAA: the national ambient air quality standards and the resulting regulatory structure for transportation conformity. The current structure of these standards under the CAA is not ideal to follow for GHG regulations. The national ambient air quality standards regulations are designed for pollutants in which local and regional concentrations are important; that is, where emissions are released is as important as how much. Thus, emissions control measures are governed by local concentrations of different pollutants. Although GHGs could in theory be regulated through a conformity-style approach, such an approach does not address the global nature of GHG concentrations, particularly for project-level analysis. Any given project, or an entire region's worth of projects, would have essentially no effect on ambient CO_2 concentrations. However, elements of the conformity approach, such as developing regional GHG emissions budgets for transportation, could be used as a way to translate national GHG targets into state or local policies to reduce emissions. One method might be to require states and MPOs to report transportation GHG emissions as part of the transportation conformity process or separately (as a requirement for all areas, even those in attainment and maintenance status for all other pollutants), even if no budgets or restrictions are set. (By analogy, EPA has instituted mandatory GHG reporting for large stationary sources under the CAA, even though emissions standards have not yet been set.) At some point, it is likely that state and local planners will be required to report GHG emissions from transportation sources, regardless of the strategy EPA or Congress pursues.

State Practice on Considering GHGs in Transportation Planning

Some states have adopted requirements or provided guidance on considering GHG emissions in state and regional transportation planning.

California Senate Bill (SB) 375 requires MPOs to develop a sustainable communities strategy that lays out a plan to meet the region's transportation, housing, economic, and environmental needs in a way that enables the area to meet the statewide GHG emissions reduction targets set by the California Air Resources Board (CARB) under Assembly Bill 32. CARB has worked with regional planning agencies throughout the state to set acceptable region-specific GHG targets from the transportation sector. To create incentives for compliance, funding for new transportation projects is linked to projects fitting into the sustainable communities strategy, and strategies such as transit-oriented development are given a streamlined state environmental review process or exempted from review altogether.

California's SB 375 GHG reductions illustrate the potential for achieving GHG reductions through land use and transportation planning. The final targets established by CARB for SB 375 GHG reductions statewide, across all the MPOs in California, amount to 3 million metric tons in 2020 (out of projected statewide GHG emissions of 596 million metric tons in 2020), or one-half of 1% of projected GHG emissions in California.

The Massachusetts Department of Transportation's GreenDOT policy, adopted in June 2010, sets reducing GHG emissions as one of three mutually reinforcing goals and establishes policies to achieve those goals. The policy requires that statewide and regional transportation planning documents, including MPO long-range transportation plans, integrate the GreenDOT goals and that statewide and regional transportation improvement programs include GHG emissions reduction as a projection selection factor (Massachusetts Department of Transportation 2010).

The New York State Energy Plan requires MPOs to conduct a GHG analysis of their transportation plans, although it does not require them to meet any reduction targets (Volpe National Transportation Center 2009).

Washington State has set per capita VMT reduction targets of 18% in 2020, 30% in 2035, and 50% in 2050. All of these targets are compared with a 2020 baseline. These benchmarks are set statewide, with no directives on regional target setting. However, Executive Order 09-05 (Washington's Leadership on Climate Change) directs the Secretary of the Department of Transportation to work collaboratively with other state agencies, local and regional governments, and others organizations to estimate current and future statewide levels of VMT, evaluate potential changes to VMT benchmarks to address low- or no-emission vehicles, develop additional strategies to reduce emissions from the transportation sector, and cooperatively develop and adopt regional transportation plans that will reduce GHG emissions and achieve the statutory benchmarks to reduce annual VMT per capita. As of late 2010, a working group is in the process of developing reports on these issues.

State Practice on Considering GHGs in State Environmental Review

Even before CEQ released its federal NEPA guidance, some states had begun grappling with the issue of GHGs in their own state environmental reviews. Three notable examples are California, Massachusetts, and Washington. These three states pursue largely similar approaches but also show important differences in how thresholds of significance are defined, how life-cycle emissions are treated, which GHGs are to be considered, and recommended protocols for quantifying emissions.

California

Effective March 18, 2010, California adopted revisions to its California Environmental Quality Act (CEQA) regulations that introduce GHGs into the CEQA process (State of California 2010). The CEQA guidance does not establish criteria for setting thresholds of significance, and CARB has been asked to recommend a method for doing so. It does note that one consideration would be the extent to which a given project would help or hinder attainment of the state's goals in reducing GHG emissions. In the context of SB 375 and other efforts throughout the state to reduce emissions, this may be understood as the extent to which a project is consistent with local or regional blueprint plans, sustainable community strategies, climate action plans, or other policies to reduce emissions. Similar to CEQ's proposed NEPA GHG regulations, the CEQA rules allow agencies to assess GHG impacts at a programmatic level, such as in a general plan; a long-range development plan; or some other GHG reduction plan. Later project-specific environmental documents may tier from and incorporate by reference the existing programmatic review. CEQA also provides a streamlined process for some types of projects that are presumed to have beneficial GHG reduction impacts; as a result, certain residential, mixed-use, and transit projects do not need to perform an assessment of GHG emissions from light-duty vehicles (LDVs).

Carbon offsets and carbon sequestration are both identified as potential mitigation measures. The policy does not specify the methodology for doing these analyses, but it does reference models that could be used, including CARB's mobile source emission factor model, EMFAC. California defines GHGs to include the six Kyoto Protocol gases: CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (SF_6).

It should be noted that there are some efforts in California to simplify or create exemptions to CEQA because of the level of difficulty involved in completing a CEQA review; for instance, the governor proposed allowing up to 100 exemptions from CEQA each year (Shigley 2010).

Massachusetts

In 2007, Massachusetts released a policy on GHGs for all new Massachusetts Environmental Policy Act (MEPA) reviews (Massachusetts Executive Office 2007). This policy calls for analysis of CO_2 emissions only and does not address other GHGs. The transportation emissions calculation protocol is relatively straightforward compared with calculations performed for criteria air pollutants. For transportation emissions, it requires project sponsors to calculate net new VMT resulting from the project, and multiply that VMT by the MOBILE6.2 CO_2 emissions factors using either individual factors for each vehicle type or using the Massachusetts fleetwide emission factor provided in the guidance. (MOBILE6.2 CO_2 emissions factors, unlike emissions factors for other pollutants in the model, do not differentiate emissions by speed or congestion conditions.) To calculate VMT reduction from travel demand management strategies, MEPA recommends the use of the EPA COMMUTER and CUTR Work Trip Reduction models.

The MEPA policy requires calculation of transportation emissions not just from transportation projects, but also from any development that has VMT impacts. For instance, an industrial facility doing a MEPA review would need to account for the VMT generated by trucks bringing supplies and by workers commuting in their cars. The policy allows for the use of carbon offsets as a mitigation tool, but it gives priority to on-site mitigation, as well as suggesting that local or regional offsets be given priority. It allows project sponsors who propose exceptional measures to reduce GHGs to opt out of doing the GHG analysis.

Washington

The Washington State Department of Transportation's (WSDOT) *Guidance for Project-Level Greenhouse Gas and Climate Change Evaluations* addresses GHG consideration in transportation project environmental review (Washington State Department of Transportation 2010). The guidance is particularly noteworthy in that it separates emissions into three categories: operational, construction, and embodied or life cycle. The guidance also provides boilerplate language to use in GHG discussions. The policy does not discuss the role of carbon sequestration and offsets.

Rather than defining a threshold of significance based on the tonnage emitted, WSDOT defines the level of analysis required by the type of environmental documentation being prepared; for example, no analysis is done for categorical exclusions; qualitative analysis is done for environmental assessments; and quantitative analysis is done for environmental impact statements (see Table A.1). The analysis varies by type of emission. For quantitative analyses, WSDOT recommends the use of EPA's MOVES model for operations emissions and the *Energy Discipline Report* for construction emissions (CH2M HILL 2009). It only recommends qualitative discussions of embodied and life-cycle emissions in an environmental impact statement, and none in an environmental assessment.

TABLE A.1. OVERVIEW OF ANALYSIS BY DOCUMENTATION TYPE, WASHINGTON STATE

Type of Emission	Categorical Exclusion	Documented Categorical Exclusion/Checklist/ Environmental Assessment	Environmental Impact Statement
Operational	No	Qualitative	Quantitative
Construction	No	Qualitative	Quantitative
Embodied or life cycle	No	No	Qualitative

Source: Washington State Department of Transportation (2010).

SURFACE TRANSPORTATION CONTRIBUTION TO GHG EMISSIONS

Emissions by Sector

The *Inventory of Greenhouse Gas Emissions and Sinks* (U.S. Environmental Protection Agency 2010b) provides historic data on GHG emissions from transportation and other sectors. Direct transportation emissions from on-road sources accounted for approximately 23% of total 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 A.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 emissions soon to be (or already) surpassing industrial emissions. The industrial sector also includes transportation-related emissions, including those associated with vehicle manufacture, fuels production, and production of cement and other materials for transportation facilities (see below).

The growth in transportation GHG emissions between 1990 and 2008 was caused by an increase in VMT (especially for medium- and heavy-duty trucks) and stagnation of fuel efficiency across the U.S. vehicle fleet. Person miles traveled by LDVs increased 36% from 1990 to 2008, ton-miles carried by medium- and heavy-duty trucks increased 55% from 1990 to 2007, and passenger miles traveled by aircraft increased 63% from 1990 to 2008 (Bureau of Transportation Statistics 2009). The increases in aircraft passenger miles were offset by improvements in aircraft efficiency, operating efficiency, and higher load factors over this time period; aircraft emissions were roughly the same in 2006 and 2007 as in 1990, and slightly lower in 2008 (U.S. Environmental Protection Agency 2010b, Table 2.15).

Although average fuel economy for the LDV fleet over this period increased slightly because of the retirement of older vehicles, average fuel economy among new vehicles sold actually declined between 1990 and 2004. This decline reflected the increasing

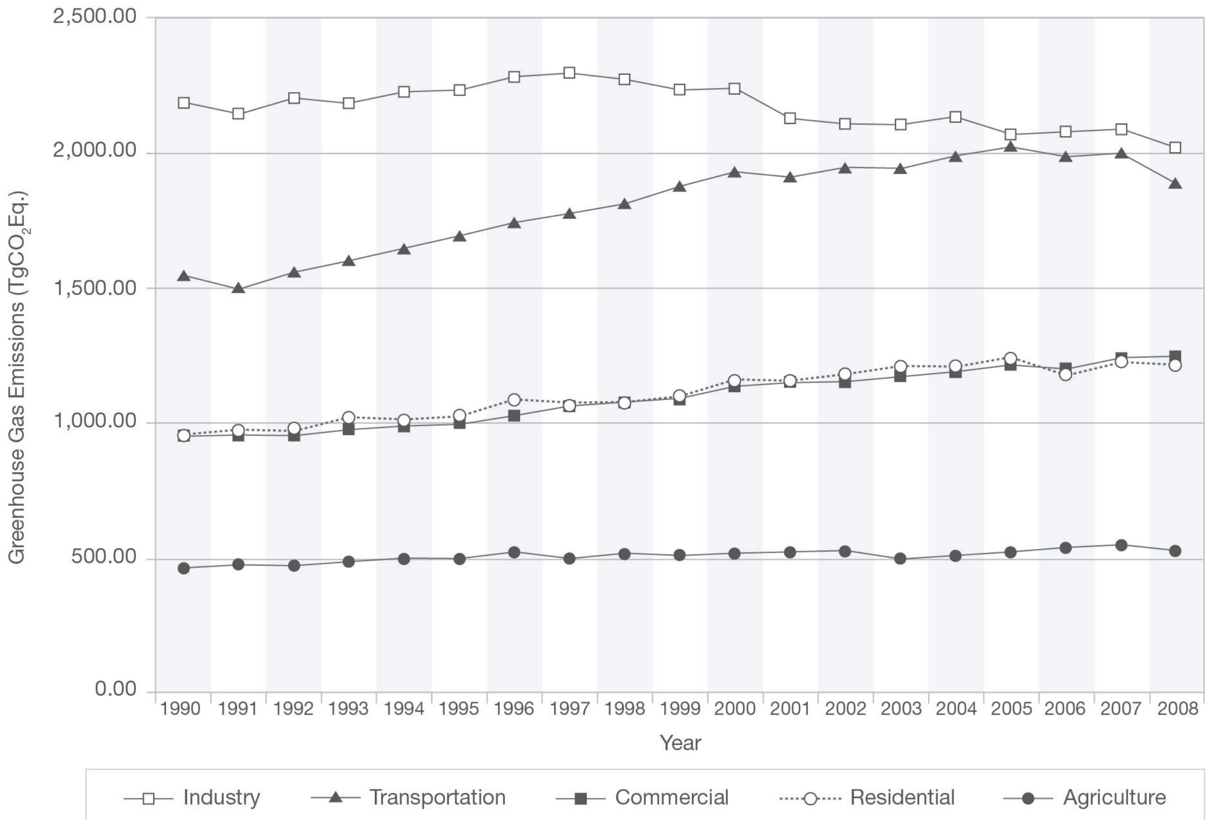

Figure A.1. *Historic trends in GHG emissions by sector.*

market share of light-duty trucks, which grew from about one-fifth of new vehicle sales in the 1970s to slightly more than half of the market by 2004.

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 VMT slowed from an annual rate of 2.6% from 1990 to 2004 to an average annual rate of 0.7% from 2004 to 2007, and in 2008 decreased for the first time since 1980 (due primarily to higher gasoline prices and the economic turndown) (Bureau of Transportation Statistics 2009, Table 1.32). There appears also to be a long-term structural lowering of VMT growth rates, as historic sources of VMT increases may well be plateauing because of factors such as the entry of women in the workforce, population growth, and LDV and licensed driver relationships coming close to saturation levels.

The U.S. Department of Energy's *Annual Energy Outlook* (AEO) provides forecasts of CO_2 emissions by sector through 2035; these forecasts are referred to as the AEO reference case (Energy Information Administration 2010). The AEO reports only CO_2 emissions, but the historic data from the EPA inventory include all GHG emissions. Since CO_2 makes up more than 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 the present and future years. The reference case projection considers the effects of LDV fuel economy standards through model year 2016 and the Renewable Fuel Standard 2 adopted in 2010, but not the effects of any post-2016 fuel economy requirements or proposed efficiency requirements for heavy-duty vehicles.

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 2030, as shown in Figure A.2. The AEO forecasts transportation energy usage and GHG emissions based on projections of activity and fuel efficiency for each mode. The 2011 early release AEO reference case projects that for LDVs between 2007 and 2035, fuel economy gains are almost entirely offset by increases in VMT. LDVs include passenger cars, motorcycles, and light trucks with less than an 8,500 lb 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 underlying factors that drive these trends, 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

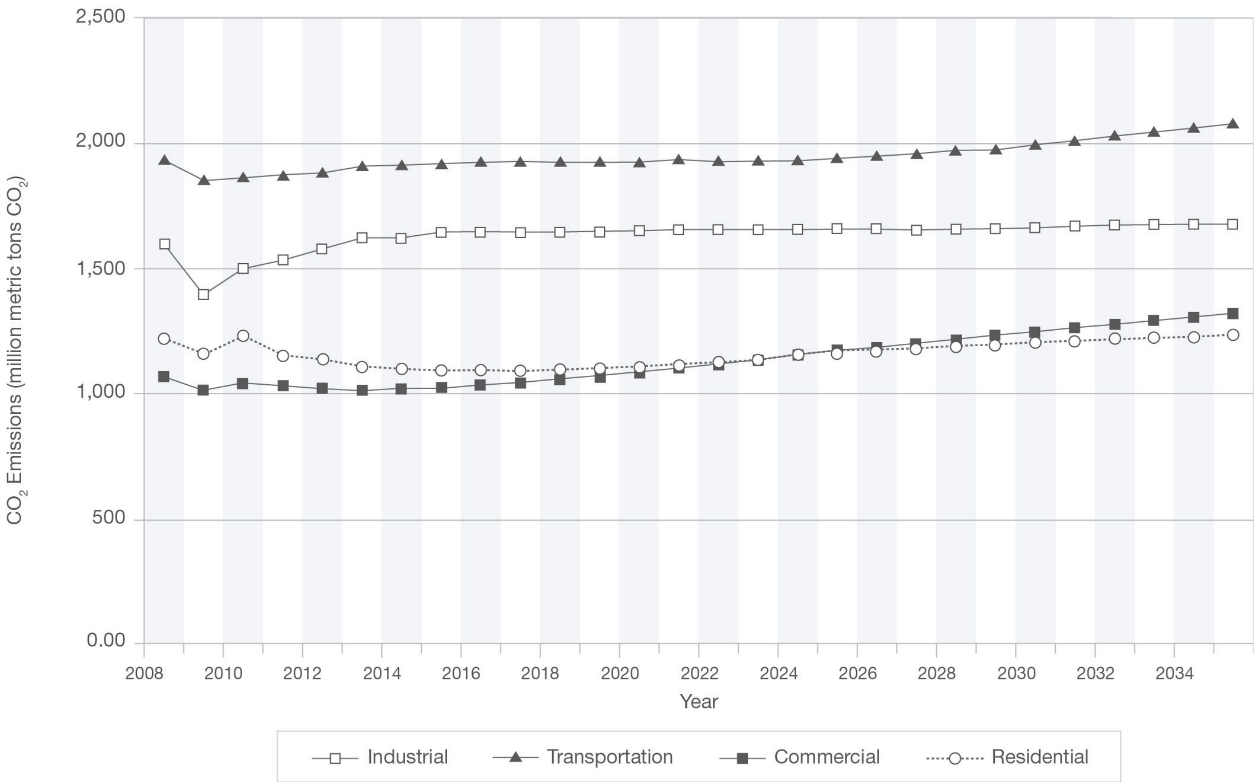

Figure A.2. *Forecasted CO_2 emissions by sector.*

as how increases in industrial output increase heavy-duty vehicle (truck) activity, as well as rail, marine, and air transport activity.

The 2011 early release AEO forecasts reflect an average annual increase in VMT of about 1.3% over the next decade (1.1% for LDVs and 2.6% for trucks) and 2.0% between 2020 and 2030 (1.5% for trucks), yielding an average annual 1.5% increase between 2006 and 2030. Although this is a reduction from previous forecasts that predicted a 1.8% increase, it still may be high considering recent economic and system usage trends.

Emissions by Mode

Figures A.3 and A.4 provide a detailed inventory of transportation-related GHG emissions sources for both historic and forecast 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%.

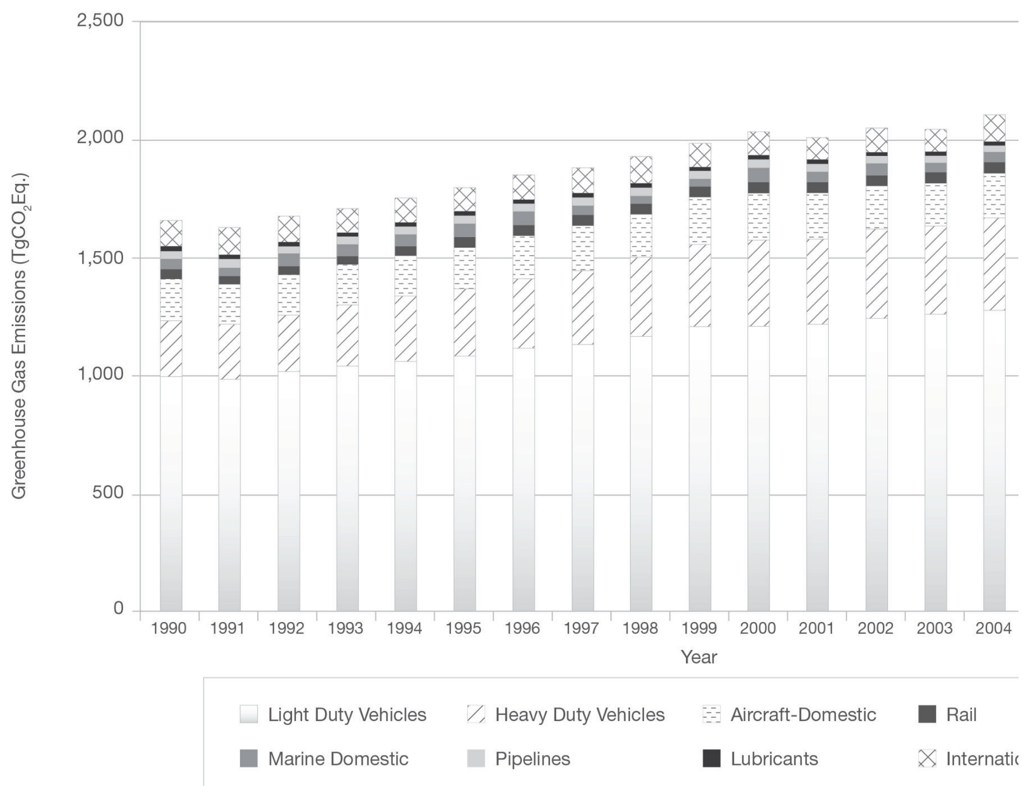

Figure A.3. *Inventory of transportation-related GHG emissions by mode.*

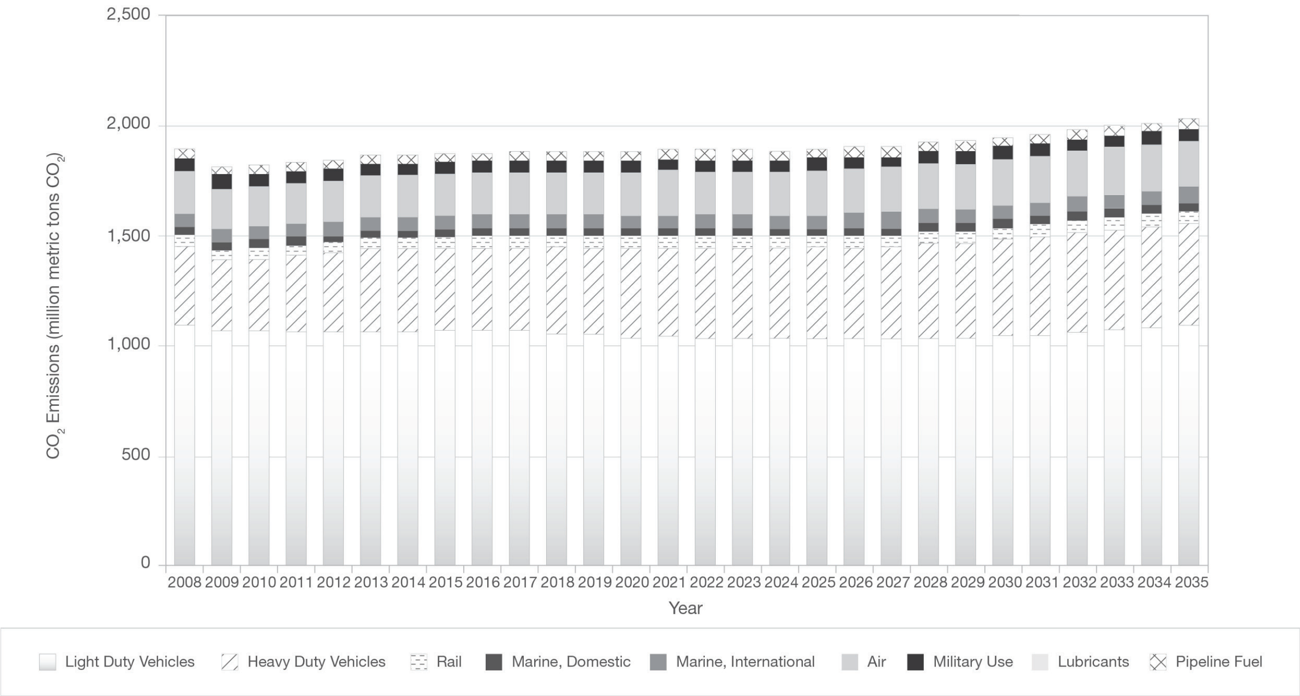

Figure A.4. *Future inventory of transportation-related GHG emissions by mode.*

As discussed above, 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. These emissions may decrease more if proposals to further increase light-duty fuel efficiency standards, as well as to adopt heavy-duty emissions standards for the first time, are implemented.

Figures A.5 and A.6 show contributions to GHG emissions by both passenger and freight modes. As shown in Figure A.5, the vast majority of passenger transportation GHG emissions come from LDVs, which accounted 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 (9% of passenger transportation emissions and 7% of total emissions). Travel by bus, motorcycle, rail, and ship accounted for the very small balance of passenger transportation and total emissions.

Figure A.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% 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.

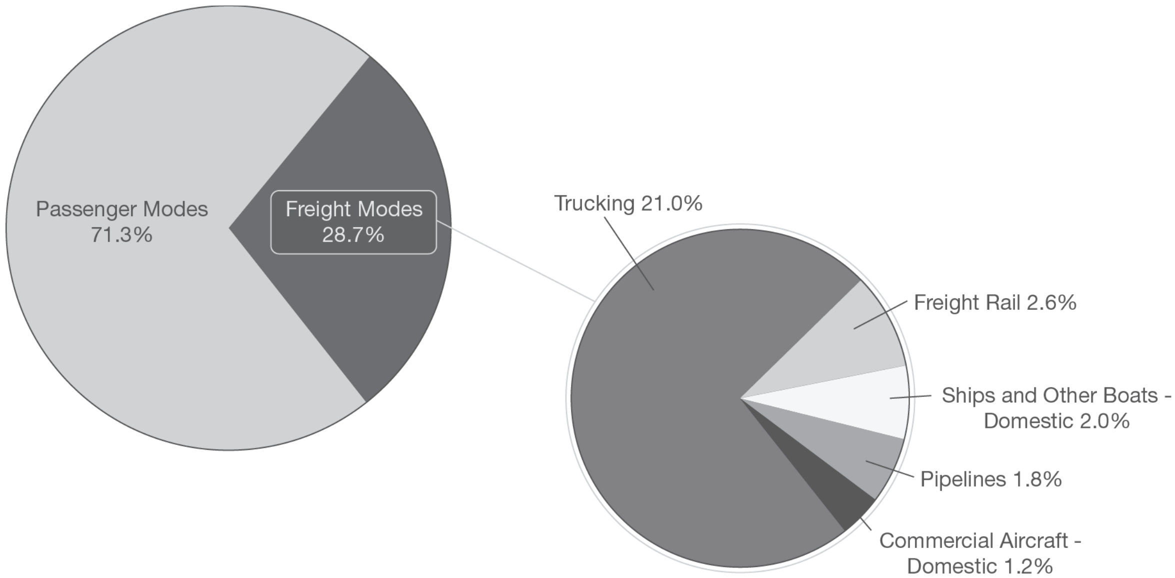

Figure A.5. *Contribution to GHG emissions, passenger modes.*

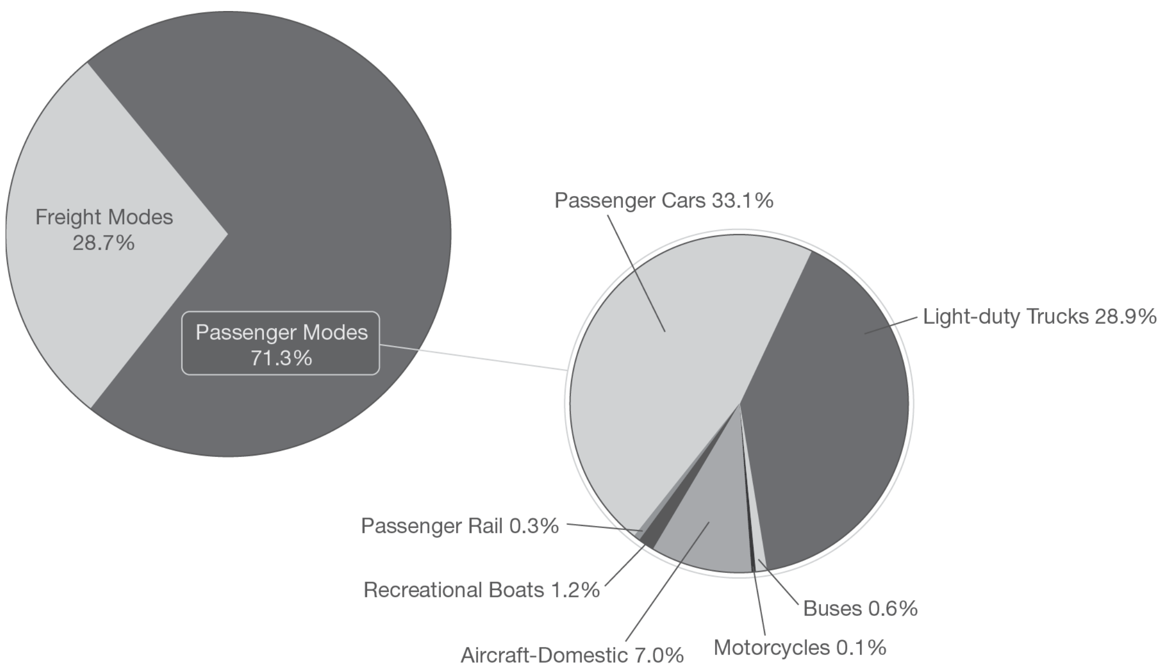

Figure A.6. *Contribution to GHG emissions, freight modes.*

Perhaps of greatest interest in freight-related GHG emissions is that emissions from heavy-duty trucks have increased rapidly since 1990, growing at three times the rate of LDV emissions. This increase is the product of decreasing fuel efficiency (per ton-mile carried) and increasing demand for freight movement by trucks. From 1990 to 2007, CO_2 emissions per ton-mile carried increased almost 12%, and 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. In October 2010 the federal government proposed heavy-duty fuel efficiency standards for the first time, which may begin to reverse this trend if implemented (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration 2010b).

CONTEXTUAL FACTORS INFLUENCING TRANSPORTATION GHG EMISSIONS

Overview of Contextual Factors

The AEO reference case presented above is just one potential 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 (e.g., speed, congestion, construction and maintenance practices, infrastructure investment, and pricing), and some over which they have little or no influence (e.g., population growth and vehicle and fuel technologies). As shown in Figure A.7, GHG emissions from passenger and freight travel are affected by five primary factors: total travel activity, the fuel efficiency of vehicles, the operational efficiency of drivers and the system (e.g., congestion, speed and aggressive driving), the carbon content of fuels, and energy use associated with construction and maintenance.

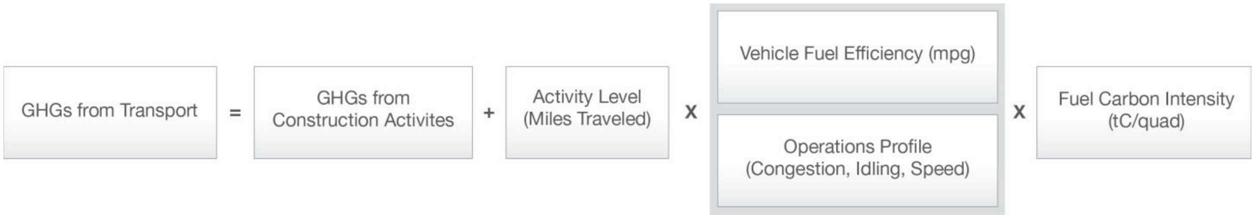

Figure A.7. *Different components of transportation-related GHG emissions.*

Table A.2 presents an overview of key contextual factors that could influence GHG emissions and surface transportation energy use. The table also identifies which of the components of transportation GHG emissions (identified above) each factor will likely affect. Additional discussion is provided in the following sections on several important factors that are most directly relevant to GHG planning and analysis. These factors include

- Transportation costs and pricing (fuel cost, public-sector user fees, parking pricing, vehicle insurance pricing, congestion pricing, and vehicle registration fees);
- Population and economic activity;
- Passenger and truck VMT;
- Vehicle technology and fuel efficiency;
- Carbon intensity of transportation fuels;
- Operational efficiency by drivers and system managers;
- Construction, maintenance, and agency operations; and
- Future scenarios for energy use, supply, and costs, including potential economy-wide federal policy initiatives directed at GHG emissions reductions (e.g., cap-and-trade carbon tax).

TABLE A.2. CONTEXT FACTORS THAT COULD INFLUENCE GHG EMISSIONS AND SURFACE TRANSPORTATION ENERGY USE

Factor Category	Factor	Influence
Transportation costs and pricing	• Congestion pricing • Parking pricing • User fees (e.g., gas taxes, VMT fees, and 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

(continued on next page)

TABLE A.2. CONTEXT FACTORS THAT COULD INFLUENCE GHG EMISSIONS AND SURFACE TRANSPORTATION ENERGY USE (CONTINUED)

Factor Category	Factor	Influence
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 (e.g., 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 and California Pavley standards and consumer purchase decisions • Emerging alternative propulsion systems (e.g., 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 A.2. CONTEXT FACTORS THAT COULD INFLUENCE GHG EMISSIONS AND SURFACE TRANSPORTATION ENERGY USE (CONTINUED)

Factor Category	Factor	Influence
Construction, maintenance, and 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 that affect 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; CAFE = corporate average fuel economy.

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 Bureau 2008, Table 1). This is important to travel trends because immigrants are usually already working age and need to travel to work, unlike people born in the United States, who will not reach working age until much later in life. 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 (U.S. Census Bureau 2008, Table 2). This increase in an older population will potentially reduce the demand for personal travel and especially work-related travel.

Economic growth also affects transportation demand, because 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

Numerous groups and organizations have developed passenger and truck VMT forecasts. 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%, but higher than the U.S. Census projection of 0.93% annual population growth. The 2009 AASHTO *Bottom Line* report (American Association of State Highway and Transportation Officials 2009) used a growth rate of 1.4% 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, lower economic growth, saturation of the workforce, plateauing of women's entry into the workforce, an 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 has been only 1.4%, with an absolute decline occurring in 2008.

The early release of the 2011 *Annual Energy Outlook* projects an annual average growth in truck VMT of 1.9% between 2011 and 2020, moderating to 1.4% through 2035. The long-term growth rate is in line with the AASHTO *Bottom Line* report, which forecasts truck VMT growth at the same 1.4% annual rate as LDV VMT. The AASHTO 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 and 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, AEO projects 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% in the 2030 projections. Dramatic shifts away from spark- and compression -ignited engines are not anticipated in the next 20 years, however, 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 expected to be down to 36%, mostly as a result of a shift in LDV sales from SUVs to midsize and large cars.

The 2007 Energy Independence and Security Act (EISA) required a change in the federal fuel economy standards for the first time in 20 years. In May 2010, EPA and the National Highway Traffic Safety Administration (NHTSA) 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 2010c). In October 2010, the agencies announced their intent to propose more stringent light-duty fuel efficiency standards for the 2017 through 2025 model years, with potential for a fuel economy standard as high as 62 mi/gal or as low as 47 mi/gal for model year 2025 (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration 2010a).

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, while the 2030 AEO 2009 forecast is for sales near 20 million units per year. Some analysts believe that the most recent historic sales are, for various reasons, artificially high, 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 for organizations to meet GHG emissions reduction targets. However, in most households with more than one vehicle, newer, fuel-efficient vehicles are likely to be used more intensively than older, less efficient vehicles, so the effect on VMT by more efficient vehicles is likely to be greater than the market penetration of new vehicles alone would suggest.

Unlike LDVs, heavy-duty vehicles are not currently subject to fuel efficiency standards. However, the 2007 EISA required that EPA evaluate fuel efficiency standards for trucks. In October 2010 EPA and NHTSA announced proposed GHG and fuel efficiency standards for heavy-duty trucks. 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 because 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 System Operations and Operational Efficiency of Drivers

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 expansions of the transportation system and maintenance and operational investments in the existing system. Many agencies, in particular state DOTs, have begun to use intelligent transportation systems (ITS) and other management and operations strategies to mitigate declines in reliability and increases in travel time 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 because of congestion, a substantial increase from 0.5 billion gallons in 1982 (Texas Transportation Institute 2007), the success of such strategies in reducing growth in delays and 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.

Lane management, a strategy that expands on the traffic management center and ITS concept, allows the transportation agency to actively manage travel lanes in real time for optimal flow conditions. Managed lanes, also known as high-occupancy toll lanes, allow carpools to ride for free, but charge other vehicles a toll that varies by time of the day and current traffic conditions. 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 emissions reductions due to fuel savings from management and operational strategies are likely to be partially offset by induced demand, or the increase in travel that results from improved travel conditions. The magnitude of the induced demand effect is a subject of considerable uncertainty and is likely to vary according to the type of strategy. For instance, strategies that reduce travel time or improve reliability (such as most ITS strategies) would be most likely to result in some amount of additional travel, thus reducing the magnitude of congestion and GHG benefits over the long run. In contrast, operations strategies that modestly increase travel time (such as enforcement of reduced speed limits) or raise monetary travel costs (such as congestion pricing) are not believed to result in additional travel demand, and could actually have a slight suppressing effect.

In calculating induced demand for GHG analysis purposes, it is critically important to exclude induced demand that is based on mere shifts in VMT from one facility to another or from one time of day to another, because these are not net increases in GHG but merely a shift in time or location. Moreover, induced demand associated with operational improvements may be lower than induced demand associated with adding highway lane capacity. Hymel et al. (2009) estimated the elasticity of statewide induced demand as being 0.037 in the short run and 0.186 in the long run; that is, their estimates are smaller than most previous estimates of induced demand. Only about 40% of this effect is associated with reducing congestion in urban areas; 60% of the induced demand effect related to shortening distances for road trips.

In the future, as vehicle technologies (such as hybrids or electric vehicles) that are more efficient in low-speed operation become more widely adopted, the GHG emissions reduction effects of operational strategies will decline. 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. This effect is by no means unique to operational strategies. It is equally true that the GHG emissions reduction effects of most other transportation strategies, including land use, transit, and other VMT-reducing strategies, will decline commensurate with success in decarbonizing vehicles and fuels.

Driver behavior is another factor in improving the operational efficiency of the system. Eco-driving (defined as avoiding rapid accelerations and braking, avoiding speeding, proper gear shifting, and using cruise control) and enhanced maintenance of vehicles are estimated to have a 1% to 5% potential in reducing GHG emissions (U.S. Department of Transportation 2010). The benefits of such efforts, however, seem to vary by how long the behavior lasts. Two U.S. studies compared fuel consumption under standard versus more aggressive driving cycles. An EPA study found that aggressive driving can reduce gas mileage by 33% at highway speeds; a CARB study found an increase in fuel consumption of 5% to 14% accompanied more aggressive driving (International Energy Agency 2005). In Europe, where eco-driving campaigns have been more widespread and implemented for a longer time than in the United States, short-term savings have been found to be higher than long-term savings. For example, one estimate found reductions in fuel consumption of 15% to 25% for drivers in the first year; this reduction dropped to an average of 6.3% in subsequent years. A Dutch study showed a 10% overall long-term reduction from an eco-driving program (Lucke and Hennig 2007). Properly keeping an engine tuned saved 4% in fuel, proper tire inflation led to a 3% reduction in fuel consumption, and using the correct motor oil resulted in a 2% improvement (International Energy Agency 2005).

The important issue for such initiatives in the United States is whether concerted efforts to change driver behavior will have any possibility of doing so in any significant way. It is likely that eco-driving campaigns and targeted marketing will occur much more frequently in the future and that these efforts will have a positive benefit on GHG emissions reduction. However, the overall impact on GHG emissions will vary greatly by how much the efforts really affect driving behavior in the longer term.

Future Scenarios for Energy Use, Supply, and Costs

Because the vast majority of transportation energy in the United States comes from petroleum, importing oil will 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 results in unavoidable uncertainty with regard to oil supply. Furthermore, although overall worldwide supplies of petroleum are nowhere near exhaustion, it is likely that the ability to expand oil supply capacity is nearing its peak and that in the near future, it will become prohibitively difficult to expand oil production beyond current levels. When this occurs, energy will need to come from other, nonpetroleum sources, most of which are likely to reduce life-cycle GHG emissions. During the transition period, there will be pressure to extract petroleum from previously uneconomical sources, 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. This land use concern is not true of all biofuels and alternative fuels, such as cellulosic and algae-based fuels. Plug-in electric vehicles require electricity production from low-carbon sources such as wind, solar, nuclear, and biomass to significantly decrease emissions.

The U.S. invests billions of dollars every year to promote energy efficiency, expand energy supply, develop energy technologies, and reduce energy costs. More than $16 billion was spent on energy subsidies in 2007 (Energy Information Administration 2007). 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 2010d). 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 quite significant, depending on the fuel and how it is produced. Figure A.8 shows relative GHG emissions, including full fuel-cycle emissions, for a variety of transportation fuels; the estimations shown are based on the Department of Energy's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model, Version 1.8b. 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 reported for the 2010 RFS2 rulemaking [U.S. Environmental Protection Agency 2010e].) Electricity shows roughly a 33% reduction with current 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 on the rate of market penetration, which will depend on a host of very uncertain factors, such as technology advancement, fuel supply, policy choices that may encourage or discourage specific fuels, and the relative prices of different fuels.

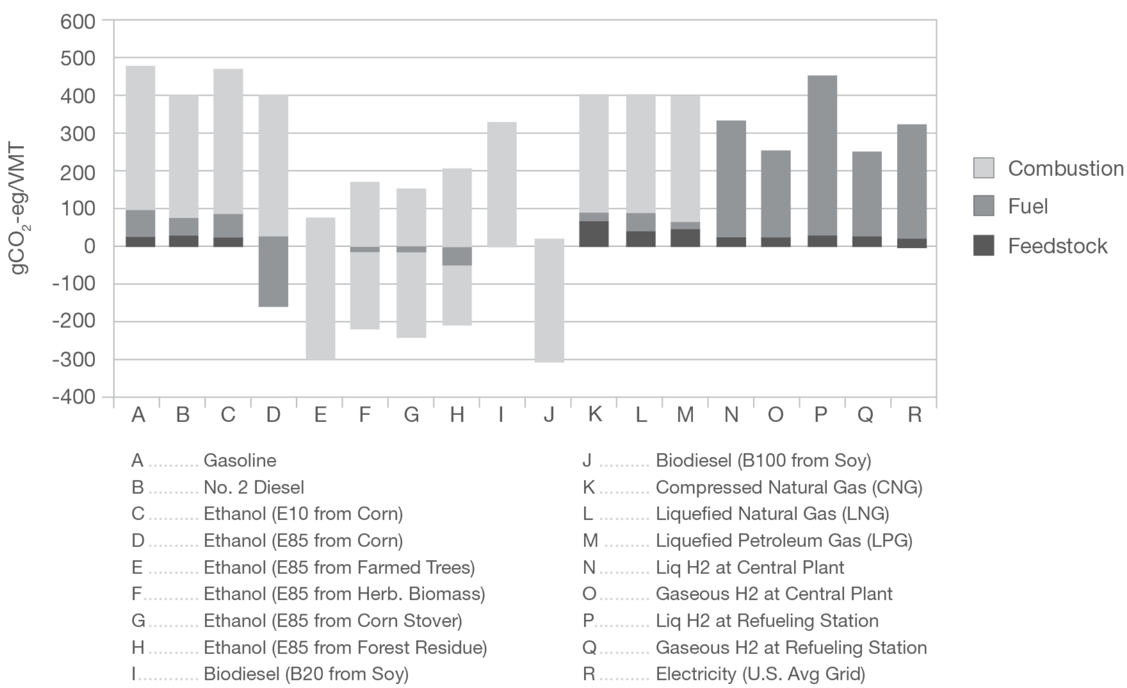

Figure A.8. *Relative GHG emissions from different fuels, GREET model.*

Potential Federal GHG Reduction Policy Initiatives

A variety of policy actions have been proposed at the federal level to reduce GHG emissions from all sectors, including transportation. The federal climate change policy landscape is likely to evolve significantly over the next few years depending on what actions are taken on transportation reauthorization, as well as energy and/or climate change legislation and regulation.

Federal policy actions affecting transportation GHGs can be grouped into five categories:

- Implement cap-and-trade or carbon price strategies to establish an economywide carbon price;
- Set vehicle and fuel standards to reduce carbon emissions per unit of travel;
- Provide vehicle and fuel market incentives to accelerate adoption of more efficient and less carbon-intensive technology;
- Fund expanded research and development of advanced vehicle and fuel technology and climate change research to realize long-term technology improvements and enhanced decision support; and
- Revise transportation programs and funding to include a focus on GHG measurement and reduction.

Some of these categories are likely to have only indirect effects on transportation planning. The magnitude of effects on transportation planning will vary based on the detailed formulation of any of these categories. A cap-and-trade system, and potentially other market incentives, will increase the price of gasoline, and the greater the increase in gasoline price, the greater the effect on transportation demand, revenues, and planning. Most cap-and-trade proposals are expected to have modest effects on VMT, at least in the next two decades. Most of these proposals would result in a gasoline price increase of 10 to 20 cents per gallon in the first few years of implementation, increasing to up to 40 to 60 cents per gallon by 2030. Analysis by the Energy Information Administration of cap-and-trade legislation found reductions in transportation GHG emissions on the order of 5% below a reference case in 2030. This reduction results in part from a decrease in LDV and truck VMT of about 2.5% to 3% up to 2030, as well as small improvements in LDV (1.2% to 1.3%) and truck (0.5% to 0.6%) efficiency. LDV efficiency improvements are small because most of the lowest-cost efficiency improvements will already have been implemented as a result of the recently enacted CAFE standards. A significant part of the reduction is due to reduced volumes of fuel shipments, particularly coal, because of the shift away from coal-fired power plants, and fuel oil through pipelines.

To the extent that pricing mechanisms, vehicle and fuel standards, and research and development are effective at reducing gasoline consumption, they will also reduce revenues for transportation infrastructure—at least until the motor fuel tax is replaced or supplemented with other revenue sources. However, it is possible that revenue obtained through pricing may be reinvested in GHG reduction programs, including transportation programs.

The last category of federal policy actions focuses specifically on the programs implemented by transportation agencies. It is possible that reauthorization of the surface transportation bill will include requirements and/or incentives to address GHG emissions and climate change issues in transportation planning. Such additions to the bill could take the form of any of the following:

- Technical assistance on GHG data and analysis procedures and planning methods;
- Regulations requiring consideration of GHGs in planning via inventory development, plan assessment, and development of mitigation measures; setting GHG emissions reduction targets at a state or metropolitan level; or requiring specific planning activities (such as integrated transportation and land use planning); and/or
- Funding incentives, either by establishing performance criteria for GHG emissions reductions and distributing funding on the basis of these criteria, or setting aside funding for implementation of specific GHG emissions reduction measures.

EFFECTIVENESS AND COST-EFFECTIVENESS OF TRANSPORTATION GHG EMISSIONS REDUCTION STRATEGIES

Both effectiveness (potential magnitude of GHG emissions reductions) and cost-effectiveness (cost per unit of reduction) are important considerations when selecting a set of strategies through the transportation decision-making process. The focus is on strategies that can be directly influenced by transportation agencies, but information on other strategies (such as vehicle efficiency and fuel standards) is also presented for comparison. Considerations affecting the feasibility of each strategy are also addressed. Users of the information in this section should recognize the considerable uncertainty present in the cost-effectiveness estimates provided.

Strategy Assessment

The strategies considered for reducing GHG emissions are found in nine major categories:

1. Transportation system planning and design;
2. Construction and maintenance practices;
3. Transportation system management and operations;
4. Vehicle and fuel policies;
5. Transportation planning and funding;
6. Land use codes, regulations, and other policies;
7. Taxation and pricing;
8. Travel demand management; and
9. Other public education.

A listing of strategies, and a definition or description of each, is provided in Table A.3. Inclusion of the 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.

TABLE A.3. POTENTIAL GHG EMISSIONS REDUCTION STRATEGIES

Strategy	Definition or Description
Transportation System Planning and Design	
Bottleneck relief	Increased capacity at bottlenecks (specific points on the transportation network where demand exceeds capacity), such as interchanges, intersections, and lane drops.
High-occupancy vehicle/high-occupancy toll (HOV/HOT) lanes	HOV: Highway lanes reserved for the use of vehicles carrying a minimum of two or three persons. HOT: Lanes that single-occupant vehicles are permitted to use at a price, which is set to ensure that lane capacity is not exceeded.
Toll lanes or roads	Highway facilities for which a price is charged, whether fixed or variable, for their use.
Truck-only toll lanes	Priced lanes for the exclusive use of trucks.
Fixed-guideway transit expansion	Urban transit systems including bus rapid transit, light rail, heavy rail, and commuter rail operating on exclusive right-of-way.
Intercity rail and high-speed rail	Rail operating over long distances between major cities.
Bicycle facilities and accommodation	Bicycle lanes, paths, parking, racks on buses, and other infrastructure improvements for bicyclists.
Pedestrian facilities and accommodation	New or improved sidewalks, pedestrian crossings, and shared-use facilities; measures such as traffic calming to enhance the pedestrian environment.
Rail system improvements	Track upgrades, clearance improvements, railyard capacity expansion, or other improvements to increase the speed and/or reduce the cost of moving goods by rail.
Marine system improvements	Improvements to ports or waterways, such as dredging or lock upgrades, to increase the speed and/or reduce the cost of moving goods by boat or ship.
Intermodal facility and access improvements	Capacity, operational, or access enhancements at truck–rail, truck–marine, or rail–marine intermodal and transload facilities.
Transportation System Management and Operations	
Traffic signal timing and synchronization	Technologies and practices to reduce congestion and smooth traffic flow through improved signal timing and/or coordination of multiple signals.
Incident management	Technologies and practices to reduce response time to incidents, clear incidents more quickly, and alert travelers.
Traveler information systems	Provision of up-to-date information to travelers and truckers on traffic conditions, incidents, and expected delays; the availability of public transportation and other travel alternatives; weather conditions; road construction; and special events.
Advanced traffic management systems	Other systems, such as speed harmonization, integrated arterial and freeway control, and applying surveillance and control to improve traffic flow.
Access management	Strategies to reduce congestion and improve safety on arterial roadways by controlling the location, design, spacing, and operation of access to adjacent land uses.
Congestion pricing	Roadway pricing that varies with the actual or expected level of congestion on the facility, with the goal of keeping traffic levels below the capacity of the system.

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TABLE A.3. POTENTIAL GHG EMISSIONS REDUCTION STRATEGIES (CONTINUED)

Strategy	Definition or Description
Speed management	Reduced speed limits on high-speed facilities, including the Interstate system, other limited-access highways, and high-speed rural major arterials, to no more than 55 or 60 mph; and/or greater enforcement of existing speed limits.
Truck and bus idle reduction	Education, laws, and/or incentives to introduce technology (such as electrical hook-ups at truck stops or on-board auxiliary power supplies) to reduce long-duration idling of heavy vehicles.
Transit fare measures	Transit fare subsidies or discounts to encourage transit use, targeted at the general population (e.g., free fare zones) or subpopulations such as workers.
Transit frequency, Level of Service, and coverage	Expanded frequency, geographic coverage, or temporal coverage of urban bus or rail transit.
Transit priority measures	Measures such as signal preemption, queue bypass lanes, and shoulder running to speed transit services relative to driving.
Land Use and Smart Growth	
Integrated transportation and land use planning	Regional or corridor activities to coordinate transportation and land use plans and projects to improve travel efficiency.
Funding incentives and technical assistance to local governments	Money or staff dedicated to helping local governments update plans, zoning, and other documents and practices consistent with smart growth principles.
Parking management and pricing	Providing disincentives to driving by pricing or limiting the amount of parking, or using pricing to encourage park-once trips.
Designated growth areas, growth boundaries, and urban service boundaries	Policy or regulatory designations to encourage growth in compact and/or central areas as an alternative to sprawl.
Transit-oriented development, infill, and other location-targeting incentives	Planning activities and fiscal and regulatory incentives to focus development in areas that can be efficiently served by transit, nonmotorized travel, and shorter automobile trips.
Freight villages and consolidation facilities	Freight facilities that are clustered together to reduce truck trip lengths and improve intermodal access; or locations where deliveries (retail, office, or residential) can be consolidated for subsequent delivery into the urban area in an appropriate vehicle with a high level of load utilization.
Travel Demand Management and Public Education	
Employer-based commute programs	Requirements for employers to reduce single-occupancy vehicle trips by their employees; or outreach, assistance, and incentive programs to encourage them to do so.
Ridesharing and vanpooling programs	Programs such as ride-matching databases, vanpooling programs, and other supportive actions to increase vehicle occupancies for work trips.
Telework and compressed work week	Working from a location other than the regular workplace using modern telecommunications and computer technology or working a regularly scheduled number of hours in a shortened span of time.
Nonwork transportation demand management programs	School pool, social marketing, individualized marketing, and other outreach and incentive-based programs aimed at reducing nonwork personal travel.
Eco-driving	Education programs directed at increasing vehicle fuel efficiency by affecting both driver behavior and vehicle maintenance.

(continued on next page)

TABLE A.3. POTENTIAL GHG EMISSIONS REDUCTION STRATEGIES (CONTINUED)

Strategy	Definition or Description
Vehicle and Fuel Policies	
Alternative fuel and high-efficiency transit vehicle purchase	Purchase of transit vehicles such as hybrid electric, natural gas, or electric buses to reduce energy use or use fuels with reduced carbon content.
Alternative fuel and electric vehicle infrastructure	Direct provision of alternative fueling infrastructure; or subsidies, incentives, or technical assistance to encourage other entities to provide such infrastructure.
Government fleet purchases	Purchase of high-efficiency and/or low-carbon fuel vehicles for government fleets.
Construction, Maintenance, and Operations Practices	
Low-energy and GHG pavement and materials	Use of less energy-intensive construction materials by state and local highway departments and other transportation agencies, such as recycled material in cement, and asphalt that is prepared at a lower temperature.
Construction and maintenance equipment and operations	Use of more efficient transportation agency or contractor equipment, and practices (such as idle reduction) to improve the efficiency of equipment utilization.
Alternative energy sources or carbon offsets	Use of transportation agency property for renewable energy generation or carbon sequestration.
Right-of-way management	Practices such as reduced mowing to reduce energy consumption and GHG emissions.
Building and equipment energy efficiency improvements	Improvements to transportation agency facilities and equipment, such as energy efficiency retrofits, to reduce energy use.

Information Sources

Information on effectiveness and cost-effectiveness is drawn from existing literature, with a focus on recent reports that summarize estimates across multiple strategies. The feasibility assessment is also based on information from the literature, as well as the judgment of the project team.

The information provided must be interpreted with caution. The literature on transportation GHG emissions reduction strategies is for the most part fairly new and focuses on summary estimates at a national level. There is considerable uncertainty surrounding the estimates for many strategies, and both effectiveness and cost-effectiveness 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 technological evolution, market trends, and changing political and societal viewpoints. Furthermore, climate and transportation analysts have yet to devise a common framework for analyzing costs. For instance, there is no common agreement as to whether reduced transit fares or increased road prices should be represented as a change in public cost, a cost to consumers, or as a transfer payment from nonusers to users.

Metrics and Methodological Issues

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 must be measured as a *percentage reduction* of emissions, either in the total transportation sector or in 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 on this topic. 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 emissions reductions starting in the present and continuing through some analysis horizon (e.g., 2030 or 2050).

Another important consideration related to cost-effectiveness is the specific costs included in the estimate. 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 a transfer between one entity and another, and therefore not a net social cost, although they affect the distribution of costs. A particularly challenging issue is the incorporation of nonmonetary costs, such as time savings or environmental externalities (e.g., air pollution and impacts on public health). For some strategies, these costs can be quite significant, but they are usually not monetized for the purpose of developing GHG cost-effectiveness estimates. Net included costs in Table A.4 refer to all the monetized costs included in the cost-effectiveness estimates; usually these are vehicle operating costs in addition to direct implementation costs. They do not include the monetary value of travel time savings nor crash reduction benefits. Finally, the estimates typically include only operating emissions benefits, and not construction or other life-cycle emissions.

Readers should be aware that the use of net included cost-effectiveness measures is controversial, with the primary argument against their use being that they ignore other positive benefits associated with such strategies and thus bias the results against highway improvement projects.

Caution should be exercised when using cost-effectiveness indices alone. For example, a cost-effectiveness index could 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.

Other Considerations

GHG 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).

Table A.4 shows a typical effectiveness assessment. This table, taken from a report to Congress (U.S. Department of Transportation 2010), shows a typical range of GHG emissions reductions reported in the literature, as well as a subjective assessment of the cost per tonne and the net cost per tonne. In addition, the extent to which a particular strategy has associated cobenefits or disadvantages (i.e., whether it provides positive or negative impacts on achieving other goals) is indicated by + (positive), – (negative), or 0 (neutral).

TABLE A.4. SYSTEM EFFICIENCY STRATEGIES

Strategy	GHG Reduction (2030)[a]	Cost per Tonne		Cobenefits	Key Federal Policy Options
		Direct	Net Included		
Highway Operations and Management					
Traffic management	Low <0.1% to 0.5%	Moderate to high	Net savings to high	+	Funding for project implementation, technical support, and institutional coordination
Real-time traveler information	Low <0.1%	High	Low to high	+	
Bottleneck relief	Low <0.1% to 0.3%[b]	NA	NA	+/–	Project funding
Reduced speed limits	Moderate 1.1% to 1.8%	Low	Net savings	–	Federal speed limit policy, funding incentives for enforcement
Truck Operations and Management					
Truck idling reduction	Low 0.1% to 0.2%	Moderate	Net savings	+	Federal anti-idling law
Truck size and weight limits	Low <0.1%	Low	Net savings	0	Revise federal policy on truck size and weight limits
Urban consolidation centers	Low <0.1%	Moderate	Net savings	+	Feasibility studies and demonstration projects
Freight Rail and Marine Operations					
Freight modal diversion	Low <0.1% to 0.2%	High	Net savings to moderate	0	Funding for rail and intermodal capacity improvements
Marine modal diversion	Low <0.1%	High	High	0	Capital investment in inland waterways; subsidies for short-sea shipping
Rail and intermodal terminal operations	Low <0.1%	Unknown	Unknown	+	Funding for rail and intermodal capacity improvements
Ports and marine operations	Low <0.1%	Unknown	Unknown	+	Tools to assist in GHG assessment; regulations or voluntary partnerships to promote GHG emissions reduction practices

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TABLE A.4. SYSTEM EFFICIENCY STRATEGIES (CONTINUED)

Strategy	GHG Reduction (2030)[a]	Cost per Tonne		Cobenefits	Key Federal Policy Options
		Direct	Net Included		
Infrastructure Construction and Maintenance					
Construction materials	Moderate 0.7%	Unknown	Unknown	0	Continue R&D on warm-mix asphalt and recycled materials; construction material requirements
Other transportation agency activities	Low 0.1%	Unknown	Unknown	0	Model practices and assessment tools; regulations to reduce GHG emissions in construction; funding incentives for GHG reduction
Combined benefits	2.9% to 6.1%				

Source: U.S. Department of Transportation (2010).

[a]The estimated benefits of traffic management, traveler information, and bottleneck relief all reflect offsetting effects of induced demand. Increased demand resulting from improved travel conditions is not reflected in other strategies in which it may be significant, such as aviation operations.

[b]Does not include emissions from construction activities or from additional delay during construction.

Figure A.9 shows a typical scenario analysis of the impact of varying levels of GHG emissions mitigation strategies (Greene and Plotkin 2011). The assumptions concerning different mitigation options are shown in Table A.5. Note that the percentages in the low-, mid-, and high-mitigation scenario columns of Table A.5 are the incremental

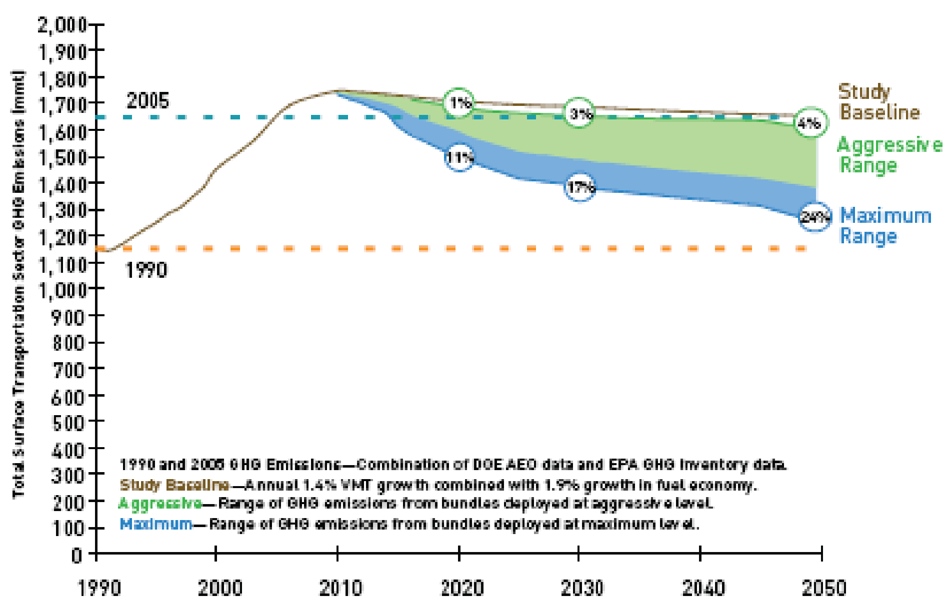

Figure A.9. *Bundle strategy results from* Moving Cooler *study (Cambridge Systematics 2009).*

changes in the 2010 *Annual Energy Outlook* (AEO) reference case projected impact. Thus, for example, for change in energy efficiency for the 2035 low-mitigation scenario, implementing fuel economy and emissions standards over those assumed in the reference case would increase the energy efficiency by 15 percentage points over the 39% projected in the reference case. More detailed information on the combination of different actions that can make up a mitigation strategy is available in the *Moving Cooler* report (Cambridge Systematics 2009) and Greene and Plotkin (2011).

TABLE A.5. CHANGES IN MITIGATION OUTCOMES FROM DIFFERENT STRATEGIES

Policy and/or Mitigation Option	AEO 2010 (2010 to 2035)	2035			2050		
		Low	Mid	High	Low	Mid	High
Change in Energy Efficiency for Total Stock	**39%**						
Fuel economy and emissions standards		15.0%	30.0%	40.0%	35.0%	60.0%	80.0%
Driver behavior and maintenance		2.5	5.0	10.0	2.5	5.0	10.0
Improved traffic flow		0.0	1.0	2.0	0.0	1.0	2.0
Pricing policies							
Carbon price		2.4	2.4	2.4	3.6	3.6	3.6
Road user tax on energy		0.0	1.6	1.9	2.2	2.2	2.2
Pay-at-the-pump insurance		0.0	4.4	4.4	0.0	5.2	5.2
Feebates		0.0	10.0	10.0	0.0	10.0	10.0
Automated highways		0.0	0.0	1.0	0.0	0.0	5.0
Change in Vehicle Miles Traveled (billions)	**54%**						
Road user tax on energy		–0.2%	–0.05%	–0.6%	–0.4%	–0.8%	–1.0%
Carbon price		–1.2	–1.2	–1.2	–1.7	–1.7	–1.7
Pay-at-the-pump insurance		0.0	–1.0	–1.0	0.0	–1.0	–1.0
Trip planning and route efficiency		0.0	–2.0	–4.0	0.0	–5.0	–10.0
Ridesharing		0.0	–0.7	–1.4	0.0	–1.0	–2.0
Land use and infrastructure development		–0.5	–1.0	–2.0	–1.5	–3.0	–5.0
Freight Trucks	**16%**						
Fuel economy and emissions standards: Long haul		15.0%	25.0%	30.0%	25.0%	35.0%	40.0%
Fuel economy and emissions standards: Local		15.0	25.0	30.0	25.0	35.0	40.0
Carbon price		1.2	1.2	1.2	1.8	1.8	1.8
Road user tax on energy		0.9	1.5	1.8	2.1	2.1	2.1
Pay-at-the-pump insurance		0.0	4.4	4.4	0.0	5.2	5.2
Traffic flow improvement		0.0	1.0	2.0	0.0	1.0	2.0
Automated highways		0.0	0.0	0.0	0.0	5.0	10.0
Rail	**–2%**						
Change in energy intensity of all trains (1,000s Btu per ton-mile)		–10.0%	–15.0%	–20.0%	–25.0%	–30.0%	–40.0%

Source: Adapted from Greene and Plotkin (2011).

Tables A.6 and A.7 provide information from the literature regarding the effectiveness, cost-effectiveness, and feasibility of transportation GHG emissions reduction strategies. Table A.6 shows transportation system strategies directed at 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 (such as land use, many of the pricing strategies, and rail and port investment), the strategies shown in Table A.6 can largely be implemented by state and metropolitan transportation agencies.

Table A.7 shows vehicle and fuel technology strategies that 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 were 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, one study's estimates of carpooling reductions assumed that vehicle occupancies could be increased substantially (e.g., adding one person per vehicle to every commute trip) (International Energy Agency 2005). 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 that could lead to or support significant changes in travel behavior. However, the estimate was not deemed realistic as an assessment of carpooling potential in the absence of such a major disruption.

Tables A.6 and A.7 contain the following information:

Key deployment assumptions: A description of the key strategy deployment assumptions in the underlying study.

Percentage fuel and GHG emissions reductions: Potential reductions in total transportation fuel consumption and GHG emissions, generally in 2030. Table A.7 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 (2005) report, 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 emissions 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 2009 AEO reference case. The AEO adjusted 2030 transportation sector baseline is 2,171 million metric tons (MMT) of 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 A.6). The estimates

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TABLE A.6. 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%]	N/A	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%]	N/A	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

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TABLE A.6. 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
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
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, Inc., and Eastern Research Group, Inc. 2010	M–H	M	M–H

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TABLE A.6. 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
Other transportation agency activities[d]	Alternative fuel DOT fleet vehicles, LEED-certified DOT buildings	0.1%	NA	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/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

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TABLE A.6. 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
Real-time traffic information[a]	511, DOT website, personalized information	0.00% [0.02%–0.07%]	$160–$500	Cambridge Systematics 2009	M	M	H
Transit Service							
Fare reductions[e]	25%–50% fare reduction	0.02%–0.09%	NA	Cambridge Systematics 2009	H	H	H
	50% fare reduction	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

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TABLE A.6. 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
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/ 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
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

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TABLE A.6. 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
Land Use Codes, Regulations, and Policies							
Compact development	60%–90% of new urban growth in compact, walkable neighborhoods (+4,000 persons/mi or +5 gross units/) (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/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

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TABLE A.6. 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
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 level of service D on all roads (average fee of 65¢/mile applied to 29% of urban and 7% of rural VMT) Areawide systems of managed lanes	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 A.6. 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 Cambridge Systematics, Inc., and Eastern Research Group, Inc. 2010	H	L	L–H
	Requirement to offer 4/40 workweek to those whose jobs are amenable (IEA)	2.4%	<$1				
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

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TABLE A.6. 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
Other Public Education							
Driver education/ eco-driving	Reach 10%–50% of population + in-vehicle instrumentation	0.8%–2.3% 3.7%	NA	Cambridge Systematics 2009 International Energy Agency 2005	L	L	H
Information on vehicle purchase[a]	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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are usually based on a string of annual cost and benefit estimates (including capital costs, annual operating costs, and annual operating GHG benefits) over a 20- to 40-year analysis horizon.

Data sources: References providing the source(s) of effectiveness and cost-effectiveness data for the strategy. The data source is cited on the same line as its respective cost and/or cost-effectiveness estimate.

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?
- **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 is evaluated in the cost-effectiveness measure).

TABLE A.7. 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	?

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TABLE A.7. 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
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
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/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.

Combined Strategy Impacts and Interactive Effects

Many GHG emissions reduction strategies interact to produce different outcomes for total GHG reductions. The benefits of each strategy (or group of strategies) are not additive, and in fact 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 synergistic 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. 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. 2009). The *Moving Cooler* study also found that transit and nonmotorized improvements were more effective in areas of higher population density (Cambridge Systematics 2009). It may also be expected that strategies (such as road pricing) that encourage the use of alternative modes would have a greater impact when applied in conditions under which better alternatives exist (as would be found with increased transit investment and more compact land use patterns). 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 (Cambridge Systematics 2009). For example, if Strategy A results in a 10% GHG emissions reduction, and Strategy B results in a 10% reduction, the combined effect will be $(1 - 0.10) \times (1 - 0.10) = 0.90 \times 0.90 = 0.81$, or a 19% combined emissions 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 reductions 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 more than $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.

Based on information included in a U.S. DOT report to Congress (2010), Cambridge Systematics, Inc. developed combined GHG emissions reduction estimates for 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 *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 accounted for 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 emissions reductions, but primarily for vehicle and fuel technology rather than travel activity and system efficiency. 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 significant an 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.

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 vehicle miles traveled (VMT) reduction is needed or can be obtained to contribute to certain GHG emissions 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 assumes that a 10% to 15% reduction in VMT from travel demand management strategies can contribute to GHG reductions along with vehicle efficiency and low-carbon fuel improvements (Mui et al. 2007).

Another example of such a scenario approach is provided by the National Cooperative Highway Research Program (NCHRP) Project 20-24, Task 59 study, which examines transportation GHG emissions through 2050 (Burbank 2009). This study makes 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 emissions reduction). The resulting GHG emissions are compared against 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.

Lutsey (2008) considers the VMT reductions needed to achieve aggressive GHG emissions reduction targets (80% reduction below 1990 levels by 2050) even after vehicle and fuel technology strategies have been fully realized.

> 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 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.

Summary

There are no simple answers to the question of what are the most and least cost-effective strategies. 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, maintenance, and so forth. 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 in GHG cost-effectiveness analysis. Therefore, the cost-effectiveness estimates shown in Table A.4, 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 very 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).

The cost-effectiveness estimates for the vehicle and fuel technology strategies shown in Table A.7 are much closer to a full social cost representation, because the non-monetary 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, the following conclusions can be drawn from the cost-effectiveness data. 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 U.S. DOT (2010) estimates that hydrogen fuel cell vehicles could reduce per vehicle GHG emissions by 80% by relying on low-carbon sources for hydrogen production. Advanced gasoline vehicles could reduce per vehicle emissions by 8% to 30%, hybrid vehicles by 26% to 54%, and plug-in hybrids by 46% to 75%.

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, including reduced speed limits, compact development, various pricing measures, and eco-driving, show larger impacts (greater than 1%); but the ability to implement these strategies at sufficiently aggressive levels is uncertain due to institutional and/or political barriers. For example, decreasing GHG emissions per VMT could reduce transportation GHG emissions by 3% to 6% through a combination of strategies such as the enforcement of lower speed limits, traffic signal synchronization, ramp metering, and truck idle reduction (U.S. Department of Transportation 2010). Strategies that decrease carbon-intensive travel activity could reduce transportation GHG emissions by 5% to 17% in 2030. This approach includes measures to reduce VMT growth through pricing, compact development, improved public transportation, enhancements to bike and pedestrian facilities, and the promotion of eco-driving through driver education and in-vehicle feedback technology. Thus, 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, whether highway or transit investment, is generally high cost. 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 very modest. Although major infrastructure investments are not among the most cost-effective GHG emissions 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). The Federal Highway Administration (FHWA) is currently funding research into the GHG benefits of highway capacity expansion and bottleneck relief when combined with congestion pricing.

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 aspirational estimates of truck–rail mode shift. Improved estimates are needed to assess the GHG emissions reductions 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 emissions 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.

Like transit infrastructure improvements, *urban and intercity transit service improvements* have high direct (public sector) costs, generally more than $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.

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 or greater enforcement of existing speed limits can provide significant benefits at modest cost, although they have mobility disadvantages and are not likely to be popular.

Studies that have examined *land use strategies* show a large range of potential reductions in GHG emissions. For example, the *Moving Cooler* report estimated a 6% to 21% GHG emissions reduction impact for its land use bundle (Cambridge

Systematics 2009); a Transportation Research Board study estimated a 6% to 12% reduction with significant changes in land use policies and investments in transit (Special Report 298 2009); and the Pew Center study assumed a 5% GHG emissions reduction from land use strategies in 2050 (Greene and Plotkin 2011). Potentially important GHG emissions reductions over the long term could occur from land use strategies, at very low public-sector cost, if stringent public policies are enacted to encourage compact development, and supporting investments are made in transit and nonmotorized transportation options. 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 difficult to achieve in the current political and economic environment (Special Report 298 2009).

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 emissions reductions, but only by pricing at levels that may be unacceptable to the public (the 2- to 5-cent per mile fee analyzed in Table A.6 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, because of the technology and administrative requirements for VMT monitoring. Cost-effectiveness improves with higher fee levels, because the same monitoring and administration infrastructure is required regardless of the amount of the fee. Pricing strategies will 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.

Transportation demand management strategies have a modest GHG emissions reduction potential 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 significantly reduce GHG emissions while providing a net savings to travelers. However, these results are based on limited European experience and have not yet been tried in any significant way in the United States.

GHG ANALYSIS TOOLS

Travel Demand and Related Models

Travel Demand Models

Travel demand models are a commonly used tool to forecast traffic conditions based on future socioeconomic and demographic projections by traffic analysis zone and alternative transportation networks. All MPOs are required to maintain travel demand forecasting models for use in transportation planning and, if needed, air quality analysis. Some regional planning agencies located outside of metropolitan areas may also maintain travel demand models, and some state DOTs have developed statewide models.

These models have varying capabilities for GHG analysis. All produce traffic volumes and speeds for each link in the modeled roadway network that can be used in conjunction with an emissions factor model such as MOVES or EMFAC to develop GHG emissions estimates from highway vehicle travel. They are best suited for analyzing changes in the transportation network such as capacity expansion or new roadways. In addition, it may be possible to analyze the following GHG strategies using some regional travel demand models (see also Sun et al. 2009):

- **Transit capacity expansion or service improvements:** Some models, especially for those used in larger metropolitan areas, have a transit component, including a transit network and mode choice model, which can be used to forecast VMT reductions from transit improvements. The sensitivity of the model for the particular transit improvements of interest should be evaluated by the analyst.
- **Regional land use patterns:** These models can be used to test changes in regional land use patterns (e.g., focus on infill, transit corridors, or activity centers) by changing the distribution of future population and employment among traffic analysis zones.
- **Bicycle and pedestrian improvements and land use design:** Some models include nonmotorized mode choice, although only a few have been enhanced to be sensitive to the effects of nonmotorized infrastructure improvements. Techniques such as 4-D postprocessors can be used in conjunction with travel model output to estimate the travel and resulting emissions impacts of changes to the various land use–related D metrics (e.g., density, diversity, design, destination accessibility).
- **Pricing:** Travel demand models generally forecast travel based on generalized travel cost, which is based on both the cost and the time of making a trip. However, the ability to model the effects of pricing measures depends on the particular measure (e.g., tolling, congestion pricing, parking pricing) and the model structure and calibration. Most models will need some level of enhancement to reasonably capture effects such as time-of-day shifting from congestion pricing or changes in the number of total trips taken.

For a discussion of travel demand model strengths, limitations, and enhancements, with a specific emphasis on smart growth and nonmotorized travel, see *Assessment of Local Models and Tools for Analyzing Smart-Growth Strategies* (DKS Associates and University of California 2007). Donnelly et al. (2010) consider advanced practices in travel demand forecasting, including integration with emissions models.

Integrated Transportation–Land Use Models

A method of forecasting the land use impacts of transportation investments, and the subsequent feedback to VMT and transportation network conditions, is necessary if the induced demand effects of transportation improvements are to be fully captured (see "Indirect Effects and Induced Demand" below). Many MPOs have a land use forecasting model for developing future projections of population and employment. Only a few, however, have developed integrated transportation and land use forecasting models (such as UrbanSim or PECAS) that are highly sensitive to both transportation improvements and various land use policies. In most cases, the use of these models for GHG analysis will not be an option because they are highly resource intensive to develop. The existing model applications are most appropriate for regional and systems-level analysis and have not yet been proven for use in analyzing individual transportation projects. Less resource-intensive methods, however, have been applied to assess the land use impacts of transportation investments and capture the resulting feedback through travel demand models.

For basic information on transportation and land use modeling, including integrated models as well as other methods, refer to NCHRP Report 466 (Louis Berger Group 2002) for a core guidance document that provides information and guidance on the various methods available for land use forecasting. This report is complemented by *Forecasting Indirect Land Use Effects of Transportation Projects* (Avin et al. 2007). *Interim Guidance on the Application of Travel and Land Use Forecasting in NEPA* identifies land use forecasting methods across a range of levels of effort suitable for use in project-level analysis (Federal Highway Administration 2010).

Intelligent Transportation Systems Deployment Analysis System (IDAS)

FHWA developed IDAS as a sketch planning tool to estimate the impacts, benefits, and costs resulting from the deployment of intelligent transportation system (ITS) components. IDAS interfaces with regional travel demand model output and can be used to estimate CO_2 emissions as well as other impacts. CO_2 factors are sensitive to speed and facility type (freeway or arterial). However, as of 2010 the factors had not been updated to account for federal fuel economy and GHG emissions standards adopted in 2010 or for California Pavley GHG standards.

Traffic Simulation Models

Traffic simulation models are used to evaluate the impacts of changes in transportation network characteristics (e.g., capacity, roadway geometry, signal timing, or ITS strategies) on traffic flow patterns (e.g., vehicle speeds, acceleration, and delay). Examples include TSIS-CORSIM, VISSIM, Paramics, SimTraffic, TransModeler, and Aimsun. Most of these models have internal data sets and modules for calculating changes in fuel use and air pollutant emissions resulting from changes in traffic characteristics (speed and acceleration). Although most traffic simulation models do not currently produce GHG emissions estimates, fuel CO_2 emission factors (see Table A.8) can be applied to fuel use changes to determine changes in GHG emissions. Model output on traffic conditions can also be used in conjunction with EPA's MOVES to incorporate the most up-to-date relationships between vehicle characteristics, operations, and emissions.

TABLE A.8. 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

Source: *General Reporting Protocol*, Version 1.1 (The Climate Registry 2012); Fuel Emission Factors (Energy Information Administration 2012b).

Traffic simulation models can be divided into two general classes: mesoscopic and microscopic. Mesoscopic models, including Dynasmart, TransModeler, Dynus-T, and VISTA, are based on deterministic relationships between roadway and intersection characteristics and traffic flow; microscopic models simulate the movement of individual vehicles through the network being modeled. Many software packages are capable of modeling both mesoscopically and microscopically, and some can run both simulations within the same model.

Microscopic models can be further divided into deterministic models and dynamic models. Deterministic models, including Synchro/SimTraffic, CORSIM, and FREQ, simulate predetermined traffic volumes and turning movements that are input by the user. Dynamic simulation models, including Paramics, VISSIM, TransModeler, Aimsun, and Dynasim, microsimulate origin–destination patterns that allow vehicles to dynamically reroute from origin to destination based on real-time congestion in the system, driver information, and alternative routes.

The predetermined volumes in deterministic models make them difficult to use for network analysis because reassigning vehicles is not possible. These packages are more suited for individual intersection analysis or signalized arterial corridors. Dynamic models capable of simulating origin–destination tables are designed to perform network-level analysis of mixed facility types (freeways and arterials), as well as transit and pedestrian operations.

GHG Inventory and Policy Analysis Tools

This category includes tools with a wide variety of characteristics. Their common thread is that they are all specifically designed to assist transportation agencies in calculating GHG emissions and/or reductions from transportation sources.

CCAP Transportation Emissions Guidebook

The purpose of this guidebook (Center for Clean Air Policy 2012) is to assist state and local officials in understanding the extent to which policy decisions affect air pollution, energy use, and GHG emissions. The guidebook provides guidance, rough estimates, and a spreadsheet calculation tool to assess the impact of various strategies and technologies. The guidebook is now a few years old, and Part 2 (Vehicle Technology and Fuels), in particular, may contain some information that is out-of-date regarding vehicle technologies and emissions impacts.

CACP 2009: Clean Air and Climate Protection

This software tool, available from ICLEI–Local Governments for Sustainability, was developed in partnership with the National Association of Clean Air Agencies and EPA (ICLEI 2012a). The software is used to develop local communitywide or internal government GHG emissions inventories, quantify emissions reductions from various emissions reduction measures, project future emissions levels, and set reduction targets and track progress toward meeting these targets. The model includes CO_2, CH_4 (methane), and N_2O (nitrous oxide) emissions, as well as criteria pollutants. Inputs include fuel use or VMT by a government vehicle fleet or the community as a whole. Therefore, this tool is best suited to translating VMT and/or fuel consumption (or changes in these) into GHG emissions (or changes), rather than directly estimating the VMT or fuel consumption impacts of strategies. The calculations are based on the principles and methods included in the Local Government Operation Protocol developed by ICLEI in collaboration with the California Air Resources Board (CARB) and The Climate Registry. Many cities have used the ICLEI software to develop baseline estimates of GHG emissions from transportation and other sectors.

Climate and Air Pollution Planning Assistant (CAPPA)

This software tool, also developed by ICLEI, is a simple spreadsheet-based tool to estimate the GHG benefits of a wide variety of transportation-related policies and strategies, including travel reduction and vehicle and fuel technology strategies, as well as nontransportation strategies (ICLEI 2012b). Its focus is on measures that can be implemented at a local (municipal) level. It includes more than 100 municipal actions (e.g., vehicle fleet purchases and light-emitting diode traffic signal replacement) and community actions (e.g., transit-oriented development and bicycle programs). The purpose of the application is to help decision makers choose a suite of measures that when combined would get them to their jurisdiction's reduction goal, rather than to model the impact of any particular measure in a detailed way. A limitation of the tool is that it generally requires user inputs of traveler response factors (such as increased transit ridership or nonmotorized travel) rather than predicting response. Users should carefully review the default assumptions embedded in the model.

Climate Leadership in Parks (CLIP) Tool

Developed by EPA and the National Park Service, the CLIP tool allows for GHG and criteria pollutant emissions estimation at the local level for all highway and nonhighway transportation and mobile sources, including off-road sources such as construction equipment (National Park Service 2012). Although default vehicle characteristics are geared toward travel situations at national parks, CLIP allows users to enter additional data to reflect local conditions. The user must estimate activity parameters such as VMT reduction, fuel use reduction, or percentage idle time reduced, and the tool converts these inputs to CO_2 emission reductions. The tool includes six strategies: (1) reduce visitor VMT; (2) reduce fuel consumption among park, concessionaire, and other vehicles; (3) reduce fuel consumption among nonroad equipment; (4) replace existing park, concessionaire, and other vehicles with more fuel-efficient vehicles; (5) replace existing park, concessionaire, and other vehicles with alternative fuel vehicles and hybrids; and (6) reduce vehicle idling.

FHWA Carbon Calculator Tool

FHWA-sponsored work was underway in the fall and winter of 2010 to develop a carbon calculator tool. The tool will use GreenSTEP (see description below) as a foundation for broader use by state DOTs and MPOs when analyzing various GHG-related scenarios, and it is likely to be a major contribution to the range of tools available to practitioners. Readers are encouraged to obtain the latest information on this calculator for their analysis.

GHG Calculator for State DOTs (GreenDOT)

This software tool, developed for NCHRP Project 25-25, Task 58, calculates CO_2 emissions from the operations, construction, and maintenance activities of state DOTs (National Cooperative Highway Research Program 2012). GreenDOT is designed to calculate emissions for geographical areas ranging from a single project to an entire state, and over time periods ranging from one day to several years. The two most likely uses of the tool are calculating annual agencywide emissions and emissions related to a specific project, covering a period of days or years. The tool's four modules calculate emissions from on-road vehicles, off-road equipment, electricity used in transportation facilities, and construction materials. In addition, an auxiliary calculator for traffic-smoothing strategies estimates changes in GHG emissions on a roadway segment based on changes in average traffic speed.

GreenDOT calculates a baseline scenario and a mitigated scenario for all modules and includes a number of common mitigation strategies, often with default percentage reductions built in. However, the tool requires detailed inputs, such as gallons of fuel for off-road equipment, metric tons of concrete and asphalt, and megawatt-hours of electricity usage.

GreenSTEP

The Greenhouse Gas Statewide Transportation Emissions Planning model (GreenSTEP) is a tool originally developed by the Oregon DOT for estimating the GHG emissions reduction potential of policy proposals for the land use and transportation subcommittee of Oregon's Global Warming Commission. GreenSTEP is designed to estimate the effects of policy changes on factors that influence GHG emissions, including metropolitan population densities and relative amounts of urban and rural development; capacity and use of transit service and highways; use of alternative fuel or technology vehicles, vehicle fuel efficiency, and future market share of efficient automobiles; the carbon content of fuels and fuel costs; potential VMT-based fees and other vehicle charges that may be levied; and GHG emissions from electrical power generation. GreenSTEP also allows modeling of several types of travel demand management and the potential for switching more travel to bicycles and other light-weight vehicles (e.g., electric bicycles). Version 2 of the model, developed in the fall of 2010, focuses on LDV travel, but Oregon DOT plans to add long-distance travel and freight models and to develop a metropolitan-area version of GreenSTEP.

New York State DOT Draft Guidance on Transportation GHG Analysis

The New York State Department of Transportation (NYSDOT) developed a series of draft guidance documents to assist in calculating the fuel consumption and GHG impacts of transportation projects for project alternatives analysis and for MPOs' long-range transportation plans and transportation improvement programs. The methods account for the direct impacts of vehicle speeds on fuel consumption and indirect impacts from construction and maintenance activities, relying on procedures summarized in the 1983 Caltrans *Energy and Transportation Systems* manual. NYSDOT has also developed the Motor Vehicle Emission Simulator–Roadway and Rail Energy and Greenhouse Gas Analysis Extension (MOVES-RREGGAE), an interface designed for NYSDOT that provides a platform for estimating energy and GHG emissions associated with transportation projects, plans, and improvement programs in New York State. MOVES-RREGGAE extends EPA's MOVES-HVI Demo model by enabling analyses of energy and GHG emissions from the operation of roadway projects, plans, and programs. MOVES-RREGGAE also includes modules for calculating energy and GHGs from the construction, maintenance, and rail components of a project, according to NYSDOT's guidance documents.

State Inventory Tool (SIT)

EPA-developed SIT is a spreadsheet-based tool designed to develop comprehensive GHG inventories at the state level using a combination of state-specific inputs provided by the user and default data preloaded for each state (U.S. Environmental Protection Agency 2012c). SIT covers all sectors of the economy, including all on-road and off-road transportation modes. Multiple calendar years can be modeled simultaneously. To estimate CO_2 emissions, SIT uses fuel consumption data (measured in British thermal units), which can be a user input or default data. Default fuel consumption data come from the Energy Information Administration's *State Energy Data*. Estimates of N_2O and CH_4 emissions from marine vessels, aircraft, and locomotives also use fuel consumption data. To estimate N_2O and CH_4 emissions from highway vehicles, state-level VMT data are required for each vehicle type; users can apply their own data or use SIT's preloaded default vehicle mix data, which come from FHWA's Highway Statistics. Inputs of emissions factors for each fuel and vehicle type are also required.

SIT has been used for many GHG inventories and forecasts developed for state climate action plans. This model does not estimate highway vehicle CO_2 emissions separately from total transportation CO_2 emissions or allocate CO_2 emissions to specific highway vehicle types. For example, the transportation estimate of diesel CO_2 from SIT includes diesel fuel used by highway vehicles, locomotives, and commercial marine vessels. Methods for allocating the transportation fuel consumption and emissions by transportation category have been developed by various analysts, but these are not included with SIT.

Emissions forecasts can be developed using SIT baseline emissions. On-road vehicle emissions can be projected based on total VMT growth rates by vehicle type at the state level, if available. If state-level VMT growth rates by vehicle type are not available, they can be developed from the national vehicle type VMT forecasts reported in the *Annual Energy Outlook 2009* (Energy Information Administration 2009). If CO_2 emissions are projected based on VMT growth rates, they should be adjusted to account for anticipated improvements in fuel efficiency.

URBEMIS

URBEMIS (Urban Emissions) is environmental management software that was originally developed by CARB as a modeling tool to assist local public agencies with estimating air quality impacts from land use projects when preparing a California Environmental Quality Act analysis (Urbemis 2012). The model was developed as a user-friendly computer program that estimates construction, area source, and operational air pollution emissions from a wide variety of land use development projects, including residential neighborhoods, shopping centers, and office buildings.

The model also identifies mitigation measures and emissions reductions associated with specific mitigation measures. The mobile source mitigation component allows the user to estimate the potential vehicle travel and emissions reduction benefits from various land use and transportation-related strategies within the project site and in the surrounding area. These strategies include pedestrian and bicycle facilities, public transit facilities and service, the design and mix of land uses, on-site services, and other measures such as telecommuting and alternative work schedules. The model uses the Institute of Transportation Engineers' *Trip Generation Manual* and CARB's EMFAC2007 model for on-road vehicle emissions and OFFROAD2007 model for off-road vehicle emissions (Urbemis 2012). Nearly all the model defaults can be modified if more accurate information is available. The outputs of URBEMIS include total trips, total VMT, and annual tons of volatile organic compounds, oxides of nitrogen, carbon monoxide, sulfur dioxide, CO_2, and 2.5- and 10-μm particulate matter.

Other Travel Demand Analysis Tools

COMMUTER

The EPA-developed COMMUTER model is designed to analyze the impacts of employer- or worksite-based transportation demand management programs and transit improvements on VMT, criteria pollutant emissions, and CO_2 (U.S. Environmental Protection Agency 2012e). The model can also be adapted for sketch-level analysis of general responses to pricing policies or to measures that affect travel time. The CO_2 calculations are simple and based on default emission factors from MOBILE6. Because the emission factors are MOBILE6-based, this model will not show the impacts of changes in speeds. This model was most recently updated in 2005 and reflects fleet-wide average fuel economy at that time.

TRIMMS

Developed by the Center for Urban Transportation Research at the University of South Florida, TRIMMS (Trip Reduction Impacts for Mobility Management Strategies) is a spreadsheet model to predict trip, VMT, fuel, and emissions impacts for worksite-based transportation demand management programs (University of South Florida 2012). It has many similarities to the COMMUTER model but uses different methodologies.

The model is also intended for cost-benefit assessment and incorporates damage costs for various pollutants. As with COMMUTER, emissions factors are not speed-based. Version 2.0, released in 2009, reflects fleetwide average fuel economy at that time.

Land Use Scenario Planning Tools

These geographic information system–based tools (including INDEX, Smart Growth INDEX PLACE^{3}S, CommunityViz, CorPlan, and others) are primarily designed to assist planners with the development and analysis of alternative land use scenarios at a site, community, or regional level. Tool outputs include a wide variety of community indicators related to transportation, land use, the environment, and other issues such as VMT per capita or household, fuel consumption, and GHG emissions. The models typically estimate changes in VMT based on elasticities, or relationships between factors such as population density, land use mix, and pedestrian design and vehicle travel. The estimates therefore tend to be relatively simplistic because they usually do not account for the regional context of the development, which tends to have a greater impact on vehicle travel and GHG emissions than the characteristics of an individual development. However, these tools can be of value in creating inputs (i.e., in the form of land use changes) to a regional travel demand model that can be used for GHG emissions analysis purposes. They also can estimate energy use and GHG emissions from buildings, taking into consideration factors such as building density, orientation, floor space, and mix of housing types. They are relatively data intensive to set up; in particular, they require detailed land use data, and (except for EPA's Smart Growth INDEX) are not intended for evaluating transportation network changes.

FHWA's Tool Kit for Integrating Land Use and Transportation Decision-Making, although a few years old, includes several case studies and examples of scenario planning and visioning projects using these and other geographic information system–based tools (Federal Highway Administration 2005). Smart Growth INDEX is available free from the EPA. PLACE^{3}S is available from the California Energy Commission, INDEX from Criterion Planners, CommunityViz from Placeways, and CorPlan from the Renaissance Planning Group.

Emissions Factor and Fuel Economy Models

GlobeWarm

GlobeWarm is a tool developed by the Washington State DOT to help easily estimate GHG emissions at a planning level using either transportation systemwide summary travel data or link-by-link travel model data. It incorporates emissions data from MOVES but does not require the user to run MOVES. Inputs related to the vehicle fleet and technology include vehicle age distribution, fuel types and market shares, vehicle fuel efficiency, vehicle emissions control technology, and GHG emissions reduction factors for alternative fuels. Defaults are provided (primarily from EPA data) for all of these inputs. System-level GHG emissions estimates can be developed by providing data on average trip length, percentage of trips beginning with a cold start, VMT, and vehicle hours traveled. Link-level estimates can be developed using link-level travel demand model output of VMT and speeds by vehicle type. The tool estimates three primary GHGs: CO_2, CH_4, and N_2O. The summary output from the tool includes estimated quantity of GHGs in the base and alternative cases and percentage change of GHG emissions from the base to the alternative case.

Motor Vehicle Emission Simulator

EPA's Motor Vehicle Emission Simulator (MOVES2010) model was released in December 2009 and is officially approved for use in state implementation plans and for transportation conformity analyses outside of California. MOVES replaces EPA's previous MOBILE6 and NMIM models. MOVES can estimate CO_2, N_2O, and CH_4 from on-road vehicles and accounts for the impacts of vehicle speeds, driving cycles, age, and vehicle stock on emissions. MOVES can be used to develop GHG emissions estimates at project, county, regional, statewide, and national levels. The model is best suited for evaluation of GHG emissions reductions from measures that would change travel characteristics on roadways (e.g., speeds, congestion levels, or idling times).

Emission Factors Model

CARB developed the Emission Factors (EMFAC) model as the California counterpart to EPA's MOBILE (now MOVES) model. Using emission factors and vehicle activity inputs, EMFAC develops emissions estimates for on-road vehicles to be used in developing emissions inventories, projections, and other project-level analyses. The CO_2 emission rates vary by vehicle speed. According to the EPA, EMFAC CO_2 predictions are close to the output from MOVES.

EMFAC combines locally specific emission rates and vehicle activity to generate hourly or daily total emissions for geographic areas (statewide, air basin, air pollution control district, or county) in California (California Air Resources Board 2010b). EMFAC estimates fuel consumption for gasoline and diesel, as well as emissions of CO_2 and CH_4 (but not N_2O). The model performs separate calculations for each of 13 classes of vehicles by fuel usage and technology group. EMFAC contains local data for each county in California; however, the user can edit inputs such as VMT, vehicle population, technology fractions, speed fractions, and other factors.

EMFAC can be run in three modes: Burden, Emfac, and Calimfac. The Burden mode is used for calculating emissions inventories and reports total emissions as tons per weekday using emissions factors, corrected for ambient conditions and speeds, combined with vehicle activity. The Emfac mode generates emissions factors as grams of pollutant emitted per vehicle activity and can calculate a matrix of emissions factors at specific values of temperature, relative humidity, and vehicle speed. One important use for the Emfac mode is to generate files for use with the DTIM model and other air quality models such as AIRSHED, CALINE, and URBEMIS. The Calimfac mode is used to calculate detailed emissions rates for each vehicle class and model years from 1965 to the scenario calendar year.

CARB made several adjustments to EMFAC output data in developing the California statewide GHG inventory (California Air Resources Board 2010a). EMFAC estimates do not include effects of the federal CAFE standards or other GHG emissions standards. However, CARB has developed the Pavley I + Low-Carbon Fuel Standard postprocessor to adjust CO_2 emissions from EMFAC output to account for the reductions caused by the adopted Pavley I regulation and the Low-Carbon Fuel Standard in the light-duty fleet (California Air Resources Board 2010c).

EMFAC differs from MOVES in how it estimates emissions. MOVES calculates emission rates associated with vehicle operating modes (e.g., cruise and acceleration). These emission rates are based on the second-by-second power demand placed on a vehicle when operating in various modes and speeds. The activity data in MOVES are vehicle operating times. In contrast, EMFAC, like MOBILE, calculates emissions estimates from trip-based travel activities. EMFAC quantifies running exhaust emissions factors in grams per mile for a specific speed bin. The emissions factors are composite emission rates aggregated from base rates by vehicle class, technology group, and model year. EMFAC uses VMT for activity data. Other differences between these two models include the following:

- EMFAC does not distinguish roadway links, and thus is better suited to regional-scale than link-level applications. MOVES can be used for regional- down to link-level inventories. However, unlike EMFAC, MOVES does not contain county-specific default activity data. For county-level runs, the user must enter county-level activity data. MOVES can derive state and county activity data by applying spatial allocation factors to national data, although this is not recommended for county-level analyses.
- EMFAC calculates hourly or daily inventories for an average weekday by month, season, and year; MOVES provides hourly, daily, monthly, or annual emissions for weekdays, weekends, months, or years.
- MOVES identifies vehicle class based on the classification used by the federal Highway Performance Monitoring System (HPMS). EMFAC uses a different vehicle classification scheme.
- MOVES can be used for any geographic area in the United States, but EMFAC only contains activity data for California counties and California-specific emission rates. If using MOVES to model California rates, additional inputs are needed to model the California-specific emission rates correctly.

Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model

Developed by the Argonne National Laboratory and sponsored by the U.S. Department of Energy, the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model is designed to fully evaluate the energy and emissions impacts of advanced vehicle technologies and new transportation fuels, considering the fuel cycle from wells to wheels and the vehicle cycle from material recovery to vehicle disposal (Argonne National Laboratory 2012a). GREET can estimate emissions of three GHGs (CO_2, CH_4, and N_2O) and five criteria pollutants (oxides of nitrogen, sulfur dioxide, 10-μm particulate matter, carbon monoxide, and volatile organic compounds), as well as total energy use. Inputs related to the fuel, fuel processing and refining, and vehicle technologies are needed to estimate emissions factors with this model. GHG emissions rates (in grams per mile) are produced for three categories of light-duty vehicles (LDVs): passenger cars, light trucks 1, and light trucks 2.

This model is most appropriate in cases for which life-cycle emissions for different types of vehicle and fuel technology are of interest. It is also useful for obtaining emissions factors for fuels other than gasoline and diesel (e.g., biofuels, electricity). The model can be used with default factors or with a wide variety of user inputs representing different fuel production processes. GREET Version 1.8c, released in March 2009, does not incorporate the latest EPA or CARB research on the life-cycle impacts of biofuels, although the U.S. Department of Energy plans to integrate this information in a future model update.

VISION

The VISION model estimates the potential energy use, oil use, and carbon emission impacts of various light- and heavy-duty vehicle technologies and alternative fuels through the year 2100 (Argonne National Laboratory 2012b). It also provides total VMT by technology and fuel type by year. This model compares the market penetration of various alternative fuel and advanced vehicle technologies to a baseline scenario in which these technologies have not been implemented. The simulation is based on a set of input parameters that includes vehicle market penetration and fuel economy ratios by technology, fuel types (including alternative fuels) and price, VMT, future vehicle sales, population and gross domestic product growth, and vehicle costs. Default values come from the *Annual Energy Outlook* for the baseline scenario, and all input values can be changed by the user to customize the simulation and show the sensitivity of various assumptions.

VISION is updated annually to reflect changes in energy consumption according to the most recent *Annual Energy Outlook*. VISION outputs include energy use by fuel type, full fuel-cycle carbon emissions (million metric tons [MMT] carbon equivalent), full fuel-cycle GHG emissions (MMT CO_2e), fuel expenditures (billions of dollars and as a percentage of gross domestic product), and light-vehicle miles per gallon gasoline equivalent. The VISION model works exclusively with highway vehicles on 10-year increments. The primary use of VISION for transportation planners is for long-term policy analyses of state- and regional-scale vehicle and fuel technology strategies.

OFF-MODEL METHODS

In many cases, an appropriate analysis tool may not exist for a particular strategy, or may have data and resource requirements that are beyond what are available for the study. Common off-model techniques include elasticities and case examples. Other existing tools for travel analysis that do not directly produce GHG emissions estimates can also support GHG estimation (e.g., by taking changes in VMT forecast using these tools and applying emissions factors).

Elasticities

Elasticities are expressions of a relationship between two factors (e.g., between the price of travel by a given mode and the amount of travel by that mode). Specifically, the elasticity value is the ratio of a percentage change in one factor to a percentage change in the other. For example, a VMT price elasticity of –0.4 means that if the price of travel increases by 10%, VMT will decline by 4% (10% × –0.4).

Elasticities are commonly used to analyze strategies that affect the cost of travel (e.g., road pricing, transit fares, commuter incentives) and strategies that affect travel time (e.g., reduction in bus headways or running time). They have also been developed for other relationships, such as VMT versus land use density. Many sketch plan methods, such as the TRIMMS model and the Clean Air and Climate Protection tool, incorporate elasticities. Caution should be used in applying elasticities developed from data in one particular location to another location, because conditions in the second location may differ from the situation for which the elasticity was developed.

Useful sources of transportation elasticities include

- *Transit Cooperative Research Program (TCRP) Report 95: Traveler Responses to Transportation System Changes*—This series of reports includes chapters providing evidence on the travel and mode shift impacts of a variety of strategies, including parking and transit pricing, ridesharing and vanpooling, transit promotion and service improvements, and land use and site design; and
- The Victoria Transport Policy Institute's *Online TDM Encyclopedia*, which provides a summary of research, examples, and evidence on a variety of travel demand management and land use strategies.

Case Examples

A case example simply refers to using data on the impacts observed in other situations to predict impacts in the situation of interest. For example, a transit agency may observe that the use of hybrid electric buses has reduced fuel consumption by 30% compared with their standard diesel buses. Case examples are usually applied in conjunction with scaling factors (e.g., size of bus fleet) to transfer percentage impacts to the situation in which the strategy is being applied. Case examples must be used with caution to ensure that conditions in the situation of interest will result in GHG reductions similar to those observed elsewhere, and that the data from the case example are valid. Case examples can be found in the TCRP and Victoria Transport Policy Institute sources referenced above.

Other Tools

A variety of other tools and resources do not directly provide GHG emissions estimates, but can assist in estimating the VMT or traffic flow impacts of many GHG reduction strategies.

Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit

This document provides guidance on estimating the GHG emissions reduction benefits of transit projects (American Public Transportation Association 2009). It identifies three types of benefits: mode shifting, congestion relief, and indirect benefits associated with more efficient land use patterns. The guidance addresses issues such as analysis boundaries, emissions factors, and emissions from electricity generation. The guidance describes how to estimate GHG emissions based on project ridership estimates and operating data; describes how to calculate congestion relief benefits; and discusses the land use multiplier, which represents additional benefits from land use changes related to transit investments.

FHWA Highway Economic Requirements System

The Highway Economic Requirements System (HERS) is an analysis tool that uses engineering standards to identify highway deficiencies and then applies economic criteria to select the most cost-effective mix of improvements for systemwide implementation. HERS is designed to evaluate the implications of alternative programs and policies on the conditions, performance, and user cost levels associated with highway systems. HERS-ST is a version of the model provided for state-level use (Federal Highway Administration 2012a). While primarily intended for economic analysis, HERS can be used to support GHG analysis by providing information on changes in vehicle speeds, volumes, and fuel consumption as a result of capacity or operational improvements to the statewide highway network. Unlike many models, HERS has explicit procedures to account for induced demand effects.

FHWA IMPACTS

IMPACTS is a series of spreadsheets developed to help screening-level evaluation of multimodal corridor alternatives, including highway expansion, bus system expansion, light rail transit investment, high-occupancy vehicle lanes, conversion of an existing highway facility to a toll facility, employer-based travel demand management, and bicycle lanes (Federal Highway Administration 2012b). Inputs are travel demand estimates by mode for each alternative. The impacts estimated include costs of implementation; induced travel demand; benefits including trip time and out-of-pocket cost changes such as fares, parking fees, and tolls; other highway user costs such as accident costs; revenue transfers due to tolls, fares, or parking fees; changes in fuel consumption; and changes in emissions.

FHWA Screening Tool for ITS

The Screening Tool for ITS (SCRITS) is a spreadsheet tool developed by FHWA for evaluating ITS strategies at a screening level when a more sophisticated evaluation using a tool such as IDAS cannot be performed (Federal Highway Administration 2012c). SCRITS includes changes in energy consumption as an output. It requires users to supply a set of baseline data, including a study area and associated travel statistics or other parameters that are used in a variety of the ITS applications. For example, the user must define the area or facilities covered and supply an estimate of VMT. The fuel efficiency factors in the model may not be up-to-date, but they can be adjusted by the user.

FHWA Sketch-Planning Analysis Spreadsheet Model

The Sketch-Planning Analysis Spreadsheet Model (SPASM) is designed to assist planners in sketch planning analyses of packages of transportation actions at the system and corridor level, including transit system improvements, highway capacity improvements, high-occupancy vehicle lane improvements, and auto use disincentives (Federal Highway Administration 2012d). Reported benefits include changes in energy use. The model takes into account congestion-related effects of changes in VMT on speeds during peak and off-peak periods, diversion of traffic among parallel highway facilities in a corridor, induced (or disinduced) traffic occurring as a result of changes in highway congestion levels, and effects of speed and cold starts on motor vehicle emissions and fuel consumption. The fuel efficiency factors in the model may not be up-to-date, but they can be adjusted by the user.

Florida DOT Transit Mode Shift Measures

The Florida DOT developed a report to produce measurable criteria that can be used by the agency to determine where and under what circumstances an investment in transit service and facilities will reduce energy consumption and realize the associated health benefits of transit (Florida State University 2009). The report provides mode shift factors for different transit modes (i.e., the percentage of people who use transit despite having another option available to them to make the trip). The factors are based on surveys of transit riders in Florida and other states. These factors on prior and/or alternative modes of travel can be combined with trip length and ridership data to estimate GHG emissions.

Guidelines for Analysis of Investments in Bicycle Facilities

This NCHRP report includes methodologies and tools to estimate the cost of various bicycle facilities and for evaluating their potential value and benefits (National Cooperative Highway Research Program 2006). The report is designed to help transportation planners integrate bicycle facilities into their overall transportation plans and on a project-by-project basis. The research described in the report has been used to develop a set of web-based guidelines that provide a step-by-step worksheet for estimating the costs, demands, and benefits associated with specific facilities under consideration (Active Communities 2012).

Using Trend Analysis to Project Future VMT

Areas with a regional travel demand model will typically have generated 20-year VMT forecasts that consider a variety of factors influencing travel, such as population, employment, household size, income levels, land use patterns, and planned transportation system improvements. These VMT forecasts can serve as a basis for GHG emissions forecasts when they are used in conjunction with VMT-based emissions factors or fuel economy projections and the carbon content of fuel.

To estimate future GHG emissions in areas without a travel demand model, VMT must be projected in other ways, such as by an extrapolation of historic trends. In most cases it is inappropriate to project future GHG emissions based only on historic emissions trends because of changes in vehicle fuel economy and carbon content of fuels over time. If a VMT trend extrapolation using a linear or other function is not reasonable for a certain area, a more detailed approach can be used that considers the factors that influence VMT. Both trend extrapolation and more detailed projections are discussed below.

Trend Extrapolation of Historic VMT

FHWA's HPMS is an ideal source for historic VMT because it offers data for all parts of the country in a standardized format. HPMS provides estimates of VMT data by county using HPMS urban and rural roadway functional classifications for every state in the country on an annual average basis.

A regression analysis using a linear, logistic, or other function can be applied to a group of recent years of HPMS VMT data to generate a VMT estimate for a planning horizon year or years. Local areas must decide the appropriate number of years to include in their regression analysis, but in general 10 to 20 years is appropriate for the longer-term forecasts often used in GHG projections. For example, in projecting VMT at the state level for GHG forecasts, several states have performed a VMT forecast based on historic VMT for each year from 1990 to the latest available year of VMT data. A shorter time period (10 years) may be more appropriate if it appears that structural factors have led to a significantly different trend in the past decade compared with previous decades, and if this new trend is expected to continue.

These regression analyses should be performed at the county level for each functional roadway classification and for each HPMS vehicle type. For rural areas along Interstate highways, a large portion of the county's VMT can be made up of through traffic. For these rural areas the VMT for the interstate facility should be forecast separately from the VMT for the rest of the county. Linear regression can result in some VMT trends for individual functional classifications becoming negative, either as a result of historically decreasing traffic counts or as a result of changes to urban–rural HPMS designations that shift the functional class bin in which traffic counts are reported. For situations in which this occurs, VMT is recommended to be held constant at the level of the latest year for which HPMS data are collected to provide a conservative estimate of VMT.

VMT Projection Using Contributing Factors

A simple extrapolation of historic VMT trends is not ideal because the various drivers of VMT (e.g., regional population, income, vehicle trip rates, trip lengths, vehicle occupancy) may change over time in ways that do not reflect the regression equation chosen. An improved approach that does not involve significantly more effort is to forecast population and VMT per capita separately and then combine them as follows: VMT = population × (VMT/capita).

Forecasts of the individual factors may be available from the following sources:

- Population growth forecasts are often generated by state or local planning agencies for use in a variety of applications, such as transportation planning, comprehensive planning, and economic development;
- Future VMT per capita can be projected using historic VMT and population data to calculate historic VMT per capita, which can be trended forward using linear projection methods as described above or professional judgment; and
- State or local programs and policies, such as travel demand management or land use planning programs, may influence future VMT per capita and may have already set specific goals for this metric.

An even more detailed projection could involve analysis of multiple factors, such as trip rates by household income level and size, trip lengths, mode shares, vehicle occupancy, and/or economic activity. For example, historic data could be used to model per capita VMT as a function of population, household size, and area employment. The model would then be used to develop future per capita VMT projections, using forecasts of these driving variables.

As a hypothetical example, VMT in Massachusetts is projected to illustrate how projections of population and VMT per capita can be used to forecast future VMT. Historic data from Massachusetts from 1990 through 2008 are used to project VMT through 2030. The steps are as follows (excerpts of the data are shown in Table A.9):

1. Historic population estimates for 1990 through 2008 were taken from the U.S. Bureau of the Census. (Note that the years between the decennial censuses are estimates that are not as accurate as the decennial census years; 2001 to 2009 values will be retrospectively adjusted to match the 2010 census totals.) The population is projected to increase by 6% in 2030 compared with 2008.

2. Population projections for 2010, 2020, and 2030 were taken from state sources, and intermediate years were obtained using linear interpolation.

3. Annual VMT for the state was obtained from the FHWA Highway Statistics, Table VM-2.

4. VMT per capita was calculated for 1990 to 2008.

5. Trendlines were used to extrapolate VMT per capita (Figure A.10). Two trendlines were established: 1990 to 2008 and 1999 to 2008. It may be observed that the growth in VMT per capita was considerably lower over the past decade than over the previous decade.

6. As a sensitivity analysis, two VMT projections were developed: one using the higher rate of VMT growth, and one using the lower rate observed over the past decade (Figure A.11). These estimates show total VMT increasing by 8% to 18% over the 2008 to 2030 time frame.

TABLE A.9. MASSACHUSETTS POPULATION AND VMT DATA

Year	Population (Historic and Projected)	Annual VMT (millions)	Historic VMT per Capita	VMT per Capita		Annual VMT (millions)	
				Low Projection	High Projection	Low Projection	High Projection
1990	6,016,425	46,177	7,675	na	na	46,177	46,177
1991	6,049,692	46,537	7,692	na	na	46,537	46,537
				↓			
2008	6,623,273	54,505	8,229	na	na	54,505	54,505
2009	6,636,136			8,238	8,274	54,666	54,906
2010	6,649,000			8,246	8,318	54,828	55,308
				↓			
2020	6,856,000			8,330	8,762	57,107	60,076
				↓			
2030	7,012,000			8,413	9,207	58,992	64,558
2030 versus 2008	5.9%			2.2%	11.9%	8.2%	18.4%

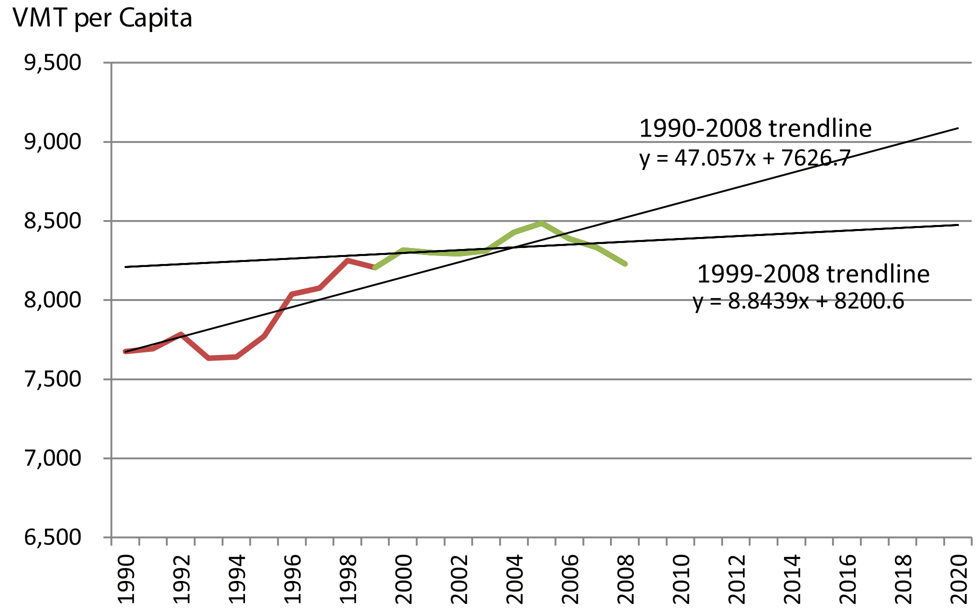

Figure A.10. *Massachusetts VMT per capita.*

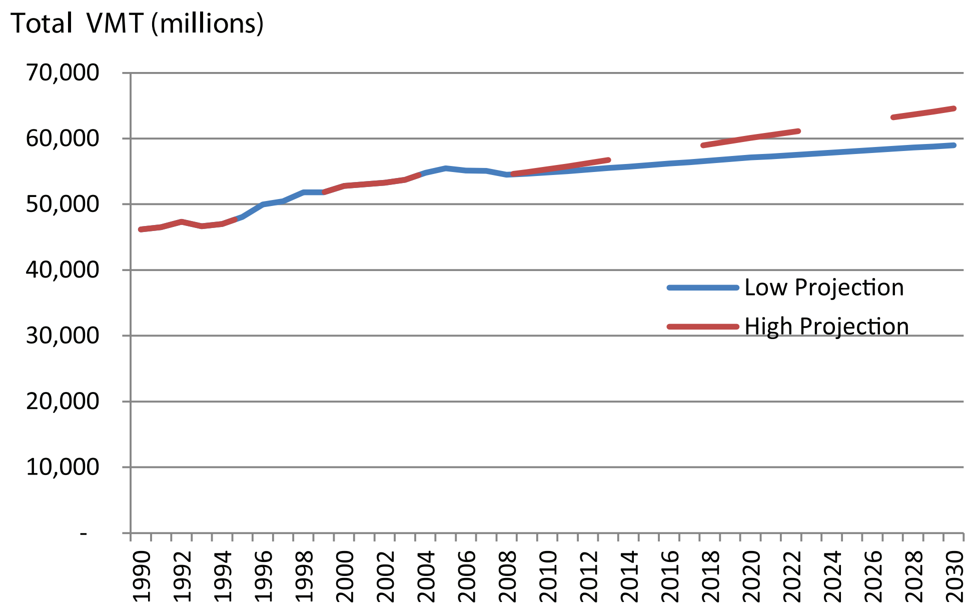

Figure A.11. *Hypothetical VMT projections for Massachusetts.*

Converting Highway and Nonhighway VMT into Emissions

Overview of Vehicle Emissions

GHG emissions estimates should always include CO_2 and will usually include CH_4 and N_2O. Hydrofluorocarbons (HFCs) may also be included to account for emissions from leaks and repairs related to air conditioning. GHG emissions from highway vehicles are dominated by CO_2. In 2005, on a CO_2e level, CO_2 accounted for about 95% of transportation emissions, with HFCs accounting for just more than 3%, N_2O slightly less than 2%, and CH_4 about 0.1% of national transportation GHG emissions (U.S. Environmental Protection Agency 2010b). Black carbon is an additional pollutant with climate change implications, but the current state of scientific knowledge does not support expression of these emissions in terms of global warming potential.

Different methods are generally used for calculating CO_2 than are used for calculating CH_4 and N_2O emissions from highway vehicles. This is because emission factors for CO_2 are generally expressed in terms of fuel consumed (e.g., grams per gallon of gasoline), but emission factors for CH_4 and N_2O are expressed as a function of vehicle activity (e.g., grams per VMT). Although the CO_2 emission factors vary only by fuel type (gasoline versus diesel), CH_4 and N_2O emission factors vary significantly according to vehicle technology. For example, N_2O emission factors range from as low as 0.001 g/mi for a diesel passenger car to as high as 0.2 g/mi for an older gasoline heavy-duty vehicle. HFC emissions are not usually calculated because they are more related to vehicle maintenance practices than VMT.

All emissions estimates are derived as the product of vehicle activity and emission rates that reflect the vehicle activity. Emission rates can be derived based on mass per time (grams per second), mass per distance (grams per mile), or mass per unit of fuel consumed (grams per gallon). Mass per time and mass per distance are related by speed. Time-based emission rates can be defined for both idling and moving vehicles. Fuel-based emission rates are useful if fuel consumption rates are known (some traffic simulation models provide outputs of fuel consumption but not GHG emissions).

Two approaches are identified that can be used to generate emission rates:

- The regulatory emissions factor models can be used (MOVES outside of California and EMFAC within California). These models generate activity-based emission rates. See below for additional guidance on using the MOVES model; or
- Fuel-based emission rates can be used. Both EPA and CARB have identified grams per gallon CO_2 emission rates for gasoline- and diesel-powered vehicles, consistent with Intergovernmental Panel on Climate Change (IPCC) protocols. This approach is covered in detail in this section.

If the necessary resources or data needed to run MOVES or EMFAC to estimate GHG emissions are not available, other more simplified methods are available that can be accomplished in a spreadsheet. CO_2 emissions are calculated as a function of fuel consumption and CH_4 and N_2O emissions are calculated based on VMT, so separate approaches are used for these two sets of pollutants, as described below. CO_2 emissions are essentially a direct function of fuel consumption, depending only on fuel type. In contrast, CH_4 and N_2O are strongly determined by the vehicle's emissions control technology, and therefore emissions factors from a model that accounts for vehicle technology must be used for these gases.

CO_2 Emissions

Historic or future CO_2 emissions from vehicles can be determined based on VMT and fuel efficiency using the following general equation:

$$\text{emissions} = \sum[(VMT_{abc}/FE_{abc}) \times EF_b]$$

where

FE = fuel economy (mi/gal),
EF = emissions factor (g/gal),
a = vehicle type (e.g., passenger car, light-duty truck),
b = fuel type (e.g., diesel or gasoline), and
c = analysis year.

The specific steps to fill in each of the variables in the equation are described below.

Step 1: Split VMT into Vehicle Types

VMT data from HPMS should already be available by vehicle type, such as passenger cars, light-duty trucks, and heavy-duty vehicles. If such data are not available, VMT can be divided using national percentage distributions from the following national sources.

Historic Years. The percentage distribution by vehicle type for historic years can be derived from FHWA's Highway Statistics, Table VM-1, or from a compilation of this table for a series of years in the Bureau of Transportation Statistics' National Transportation Statistics, Table 1-32. Both of these tables provide VMT by vehicle type, which can be converted to percentage distributions. These data are available for six vehicle types, but can be combined into three vehicles types as shown in the example percentage distributions in Table A.10.

TABLE A.10. EXAMPLE VEHICLE TYPE PERCENTAGE DISTRIBUTION FOR HISTORIC YEARS

Vehicle Type	2000	2001	2002	2003	2004	2005	2006	2007
Passenger cars	58.48%	58.41%	58.27%	58.04%	57.53%	57.35%	56.31%	55.40%
Light-duty trucks	33.73%	33.84%	33.94%	34.16%	34.76%	34.95%	36.06%	36.84%
Heavy-duty trucks	7.79%	7.75%	7.78%	7.80%	7.70%	7.70%	7.63%	7.76%

Source: Bureau of Transportation Statistics (2009), Table 1-32.

Future Years. The percentage distribution by vehicle type for future years can be derived from two tables from the AEO (Energy Information Administration 2010). Table 7 from the AEO reference case provides VMT for LDVs, commercial light trucks, and freight trucks. This can be combined with Supplemental Table 58 to divide the LDVs into passenger cars and light-duty trucks. Table A.11 gives an example of distributions derived from the VMT and vehicle stock estimates from these AEO tables.

TABLE A.11. EXAMPLE VEHICLE TYPE PERCENTAGE DISTRIBUTIONS FOR FUTURE YEARS

Vehicle Type	2010	2015	2020	2025	2030	2035
Passenger cars	51.64%	49.17%	49.85%	52.07%	54.34%	56.27%
Light-duty trucks	41.51%	43.18%	42.32%	40.22%	37.96%	35.96%
Heavy-duty trucks	6.84%	7.66%	7.83%	7.70%	7.70%	7.77%

Source: Energy Information Administration (2010), Table 7 and Supplemental Table 58.

Step 2: Calculate Fuel Consumption by Dividing by Fuel Economy

Fuel economy should be collected for each vehicle type into which VMT was split. Care must be taken to understand whether the stated fuel economy represents the fuel economy of a specific vehicle model year or whether it represents the fleetwide average of all vehicles in use. The fleetwide average of all vehicles in use should always be used. Also, care should be taken to note which fuel the fuel economy provides for so that the appropriate carbon contents can be applied in the next step. Most passenger cars and light-duty trucks use gasoline and most heavy-duty trucks use diesel, but exact gasoline–diesel splits can be obtained from the EPA if a more detailed estimate is desired. If available, local data on fuel economy can be used; otherwise, the following national sources are recommended. If using these national sources, analysts should note whether the area they wish to use for comparison uses reformulated gasoline as a result of being an ozone nonattainment area; if so, the fuel efficiency should be adjusted to be 1% to 3% worse than the amounts given here to account for the poorer fuel economy from reformulated gasoline (U.S. Environmental Protection Agency 2010d).

Historic Years. The fuel economy by vehicle type for historic years can be derived from FHWA's Highway Statistics, Table VM-1, or a compilation of this table from a series of years in the Bureau of Transportation Statistics' National Transportation Statistics, Tables 4-13, 4-14, 4-15, and 4-23. Although these tables provide fuel economy for six vehicle types, the data shown in Table A.12 combine single-unit trucks, combination trucks, and buses into the heavy-duty trucks category by using a VMT weighted average.

TABLE A.12. EXAMPLE FUEL ECONOMY FOR 2000 TO 2007

Vehicle Type	2000	2001	2002	2003	2004	2005	2006	2007
Passenger cars	21.9	22.1	22.0	22.2	22.5	22.1	22.5	22.5
Light-duty trucks	17.4	17.6	17.5	16.2	16.2	17.7	17.8	18.0
Heavy-duty trucks	6.01	6.12	6.01	6.91	6.85	6.28	6.17	6.20

Source: Bureau of Transportation Statistics (2009), Tables 4-13, 4-14, 4-15, and 4-23.
Note: Fuel economy is expressed in miles per gallon of gasoline equivalent.

Future Years. Fuel economy by vehicle type for future years can be derived from the AEO. Data are available for passenger cars and light trucks (AEO Supplemental Table 59) and medium- and heavy-duty vehicles (AEO Supplemental Table 67); these data are summarized for select years in Table A.13. Note that this table reports fuel economy in miles per gallon of gasoline equivalent. A gallon of gasoline equivalent is the amount of fuel that has the same energy content as a gallon of gasoline.

TABLE A.13. EXAMPLE FUEL ECONOMY FOR FUTURE YEARS

Vehicle Type	2010	2015	2020	2025	2030	2035
Passenger cars	23.67	25.29	27.73	29.79	31.46	32.68
Light-duty trucks	18.37	19.47	21.05	22.57	23.93	25.08
Heavy-duty trucks	6.05	6.30	6.62	6.82	6.95	7.03

Source: Energy Information Administration (2010), Supplemental Tables 59 and 67.
Note: Fuel economy is expressed in miles per gallon of gasoline equivalent.

Step 3: Apply CO_2 Emissions Factors

Once the amount of fuel consumed is calculated, it should be multiplied by a fuel-specific CO_2 emission factor (kilograms per gallon) to calculate the total amount of direct CO_2 emitted. The emissions factors shown in Table A.8 are for gasoline and diesel fuel. Because alternative fuels often have significant CO_2 emissions in the rest of the life cycle beyond fuel consumption, emissions factors for alternative fuels are covered below in "Vehicle and Fuel Life-Cycle Emissions." It should be noted that gasoline and diesel also have additional life-cycle emissions; using the factors shown in Table A.8 only calculates the direct emissions from burning the fuel in vehicles. Many areas of the country that are in nonattainment for ozone air quality standards use reformulated gasoline, which has slightly different CO_2 emission factors because of the addition of ethanol or other additives to the gasoline. Alternate CO_2 emission factors for gasoline with 10% ethanol (E10) are available in Table A.8. Step 2 contains details for adjusting the fuel economy to account for reformulated gasoline.

CH_4 and N_2O Emissions

CH_4 and N_2O collectively represent only a small fraction of GHG emissions from motor vehicles: about 2% for LDVs and about 0.3% for diesel-powered heavy-duty vehicles as measured in CO_2e. In 2010, CH_4 represented about 2.0% of GHG emissions from LDVs and N_2O represented about 0.1%. CH_4 emissions from trucks were negligible, and N_2O emissions represented 0.3% of total GHG emissions from these vehicles. These figures are from Cambridge Systematics (2009) calculations based on AEO Table 2-15, which shows historic data through 2006 extrapolated through 2010 (Energy Information Administration 2009). CH_4 and N_2O emissions do not offer large opportunities in terms of mitigation potential and should be considered a lower priority to calculate. The simplest approach to including these emissions in a GHG emissions inventory is to scale up CO_2 emissions by 2% for LDVs and 0.3% for heavy-duty vehicles, or to use alternative scaling factors using future year emissions factors.

If a more detailed approach to estimating CH_4 and N_2O emissions is desired, the general methodology employed in the EPA GHG *Inventory* (U.S. Environmental

Protection Agency 2010b), described in the following equation and The Climate Registry's *General Reporting Protocol*, can be used:

$$\text{emissions} = \sum(EF_{abc} \times \text{activity}_{abc})$$

where

EF = emissions factor (e.g., g/mi),
activity = activity level measured in the units appropriate to the emission factor (e.g., mi),
a = fuel type (e.g., diesel or gasoline),
b = vehicle type (e.g., passenger car, light-duty truck), and
c = model year.

Once CH_4 and N_2O emissions are calculated it is often useful to sum them with CO_2 emissions to get total GHGs. However, because each of these GHGs has different abilities to trap heat in the atmosphere, it is necessary to weight the emissions of CH_4 and N_2O relative to the ability of CO_2 to trap heat. A global warming potential factor is used to provide this weighting and to convert CH_4 and N_2O emissions into grams of CO_2e. The global warming potential values currently used by the EPA in the *Inventory of U.S. Greenhouse Gas Emissions* are provided in Table A.14. These values are based on IPCC's second assessment report (Intergovernmental Panel on Climate Change 1996); the 2007 fourth assessment report values are shown for comparison.

TABLE A.14. 100-YEAR GLOBAL WARMING POTENTIAL OF SELECT GHGS

Gas	EPA Inventory/IPCC 2nd Assessment	IPCC 4th Assessment
CO_2	1	1
CH_4	21	25
N_2O	310	298

Source: March 2009 public review draft of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*; *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, eds.). Cambridge University Press, Cambridge, United Kingdom, 2007.

CH_4 and N_2O emissions depend heavily on the type of emissions control technology used in the vehicle, and the type of control technology used generally correlates with the year of vehicle manufacture. Control technologies include uncontrolled, non-catalyst, oxidation catalyst, Tier 0, Tier 1, Tier 2, and low-emission vehicles. Because the introduction of these control technologies and the emission rates for N_2O and CH_4 both vary by model year for each vehicle type, VMT should be divided accordingly.

The following steps should be used to calculate N_2O and CH_4 emissions.

Step 1: Split VMT into Vehicle Types

This can be done using the details in Step 1 from the CO_2 emissions section above.

Step 2: Split VMT into Vehicle Model Years

State registration databases, which give the number of vehicles for each model year, can be used in combination with mileage accumulation assumptions by model year to distribute VMT among all model years. For nonattainment areas, this data should be readily available from transportation conformity analyses. For other areas, national defaults from the MOVES emissions model can be used.

Step 3: Obtain N_2O and CH_4 Emission Factors

Emission factors on a gram per mile basis for specific vehicle types and model years are available from the EPA's GHG *Inventory* or The Climate Registry's *General Reporting Protocol*. These rates are shown in Table A.15. Updated versions of these documents should be consulted for emissions factors for more recent model years as they become available.

Step 4: Multiply VMT by N_2O and CH_4 Emission Factors

To calculate the N_2O and CH_4 emissions, multiply the VMT distributed by vehicle type and model year by the corresponding emissions factors. Then sum all N_2O emissions and all CH_4 emissions.

The mobile combustion module of EPA's State Inventory Tool may also be of use in helping to perform these calculations at a regional level (U.S. Environmental Protection Agency 2012c).

TABLE A.15. N_2O AND CH_4 EMISSION RATES

Vehicle Type and Model Year	N_2O (g/mi)	CH_4 (g/mi)
Gasoline Passenger Cars		
1984 to 1993	0.0647	0.0704
1994	0.056	0.0531
1995	0.0473	0.0358
1996	0.0426	0.0272
1997	0.0422	0.0268
1998	0.0393	0.0249
1999	0.0337	0.0216
2000	0.0273	0.0178
2001	0.0158	0.011
2002	0.0153	0.0107
2003	0.0135	0.0114
2004	0.0083	0.0145
2005	0.0079	0.0147

(continued on next page)

TABLE A.15. N_2O AND CH_4 EMISSION RATES (CONTINUED)

Vehicle Type and Model Year	N_2O (g/mi)	CH_4 (g/mi)
Gasoline Light Trucks (Vans, Pickup Trucks, SUVs)		
1984 to 1993	0.1035	0.0813
1994	0.0982	0.0646
1995	0.0908	0.0517
1996	0.0871	0.0452
1997	0.0871	0.0452
1998	0.0728	0.0391
1999	0.0564	0.0321
2000	0.0621	0.0346
2001	0.0164	0.0151
2002	0.0228	0.0178
2003	0.0114	0.0155
2004	0.0132	0.0152
2005	0.0101	0.0157
Gasoline Heavy-Duty Vehicles		
1985 to 1986	0.0515	0.409
1987	0.0849	0.3675
1980 to 1989	0.0933	0.3492
1990 to 1995	0.1142	0.3246
1996	0.168	0.1278
1997	0.1726	0.0924
1998	0.1693	0.0641
1999	0.1435	0.0578
2000	0.1092	0.0493
2001	0.1235	0.0528
2002	0.1307	0.0546
2003	0.124	0.0533
2004	0.0285	0.0341
2005	0.0177	0.0326
Diesel Passenger Cars		
1960 to 1982	0.0012	0.0006
1983 to 2004	0.001	0.0005
Diesel Light Trucks		
1960 to 1982	0.0017	0.0011
1983 to 1995	0.0014	0.0009
1996 to 2004	0.0015	0.001
Diesel Heavy-Duty Vehicles		
All model years	0.0048	0.0051

Source: The Climate Registry (2012), Table 13.4.

Refrigerant Emissions

Refrigerants used in air conditioning and refrigeration systems represent an additional source of GHG emissions from highway vehicles. Emissions from mobile air conditioners and refrigerated transport accounted for about 4% of GHG emissions from cars, 5% from light-duty trucks, and 0.6% from heavy trucks in 2006 (Cambridge Systematics 2009; calculations are based on AEO Table 2-15, April 2009 release). Modern refrigerants are potent GHGs with a high global warming potential. HFC-134a, the most commonly used refrigerant today, has a global warming potential of 1,300. HFCs are released into the atmosphere through leaks in mobile air conditioners or refrigerated transport units during servicing, operation, and retirement.

Refrigerants may or may not be included in transportation GHG inventories. For example, EPA's State Inventory Tool does not attribute refrigerant emissions to the mobile sector, but rather includes them in the industrial sector (because they are dispensed and recovered at automobile repair facilities). Mobile source emissions factor models do not provide for refrigerant emissions, so if they are to be included in a transportation inventory, they will need to be scaled from nonrefrigerant emissions using AEO data.

Black Carbon

While less is understood about the effect of black carbon on climate change than the above-mentioned GHGs, there is increasing evidence that it causes direct positive radiative forcing (i.e., has a net warming effect on the earth). Black carbon differs from GHGs such as CO_2 because it remains in the atmosphere for only days or weeks and dissipates before it reaches a global scale; in contrast, CO_2 remains in the atmosphere for decades and has a global spatial scale. The exact definition of black carbon varies by the source consulted, but in general it is a component of particulate matter, or soot, produced from the incomplete combustion of fossil fuel, biofuels, and biomass (Diesel Technology Forum 2012). Black carbon is also referred to as elemental carbon.

Black carbon has a warming effect because it absorbs light and turns it into heat. When black carbon is deposited on ice and snow, it reduces their ability to reflect light, which in turn reduces their global cooling effect and simultaneously heats the ice and snow to melt them. In climate change research, black carbon is often grouped with other aerosols, such as sulfate, organic carbon, nitrate, and dust, because of their similar characteristics as short-lived climate forcers. However, many of these aerosols have a cooling effect on the climate, as opposed to the warming effect of black carbon.

Black carbon is not required to be included in official GHG emissions inventories, so little information is available on the amount of black carbon emissions from specific transportation sources in the United States. However, some studies offer global inventories of black carbon. For example, Bond (2009) estimates that on-road transport sources contribute 16% of total black carbon emissions and off-road transport contributes 9%. The remaining sources are open biomass burning (39%), residential cooking and heating (25%), and industrial (11%).

The nature of black carbon as a subspecies of particulate matter suggests that among transportation sources, those that emit high levels of particulates, such as heavy-duty diesel vehicles, would also emit high levels of black carbon and would be a potential target of mitigation strategies. Mitigation strategies could include those already being promoted to control particulate emissions, such as clean diesel fuels, advanced engine designs, and control technologies (e.g., particulate filters). There would be cobenefits for human health because of a simultaneous reduction in particulate matter from implementing these types of mitigation strategies. These mitigation strategies may also reduce other particulate subspecies that have a cooling effect on the climate, such as organic carbon. Therefore, care must be taken to calculate the overall net effect on cooling and warming when considering mitigation strategies.

The MOVES model produces emissions outputs for both elemental carbon (black carbon) and organic carbon as particulate matter subspecies. However, because of the current lack of knowledge related to quantifying the warming effect of these emissions, it is not recommended that agencies calculate black carbon emissions until further research is available. Typically, emissions of GHGs are converted to CO_2e emissions based on their global warming potential over 100 years. However, because the residence time of black carbon in the atmosphere is much shorter than 100 years and the amount of its warming effect is still uncertain, using this conversion is not possible. Similar uncertainty exists for the cooling particulate subspecies, which must be included in the calculation to take into account the net cooling and warming effects.

EPA is currently funding research on black carbon's role in global- to local-scale climate and air quality, including alternative conversion schemes (U.S. Environmental Protection Agency 2010a).

GHG EMISSIONS FROM TRANSIT VEHICLES

GHG emissions from transit can be calculated in a manner similar to highway vehicles as outlined above, with the exception of electrically powered transit vehicles. There are also different sources of data, such as the National Transit Database (NTD). NTD provides direct fuel consumption data for transit systems across the United States, which allows the analyst to omit the fuel consumption calculation using VMT and fuel economy.

Historic GHG Emissions from Transit

Transit Buses

VMT data from HPMS include buses that travel on public roadways, but do not include other transit vehicles such as light rail, heavy rail, commuter rail, or buses that travel on a dedicated transit right-of-way. To avoid double-counting, one of the following approaches should be used:

- Remove transit bus VMT from the HPMS data before calculating transit bus GHG emissions separately. This approach is desirable if the transportation project or plan alternatives being analyzed will include different levels of transit service; or

- Leave transit bus VMT in the HPMS data and calculate transit bus GHG emissions as part of the process described above.

If calculating transit bus emissions separately, the following equations can be used:
CO_2 emissions = fuel consumption × CO_2 emission factor (g/gal),
N_2O emissions = annual distance driven × N_2O emission factor (g/mi), and
CH_4 emissions = annual distance driven × CH_4 emission factor (g/mi).

NTD data provide annual fuel consumption to calculate CO_2 and annual miles to calculate CH_4 and N_2O. The following steps describe the specific calculation processes.

CO_2 Emissions

Step 1: Determine Transit Bus Fuel Consumption. Fuel consumption by mode for each transit system can be found in Table 17 (Energy Consumption) from the NTD Annual Databases (Federal Transit Administration 2012). Table 17 provides gallons of liquid fuels (diesel, gasoline, compressed natural gas) used and kilowatt-hours of electricity used (see "Electric Transit Vehicles" below). Table A.16 uses the Los Angeles County Metropolitan Transit Authority (LACMTA) as an example of the data format available in NTD. NTD has more types of fuel listed in additional columns, but they are deleted from this example for simplicity because they were zero for LACMTA.

TABLE A.16. EXAMPLE OF FUEL CONSUMPTION DATA AVAILABLE FOR LACMTA FROM NTD

	Sources of Energy (in thousands)			
	Gallons			Kilowatt-Hours
Mode	Diesel	Gasoline	Compressed Natural Gas	Electric Propulsion
Heavy rail	0.0	0.0	0.0	84,828.0
Light rail	0.0	0.0	0.0	92,637.2
Motor bus	1,439.5	0.0	41,327.5	0.0

Source: Federal Transit Administration (2012), Table 17.

Step 2: Apply CO_2 Emission Factors. The amount of fuel consumed can be multiplied by the fuel-specific emission factor to calculate the CO_2 emissions. Table A.17 provides CO_2 emission factors from The Climate Registry's *General Reporting Protocol*. For compressed natural gas, care should be taken to convert the units, because NTD provides gallons and the *General Reporting Protocol* provides kilograms of CO_2 per standard cubic foot (scf). The compressed natural gas industry has adopted a standard measurement that states that 135 scf of natural gas is equal to 1 gallon of liquid diesel fuel (or 124 scf for 1 gallon of gasoline).

TABLE A.17. CO_2 EMISSION FACTORS BY FUEL TYPE

Fuel Type	CO_2 Emission Factor	Unit
Diesel	10.15	kg CO_2/gal
Gasoline	8.81	kg CO_2/gal
Liquefied petroleum gas	5.79	kg CO_2/gal
Liquefied natural gas	4.46	kg CO_2/gal
Methanol	4.1	kg CO_2/gal
Ethanol (E100)	5.56	kg CO_2/gal
Compressed natural gas	0.054	kg CO_2/scf
Kerosene	9.76	kg CO_2/gal
Biodiesel (B100)	9.46	kg CO_2/gal

Source: The Climate Registry (2012), Table 13.1.

N_2O and CH_4 Emissions

Step 1: Determine Transit Bus VMT. VMT by mode for each transit system can be found in Table 19, Transit Operating Statistics: Service Supplied and Consumed, from the NTD Annual Databases. Table 19 provides annual vehicle miles for each mode of directly operated or purchased transportation in the transit system. Annual vehicle revenue miles and annual scheduled vehicle revenue miles are also available from this table, but they should not be used because they do not cover all VMT (they exclude miles traveled to and from storage and maintenance facilities). Table A.18 uses LACMTA as an example to show the format of data available in NTD. NTD has more metrics for service supplied in additional columns, but they are deleted from this example for simplicity. This example shows 107,955,500 vehicle miles traveled for all motor buses.

TABLE A.18. EXAMPLE OF VMT DATA AVAILABLE FOR LACMTA FROM NTD

		Service Supplied (in thousands)		
Mode	Type of Service	Annual Scheduled Vehicle Revenue Miles	Annual Vehicle Miles	Annual Vehicle Revenue Miles
Heavy rail	Directly operated	6,034.1	6,200.7	6,003.5
Light rail	Directly operated	8,928.6	8,940.4	8,812.5
Motor bus	Directly operated	85,105.7	99,732.9	83,530.0
Motor bus	Purchased transportation	6,786.3	8,222.6	6,751.7
Vanpool	Purchased transportation	0.0	13,065.2	13,065.2

Source: Federal Transit Administration (2012), Table 19.

Step 2: Apply N_2O and CH_4 Emission Factors. VMT can be multiplied by a fuel-specific emission factor to calculate N_2O and CH_4 emissions. Table A.19 provides N_2O and CH_4 emission factors from The Climate Registry's *General Reporting Protocol*. These emissions are almost negligible for diesel vehicles because of their lack of catalytic converters, but CH_4 emissions from compressed natural gas vehicles can be significant because of incomplete combustion of natural gas (methane).

TABLE A.19. N_2O AND CH_4 EMISSION FACTORS FOR BUSES

Bus Fuel Type	N_2O (g/mi)	CH_4 (g/mi)
Diesel	0.0048	0.0051
Methanol	0.175	0.066
Compressed natural gas	0.175	1.966
Ethanol	0.175	0.197

Source: The Climate Registry (2012), Tables 13.4 and 13.5.

Commuter Rail Vehicles and Ferry Boats

CO_2 emissions for commuter rail vehicles (considered locomotives) and ferry boats should be calculated using the same fuel consumption–based method described above for transit buses. However, for N_2O and CH_4 emissions, a fuel consumption–based method is normally used, as opposed to a mileage-based method as described for transit buses. NTD Table 17 for fuel consumption and the emission factors in Table A.20 can be used to calculate N_2O and CH_4 emissions for commuter rail vehicles and ferry boats.

TABLE A.20. N_2O AND CH_4 EMISSION FACTORS FOR COMMUTER RAIL AND FERRY BOATS

Vehicle and Fuel Type	N_2O (g/gal)	CH_4 (g/gal)
Ships and Boats		
Residual fuel oil	0.3	0.86
Diesel fuel	0.26	0.74
Gasoline	0.22	0.64
Locomotives (Rail)		
Diesel fuel	0.26	0.8

Source: The Climate Registry (2012), Table 13.6.

Electric Transit Vehicles

To calculate GHG emissions from electric transit vehicles, Table 17, Energy Consumption, from the NTD Annual Databases can be used. This table provides electric consumption in kilowatt-hours for a variety of transit modes including heavy rail, light rail, and trolley bus. Table A.21 provides electric emission factors for the three major GHGs and the combined CO_2e amount from EPA's eGRID database. The most recent rates available as of this writing are for 2007, but the EPA's website should be consulted for updated rates (U.S. Environmental Protection Agency 2012a). These emissions factors are organized by the subregions of the country shown on the map in Figure A.12. Depending on the mix of electric generation sources, rates for local utilities may vary from these regional rates. To calculate CO_2, N_2O, and CH_4 emissions, each of the emission factors can be multiplied by the kilowatt-hours of electricity consumption from the NTD data.

TABLE A.21. ELECTRIC EMISSION FACTORS (2007) BY eGRID SUBREGION

eGRID Subregion Acronym	eGRID Subregion Name	CO_2 (lb/mW-h)[a]	CH_4 (lb/gW-h)[b]	N_2O (lb/gW-h)	CO_2e (lb/mW-h)
AKGD	ASCC Alaska Grid	1232.4	25.6	6.5	1234.9
AKMS	ASCC Miscellaneous	498.9	20.8	4.1	500.6
AZNM	WECC Southwest	1311.1	17.5	17.9	1317
CAMX	WECC California	724.1	30.2	8.1	727.3
ERCT	ERCOT All	1324.4	18.7	15.1	1329.4
FRCC	FRCC All	1318.6	45.9	16.9	1324.8
HIMS	HICC Miscellaneous	1514.9	314.7	46.9	1536.1
HIOA	HICC Oahu	1812	109.5	23.6	1821.6
MROE	MRO East	1834.7	27.6	30.4	1844.7
MROW	MRO West	1821.8	28	30.7	1831.9
NEWE	NPCC New England	927.7	86.5	17	934.8
NWPP	WECC Northwest	902.2	19.1	14.9	907.3
NYCW	NPCC NYC/Westchester	815.5	36	5.5	817.9
NYLI	NPCC Long Island	1536.8	115.4	18.1	1544.8
NYUP	NPCC Upstate NY	720.8	24.8	11.2	724.8
RFCE	RFC East	1139.1	30.3	18.7	1145.5
RFCM	RFC Michigan	1563.3	33.9	27.2	1572.4
RFCW	RFC West	1537.8	18.2	25.7	1546.2
RMPA	WECC Rockies	1883.1	22.9	28.8	1892.5
SPNO	SPP North	1960.9	23.8	32.1	1971.4
SPSO	SPP South	1658.1	25	22.6	1665.7
SRMV	SERC Mississippi Valley	1019.7	24.3	11.7	1023.9
SRMW	SERC Midwest	1830.5	21.2	30.5	1840.4
SRSO	SERC South	1489.5	26.3	25.5	1498
SRTV	SERC Tennessee Valley	1510.4	20.1	25.6	1518.8
SRVC	SERC Virginia/Carolina	1134.9	23.8	19.8	1141.5

Source: U.S. Environmental Protection Agency (2012a), Year 2005 GHG Annual Output Emission Rates.
[a]mW-h = megawatt-hour (1,000 kilowatt-hours).
[b]gW-h = gigawatt-hour (1,000,000 kilowatt-hours).

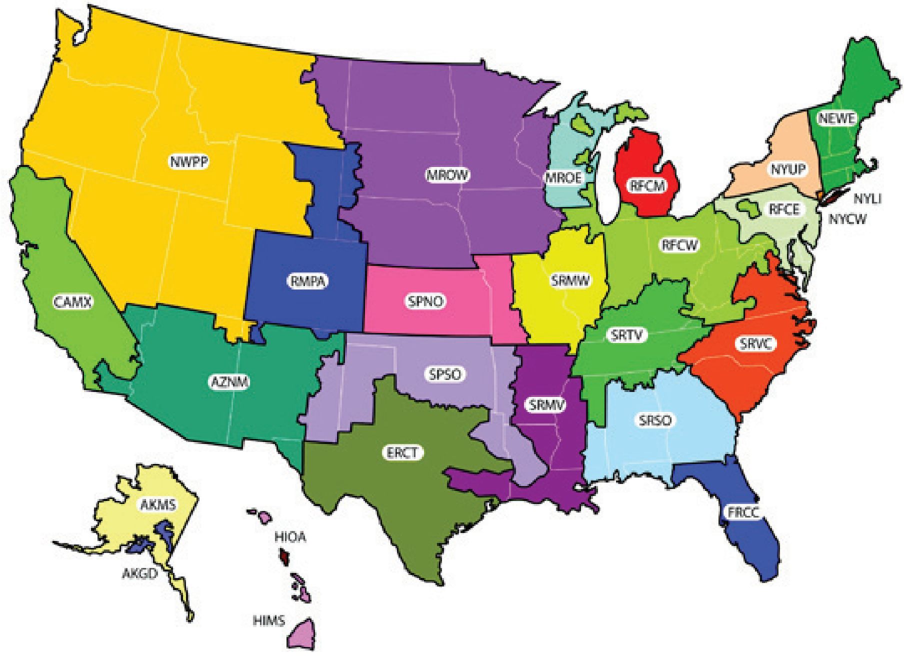

Figure A.12. *EPA eGRID subregions.*

Future Year Transit GHG Emissions

To calculate transit emissions for future years it is necessary to estimate future year annual distance driven by mode. This can be done in three ways:

- First, for buses included in the HPMS inventory, use general roadway VMT forecasts and assume that buses continue to make up the same fraction of future VMT;
- Second, for other modes, or for buses not included in the HPMS highway inventory, extrapolate future service levels (total vehicle miles, as illustrated in Table A.6) from recent historic trends using NTD data; or
- Finally, develop future estimates based on transit service growth assumptions provided by local transit agencies or other transportation planning agencies. This is usually the most appropriate approach; the previous extrapolation approaches should be used only if consultation with local agencies is not possible.

It is also necessary to forecast emissions factors for future years. There are several options for accomplishing this.

For transit buses, adjust base year emission rates to account for any known efficiency standards or improvements planned to be implemented by the local transit agency through the purchase of more efficient or alternative fuel vehicles. This can be done based on emissions data for the specific types of transit vehicles as provided by the manufacturer or obtained from other transit agencies or research studies.

For transit vehicles operating on electricity, current electricity emission factors from the eGRID database can be adjusted downward based on applicable state, regional, or national initiatives to reduce GHG emissions from electricity generation.

For example, the Regional Greenhouse Gas Initiative in the northeastern and mid-Atlantic states aims to reduce GHG emissions from electricity-generating sources by 2.5% per year between 2014 and 2018.

The *Annual Energy Outlook* can be used to develop projections of electric generation GHG intensity. It is recommended that the AEO's regional forecasts be used (the AEO provides forecasts for nine regions of the country). Table 1 of the AEO can be used to identify total electric energy consumption, and Table 21 can be used to identify total CO_2 emissions from the electric sector; these can be combined to calculate carbon intensity. It may be desirable to factor current emissions factors from eGRID by the future trend in carbon intensity from the AEO because eGRID provides greater geographic detail on the electricity generation mix.

If it is believed that GHG emission rates from electricity generation will decline at a different rate than identified from the above sources, emission rates may be assumed from a credible scenario analysis that most closely resembles future conditions for the area under consideration. For example, the Electric Power Research Institute provides emission rates for low, medium, and high CO_2 intensity scenarios based on assumptions about the price of CO_2 emissions allowances, the rate at which older power plants are retired, the availability and performance of new generation technologies, and the annual growth in electricity demand (Electric Power Research Institute 2007). Table A.22 shows the assumptions for each scenario and the CO_2e emission rates for each. These scenarios represent national average conditions and would need to be adjusted for local differences.

TABLE A.22. EPRI 2050 SCENARIOS FOR ELECTRIC SECTOR CO_2E EMISSION RATES

	CO_2 Intensity		
Scenario Definition	**High**	**Medium**	**Low**
Price of GHG emissions allowances	Low	Moderate	High
Power plant retirements	Slower	Normal	Faster
New generation technologies	Unavailable: Coal with CCS New nuclear New biomass	Available: IGCC coal with CCS New nuclear New biomass Advanced renewables	Available: Retrofit of CCS to existing IGCC and pulverized coal plants
	Lower performance: SCPC, CCNG, GT, wind, and solar	Nominal EPRI performance assumptions	Higher performance: Wind and solar
Annual electricity demand growth	1.56% per year on average	1.56% per year on average	2010 to 2025: 0.45% 2025 to 2050: None
2050 electric sector average CO_2e intensity (g/kW-h)[a]	412	199	97

Source: Electric Power Research Institute (2007).

Note: IGCC = integrated gasification combined-cycle; SCPC = supercritical pulverized coal; CCNG = combined-cycle natural gas; GT = gas turbine (natural gas); CCS = carbon capture and storage; EPRI = Electric Power Research Institute.

[a]For comparison, the average CO_2e intensity of the electric sector in 2005 was 612 g/kW-h; the EPRI-predicted rate was 573 g/kW-h in 2010.

Improvements in GHG emission rates for all transit modes can also be estimated based on local analysts' expectations regarding technology improvement. For example, a recent study of nationwide GHG reduction measures developed its own estimates of efficiency improvements based on NTD energy consumption trends, transit mode shares, transit trip lengths, improved bus technology, and decreased power generation emissions to estimate GHG emissions per passenger mile in 2050 for each transit mode (Cambridge Systematics 2009). The results assume that transit load factors remain constant. Percentage per year reductions derived from this analysis are provided in Table A.23. These reductions represent aggressive improvements that were developed to correspond to similarly aggressive improvements in LDV efficiency.

TABLE A.23. ESTIMATED ANNUAL IMPROVEMENTS IN GHG EMISSION RATES

Transit Mode	Annual Reduction in GHG Emission Rates Through 2050 (%)
Commuter rail	1.07%
Heavy rail	1.46%
Light rail	1.25%
Bus	0.54%
Other[a]	0.57%

Source: Cambridge Systematics (2009), Appendix B, Table 4.8.
[a]Automated guideway, cable car, ferry, incline, trolley bus, and vanpool.

GHG EMISSIONS FROM NONROAD SOURCES

Although the majority (about 80%) of GHG emissions from the transportation sector is from on-road sources, nonroad sources (including air, rail, and marine) also contribute to GHG emissions. The statewide and metropolitan transportation planning process usually focuses exclusively or primarily on surface transportation, especially highway and transit. However, freight rail and marine transport may be included, especially at a statewide level, but also in metropolitan plans. Aviation, particularly airport facilities, may also be included in these plans.

This section provides basic information on developing GHG inventories for nonroad sources. EPA's State Inventory Tool (SIT; discussed above) provides a framework for developing nonroad GHG inventories at the state level. The tool calculates CO_2 emissions based on fuel sales by fuel type, which for the most part is not useful for developing mode-specific inventories. However, the mobile combustion module for calculating CH_4 and N_2O provides a framework for assembling mode-specific activity data that could also be used for calculating CO_2 emissions. Some fuel types in SIT, notably aviation fuel and residual fuel, correspond with specific submarkets (aviation and large ships, respectively) and can be used to support inventories for these modes.

Rail Transportation

Urban rail

Emissions from urban rail transportation (light and heavy rail, commuter rail) can be calculated using the data sources and methods described above in "GHG Emissions from Transit Vehicles."

Intercity Passenger Rail

Emissions can be estimated for a state-level inventory based on train counts from Amtrak schedules and estimates of route mileage within the state or metropolitan area based on data from Amtrak or user-generated estimates. Activity should be estimated for both diesel and electric locomotives. Table 4-26 in the National Transportation Statistics provides historic information on the average energy intensity of passenger rail services in the United States, including diesel and electric services combined (Bureau of Transportation Statistics 2009). Future improvements in efficiency may be estimated by using either the AEO reference case projections for freight rail or other assumptions as determined appropriate by the analyst. More detailed analysis of existing and future efficiencies by locomotive type may be warranted for analysis of specific intercity rail policies, such as implementation of high-speed rail or electrification.

Freight Rail

Estimates and forecasts of ton-miles carried by rail within a state may be available in summary form from a state rail or freight plan. Current estimates are usually derived from data obtained directly from the rail carriers or from FHWA's Freight Analysis Framework. Forecasts may be obtained from the Freight Analysis Framework or other analysis conducted for the state rail or freight plan. Current and forecast energy efficiency (measured in ton-miles per thousand Btu) may be obtained from Table 7 of the AEO. These must be converted to ton-miles per gallon using Btu/gallon factors for diesel fuel such as those provided by the U.S. Department of Energy (Energy Information Administration 2012a).

Marine Transportation

Marine transportation includes domestic and international shipping, ferries, and recreational boats. National GHG inventories do not include the international bunker fuels used for international shipping, so these fuels are typically not included in state inventories. Ships typically use residual fuel (a less refined form of diesel fuel). The fuel-based estimates for diesel and residual fuel contained in EPA's SIT may correspond fairly closely with domestic and international shipping. However, the data may be of questionable quality, showing substantial variation from year to year. State-level gasoline and diesel fuel use in smaller boats can also be found in SIT (although again it may be of questionable quality), with the assumption that these fuels are used in smaller boats. Activity or port call data (typically expressed as horsepower-hours) representing the operation of both primary and auxiliary engines for the vessel fleet may also be available from the relevant port authority in an area. Projections may be developed by factoring state-level current estimates by AEO national-level forecast changes in U.S. shipping volume (ton-miles) and efficiency (ton-miles per thousand Btu) from Table 7.

Activity data for ferries can be obtained from NTD for individual ferry transit operators. However, fuel consumption (gallons per vessel mile) is not available at this level and must be based on national average fuel consumption from NTD. If specific policies affecting marine operations are to be analyzed, a more detailed analysis of this sector based on locally obtained data (e.g., from a ferry operator or port authority) may be warranted.

Aviation

Data on sales of jet fuel and aviation fuel by state are included in SIT (although, like the marine fuel use data, this information can be of questionable quality, and international bunker fuels for aviation are not included in national inventories). GHG emissions from aircraft are typically allocated to the airport at which the aircraft's flight originates. It is assumed that fuel sales by location correspond with the fuel used for flights originating from that location.

The Federal Aviation Administration's Emission Dispersion Modeling System (EDMS) is a modeling tool for estimating GHG (and other criteria pollutant) emissions from aircraft. EDMS relies on user-provided landing and takeoff data by aircraft type, which may be obtained directly from airports in a specific metropolitan area. An advantage to using EDMS is that it also estimates ground support equipment and auxiliary power unit emissions associated with the specified aircraft activity. An alternative approach, and one that can be used for forecasting, is to obtain estimates of seat miles originating from major airports from the Bureau of Transportation Statistics and to multiply by efficiency (expressed as seat miles per gallon) from AEO Table 7. Future year emissions can be projected by adjusting base year emissions by forecasts of general aviation and commercial aircraft operations in the state, which may be available from the state or regional aviation authority, or from the Federal Aviation Administration's Terminal Area Forecasts. Future year aircraft efficiency can also be adjusted by seat mile efficiency projections from AEO.

Emissions from Construction, Maintenance, and Operations

Overview

Construction, maintenance, and operations (CMO) emissions are GHG emissions associated with constructing a transportation facility (such as material inputs and construction equipment operations), as well as with ongoing maintenance and operations activities for the facility or system (such as repaving, mowing, plowing, and installing and maintaining traffic signals). These emissions are not typically included in inventories for the transportation sector because they involve nontransportation mobile sources, such as construction equipment, mowers, snow removal trucks, and aircraft ground support equipment. Nevertheless, transportation agencies may be interested in GHG emissions associated with these activities, and state DOTs, metropolitan planning organizations, and other transportation agencies may wish to examine ways to reduce GHG emissions from their own processes as part of an environmental management system or other commitments to reduce emissions.

Washington State has developed Greenroads, a sustainability performance metric and rating system for roadway design and construction best management practices that uses information from pavement life-cycle analysis studies (Greenroads 2012). Greenroads is applicable to new, reconstructed, and rehabilitated roadways and works by awarding points for approved sustainable practices. Several European studies have looked directly at energy and emissions related to construction and maintenance (Commission of the European Communities 2006; Karlsson and Carlson 2010). These studies suggest that construction GHG emissions are on the order of 1 to 2 years of operational emissions, and annual maintenance is about 10% to 20% of construction emissions. Greenroads estimates that materials production accounts for about 75% of energy use and 60% to 70% of CO_2 emissions associated with construction.

Appropriate Situations in Which to Analyze CMO Emissions

CMO emissions can be assessed at a project level to support environmental impact analysis and the development of construction and maintenance GHG mitigation strategies, such as the use of recycled materials or energy-conserving processes. They may be a lower priority for evaluation at a regional or corridor level, because it is difficult to estimate facility-related emissions and reduction opportunities at such a general scale. However, it still may be desirable to assess the relative magnitude of CMO emissions from various levels of plan investment.

Data Sources and Calculation Methods

Because CMO energy use and emissions have received little research attention until the past few years, there are limited data on which to base an assessment of CMO GHG emissions. However, there is considerable interest in the topic and hence a growing body of literature that is likely to drive rapid evolution of the state of the practice.

At least two tools are available as of late 2010 for estimating emissions from construction and maintenance activities based on detailed vehicle activity data and/or materials inputs: the Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT), developed in 2010 through an NCHRP project, and EPA's NONROAD model.

GreenDOT calculates emissions from state DOT activities based on detailed inputs, such as gallons of fuel for off-road equipment, metric tons of concrete and asphalt, or megawatt-hours of electricity usage. For more information, see "GHG Calculator for State DOTS" above.

The NONROAD model can calculate pollutant emissions, including CO_2, for various equipment types relevant to construction activities (e.g., excavators, graders) and maintenance operations (e.g., mowers, paint sprayers) (U.S. Environmental Protection Agency 2008). Emissions and associated energy use depend on equipment populations and characteristics such as fuel type, engine horsepower, and hours of use. NONROAD is primarily intended for generating state- or county-level emissions inventories, but subcounty inventories may also be produced. NONROAD provides county-level emissions estimates based on default values for populations and activity data, but for a specific area, users may provide local data to better reflect their fleet numbers and characteristics. Activity on a project basis can be estimated by making adjustments to the state-level equipment population files and associated county allocation files to reflect the fraction of county populations in use for a given project. In addition, emissions for time periods less than 1 year can be developed, and hours of use can be changed to reflect the actual amount of time equipment is operating.

The following actions may be considered as an alternative approach to estimating CMO emissions without gathering extensive data for materials or equipment activity inputs:

- Gather data on basic infrastructure outputs (new lane miles of road by facility type, miles of rail transit by type, number of rail transit stations by type) associated with each plan or project alternative.
- Apply emissions factors by activity and facility type. Some general rules derived from the European literature are provided in Table A.24. These may be updated as additional research from the United States becomes available. As of this writing, research on construction emissions is underway for Caltrans and the New Jersey DOT.
- Optional: Refine with more detailed facility breakdowns (e.g., miles of surface versus tunnel versus bridge alignment). For transit, if a detailed breakdown of the amount of building materials or revenue vehicles purchased is known, the American Public Transportation Association provides default emission factors for transit capital projects; these factors are shown in Table A.25.

TABLE A.24. TYPICAL CO_2 EMISSIONS FOR ROAD CONSTRUCTION AND MAINTENANCE

Facility Type	Construction Emissions (tons/mi)	Maintenance Emissions (tons/mi/year)
Collector	330	2.8
Arterial	460	3.3
Divided highway	560	2.5

Source: Derived from Karlsson and Carlson (2010).
Note: Assumes 60-year average for maintenance.

TABLE A.25. DEFAULT EMISSION FACTORS FOR TRANSIT CAPITAL PROJECTS

Reporting Year Input	Default Emission Factor (metric tons of CO_2e)
Steel used	1.06 per metric ton of steel used
Cement used	0.99 per metric ton of cement used
Asphalt used	0.03 per metric ton of asphalt used
Revenue vehicles purchased	85 per light rail train 42 per bus

Source: American Public Transportation Association (2009).

VEHICLE AND FUEL LIFE-CYCLE EMISSIONS

Overview

The term *life cycle* is often used to refer to all emissions associated with the construction, maintenance, and operation of the transportation system and the vehicles that use that system. In addition to the emissions associated with infrastructure construction, maintenance, and operations as described in the previous section, these include the full range of emissions associated with vehicles and the fuels they consume.

Life-cycle fuel emissions for transportation fuels include GHG emissions associated with the production and distribution of the fuel used, in addition to the direct or tailpipe GHG emissions from vehicle operation. The full fuel cycle includes upstream emissions (sometimes called well-to-pump emissions) associated with drilling, exploration and production, crude oil transport, refining, fuel transport, storage, and product retail; and downstream disposal or recycling of oil products. Life-cycle analysis can also be expanded to include the full *vehicle life cycle*, including vehicle manufacturing (raw material extraction, processing, and transport; manufacture of finished materials; assembly of parts and vehicles; and distribution to retail locations), maintenance, and disposal. Fuel and vehicle life-cycle emissions are also known as *embodied emissions*.

Fuel-Cycle Emissions

Fuel-cycle emissions for fossil fuels are typically 5% to 29% higher than direct GHG emissions, varying by vehicle and fuel type. These percentages are based on a comparison of the data in the GREET model, Version 1.8c, and per gallon emissions found in the *General Reporting Protocol*, Version 1.1 (The Climate Registry 2012). The fuel-cycle emissions of biofuels show much greater variability (when compared with direct emissions) than those of fossil fuels. Table A.26 compares CO_2e emissions for LDVs (a mix of passenger cars and light-duty trucks) powered by different fuel sources. Direct combustion emissions come from The Climate Registry's *General Reporting Protocol*, using the sum of emissions from CO_2, CH_4, and N_2O for a model year 2005 vehicle. These are compared with fuel-cycle emissions from the GREET model for current average fuel production conditions and vehicle efficiencies in the United States.

The California Air Resources Board has also examined life-cycle emissions and developed carbon intensity factors for gasoline, diesel, and a variety of alternative fuels for use in implementing the state's low-carbon fuel standard (California Air Resources Board 2012). These factors reflect production pathways specific to the California fuel supply. Table A.27 shows examples of direct and total emissions for conventional fuels versus biofuels with different production pathways.

Biofuel emissions may vary significantly depending on production pathways. Furthermore, the emissions estimates for biofuels in Table A.26 do not reflect indirect impacts from the production of these fuels, such as conversion of other land to cropland to make up for production lost to biofuels. EPA conducted an in-depth study of biofuel impacts in support of its March 2010 Renewable Fuel Standard (RFS2) rulemaking. The study compared life-cycle GHG emissions for a variety of biofuels with conventional gasoline and diesel under different assumptions about production pathways and other factors (U.S. Environmental Protection Agency 2010e). EPA provides

TABLE A.26. DIRECT AND LIFE-CYCLE EMISSION FACTORS BY TRANSPORTATION FUEL, AVERAGE FOR PASSENGER VEHICLES

Motor Vehicle Fuel	Direct Emissions, kg CO_2e/gal (from The Climate Registry)	Fuel Cycle Emissions, kg CO_2e/gal (from GREET)	Percentage Difference	
			Fuel Cycle versus Direct	Fuel Cycle versus Gasoline or Diesel
Gasoline	8.85	10.45	18.2%	
Corn ethanol (E100)[a]	6.22	8.94	43.7%	–14.4%
Corn ethanol/gasoline (E10)[a]	8.59	10.30	19.9%	–1.4%
Corn ethanol/gasoline (E85)[a]	6.61	9.17	38.6%	–12.3%
Cellulosic ethanol (E100)[a]	6.22	1.47	–76.4%	–85.9%
Diesel	10.22	10.72	4.9%	
Biodiesel (B100)[a]	9.46	0.83	–91.2%	–92.3%
Biodiesel (B20)[a]	10.07	8.74	–13.2%	–18.5%
CNG	6.89[b]	8.92	29.5%	–16.8%[c]

Note: CNG = compressed natural gas.
[a]E100 refers to 100% ethanol and B100 to 100% biodiesel. Fuels in use today include ethanol at up to a 10% blend (E10) in gasoline vehicles, ethanol at an 85% blend (E85) in dedicated or bifuel vehicles, and biodiesel at up to a 20% blend (B20) in diesel vehicles. Emission factors for the different fuel types are weighted according to the composition of the fuel.
[b]This direct emissions factor for CNG is from GREET. The Climate Registry emissions factor for CNG was expressed in different units, making the comparison with other fuels less clear. The CNG figure expressed here is for an amount of CNG with energy content equivalent to 1 gallon of gasoline.
[c]CNG is compared with diesel fuel.

TABLE A.27. COMPARISON OF SELECT BIOFUELS TO CONVENTIONAL FUELS IN CALIFORNIA

Fuel	Pathway Description	Direct Emissions (gCO_2e/MJ)	Land Use or Other Indirect Effect (gCO_2e/MJ)	Total Emissions (gCO_2e/MJ)	Versus Average Gasoline or Diesel
Gasoline	California Average	95.86	0	95.86	
Ethanol from corn	Midwest average; 80% dry mill; 20% wet mill; dry DGS	69.40	30	99.40	3.7%
	California average; 80% Midwest average; 20% California; dry mill; wet DGS; NG	65.66	30	95.66	–0.2%
	Midwest; dry mill; wet DGS; 80% NG; 20% biomass	56.80	30	86.80	–9.5%
	California; dry mill; wet DGS; NG	50.70	30	80.70	–15.8%
Ethanol from sugarcane	Brazilian sugarcane using average production processes	27.40	46	73.40	–23.4%
Diesel	California Average	94.71	0	94.71	
	Conversion of waste oils to biodiesel when “cooking” is required	15.84	0	15.84	–83.3%
	Conversion of Midwest soybeans to biodiesel	21.25	62	83.25	–12.1%

Source: California Air Resources Board (2009), Table 6.
Note: DGS = distiller’s grain with solubles; NG = natural gas.

midpoint estimates of GHG emissions reductions of 22% for corn ethanol (E100) versus gasoline, and 57% for soy biodiesel (B100) versus diesel, assuming typical 2022 production pathways.

The EPA's midpoint 2022 values may not be representative of current or local production conditions. Selected findings from the EPA analysis, illustrating the uncertainty inherent in the estimates, are shown in Table A.28. This table shows both the midpoint estimate in GHG emissions reductions and the upper and lower bounds of a 95% confidence interval. For example, the table shows that one can say with 95% certainty that corn ethanol from a new natural gas plant in 2022, using the identified production technology, will reduce GHG emissions by between 7% and 32% compared with conventional gasoline. The table also illustrates that ethanol production from a coal-fired plant has the potential to increase life-cycle emissions, but production from a biomass-fired plant may decrease emissions more significantly.

TABLE A.28. CHANGE IN LIFE-CYCLE GHG EMISSIONS FROM BIOFUELS VERSUS CONVENTIONAL FUELS

Fuel and Source	95% Confidence Interval, Upper Bound	Midpoint Estimate	95% Confidence Interval, Lower Bound
Ethanol from corn—natural gas plant[a]	–7%	–21%	–32%
Ethanol from corn—coal plant[b]	+19%	+5%	–7%
Ethanol from corn—biomass plant[b]	–24%	–38%	–49%
Biodiesel from soybeans	–22%	–57%	–85%
Ethanol from sugarcane[c]	–52%	–61%	–71%
Ethanol from switchgrass[d]	–102%	–110%	–117%

Source: U.S. Environmental Protection Agency (2010e), Section 2.6.

Note: Ethanol is compared with gasoline and biodiesel with diesel. Negative value denotes a net benefit for the biofuel. All results are for an average new 2022 plant. Results assume a 30-year time horizon and 0% discount rate. Future benefits with a higher discount rate will be lower, because future benefits are discounted, and therefore the initial investment (i.e., land clearing for crop production) takes longer to pay back. Using a longer time horizon will show greater benefits.

[a]Natural gas plant, 63% dry, 37% wet distiller's grain with solubles (DGS) with fractionation. (Fractionation separates the corn kernel into its pieces, including food-grade corn oil and protein, which are valuable coproducts that can be sold for agricultural use. DGS is the primary coproduct from a dry-mill plant. Wet versus dry DGS is the percentage of coproduct sold prior to drying.)

[b]Dry DGS with fractionation.

[c]No residue collection.

[d]Biochemical process producing ethanol, excess electricity production.

Vehicle-Cycle Emissions

GREET and the Life-Cycle Emissions Model (LEM) provide estimates of GHG emissions from vehicle-cycle processes for on-road vehicles; additional estimates are provided by Chester (2008). With these estimates expressed relative to combustion emissions, the manufacture-cycle GHG emissions represent an additional 14% to 19% beyond gasoline combustion emissions, and manufacturing of freight trucks is 6% to 17% beyond diesel combustion emissions (U.S. Department of Transportation 2010).

Vehicle life-cycle emissions may be considered in the context of transportation planning if the impact of policies on vehicle ownership (e.g., transit, land use, and parking policies that encourage people to own fewer vehicles) can be assessed. Another reason to incorporate vehicle life-cycle effects is to quantify the effects of VMT increases on vehicle replacement rates. All else being equal, increases in VMT due to a transportation plan or project will mean that vehicles will reach the end of their useful life sooner and need to be replaced.

Appropriate Situations in Which to Analyze Life-Cycle Impacts

A life-cycle assessment may be conducted when a more complete inventory of GHG emissions is desired. It also is important when evaluating transportation policies that affect vehicle fuels and technology types. For alternative fuel vehicle strategies (e.g., purchases of alternative fuel buses, incentives for consumer use of alternative fuel vehicles), the benefits of strategies on a life-cycle GHG basis may be markedly different than when only examining direct vehicle emissions. Many alternative fuels have relatively high life-cycle emissions compared with direct emissions. Life-cycle emissions must be considered in any analysis of alternative fuels such as biofuels (including biodiesel, ethanol, and biobutanol), as well as natural gas and hydrogen. Life-cycle emissions also must be considered when analyzing electrically powered vehicles, because these vehicles do not have any tailpipe emissions.

Probably the most important application for life-cycle analysis in transportation planning is at the project level, because a project may have a small impact on operational GHG emissions but a large construction footprint. Life-cycle analysis can be used to calculate the payback period, the period over which the operational improvements are sufficient to offset the GHG emissions associated with construction. This is particularly important when GHG emissions reduction is part of the purpose and need (e.g., the project is being implemented as part of a climate action plan) or is one of the claimed benefits of the project. If the project is being implemented under a climate action plan, decision makers should have information as to whether the project will have net benefits (beyond the payback period) by the target year(s) in the climate action plan.

Data Sources and Calculation Methods

Full fuel-cycle emissions factors (GHGs per vehicle mile) can be obtained from the GREET model or by adjusting gasoline or diesel emissions by a carbon intensity factor derived from a source such as EPA or the California Air Resources Board.

GHG emissions for electricity generation can be obtained from EPA's eGRID database. These factors will vary by region of the country, depending on the regional electricity generation mix. For a discussion and examples, see "GHG Emissions from Transit Vehicles."

For developing future year life-cycle emission factors, it may be assumed that fuel-cycle emissions decline in proportion to direct (tailpipe) emissions as vehicle fuel economy improves. This assumes that the GHG emissions associated with producing a gallon of fuel remain constant. This factor may decline in the future if production and distribution practices become more efficient, or alternatively, may increase if more energy-intense methods are used (such as gasoline or diesel production from tar sands). To some extent, the GREET model may be used to evaluate different production pathways and assumptions.

Emissions factors for electricity generation may also change in the future as the mix of electricity generation methods changes. The GREET model can also be used to evaluate changes in the generation mix. See "GHG Emissions from Transit Vehicles" for additional discussion of potential assumptions regarding future emissions from electricity generation.

A recent inventory of GHG emissions in the 13-county North Jersey region developed by the North Jersey Transportation Planning Authority included full fuel-cycle (energy-cycle) emissions factors for comparison with direct emissions only. The inventory included estimates of both direct emissions (those occurring within the region's boundaries) and consumption-based emissions, which were allocated based on trips that ended within the region. For a complete accounting of GHG emissions, energy-cycle GHG emissions associated with the production, refining, and transport of motor vehicle fuels were also calculated based on the consumption-based emissions estimate.

Energy-cycle emissions factors were developed for gasoline, diesel, and ethanol-blend fuels using GREET, Version 1.8b. 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.

A comparison of fuel combustion emissions from The Climate Registry's *General Reporting Protocol* with energy-cycle emissions from GREET showed that 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 emission estimates were developed using GREET Version 1.8b emissions factors, which differ from the GREET Version 1.8c factors cited above). In order to estimate energy-cycle emissions, the consumption-based GHG emissions estimates were multiplied by the appropriate energy-cycle multiplier, which varied between 11% and 23% depending on the amount of diesel versus gasoline used by vehicle type. For example, light commercial trucks use (84.7% gasoline * 23.0% increase) + (15.3% diesel * 10.8% increase). This results 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 A.29 shows the resulting differences in consumption emissions versus full energy-cycle emissions.

TABLE A.29. ON-ROAD VEHICLE GHG EMISSIONS PROJECTIONS IN NORTH JERSEY

Total Emissions (MMT CO_2e)	2006	2020	2035	2050
Consumption	17.0	21.2	29.1	26.6
Energy cycle	20.8	25.9	35.5	32.4

The Columbia River Crossing Project energy and CO_2e analysis for a large bridge replacement and freeway upgrade project in Portland, Oregon, and Vancouver, Washington, shows the type of analysis that can occur at a project level (Columbia River Crossing Project Team 2008). Energy supply and demand in the states of Washington and Oregon were characterized by energy supply sources and use sectors. Specific data relating to fuel consumption rates were obtained from the state DOTs and the U.S. Department of Energy. The state DOTs also provided traffic volumes and vehicle classification, and transit vehicle energy consumption data were provided by local transit agencies.

The energy analysis addressed four primary issues:

- Energy consumed during construction of the project;
- Energy consumed during operation of the project;
- Measures to reduce or offset construction and operational effects on energy; and
- CO_2e emissions resulting from use of electricity, gasoline, and diesel.

Emissions factors obtained from EPA were used to estimate 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.

A general equation used for estimating CO_2 and CO_2e emissions was

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

where

EM = emissions of CO_2 or CO_2e (lbs),
FC = fuel consumed (gals or kW-h),
EF = emission factor (lbs of CO_2/gal or lbs of CO_2/kW-h) (based on fuel type), and
CDE = CO_2e conversion factor (100/95).

The fuel consumed was the amount used to operate the facility. The approach for determining energy use during construction was based on an input–output method developed by Caltrans. 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 with the amount of energy required to manufacture, process, and place construction materials and structures.

The general equation for estimating energy consumed during construction was

$$E = C \times EF \times DC$$

where

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

Because the Caltrans energy factors were based on construction cost estimates in 1973 dollars, a dollar conversion was necessary because the project's cost estimates were in 2007 dollars.

The results of the analysis are shown in Tables A.30 and A.31.

TABLE A.30. DIFFERENCES BETWEEN SYSTEM-LEVEL CHOICES OF DAILY ENERGY USE AND CO_2E EMISSIONS

	Energy Consumed		Electricity Consumed		Gasoline Consumed		Bio/Diesel Consumed		CO_2e Emissions	
System-level Choice	**mBtu**	**Change (%)**	**kW-h**	**Change (%)**	**gal**	**Change (%)**	**gal**	**Change (%)**	**tons**	**Change (%)**
Build-replace	–506.6	–8.8%	–8,018	–5.0%	–147	–1.5%	–3,343	–11.6%	–43.5	–8.8%
Build-Supplement	—	—	—	—	—	—	—	—	—	—
Bus Rapid Transit	—	—	–9,435	–5.8%	—	—	—	—	–0.1	0.0%
Light Rail Transit	–5.8	–0.1%	—	—	0	0.0%	–289	–1.1%	—	—
Vancouver alignment	–27.5	–0.7%	–649	–0.4%	0	0.0%	–182	–0.8%	–2.4	–0.7%
Interstate 5 alignment	—	—	—	—	—	—	—	—	—	—
Full Length	—	—	—	—	—	—	—	—	—	—
Clark College MOS	–7.7	–1.4%	–2,262	–1.4%	0	0.0%	0	0.0%	–0.8	–1.4%
Mill Plain MOS	–13.2	–2.4%	–3,854	–2.4%	0	0.0%	0	0.0%	–1.4	–2.4%
No Toll	—	—	—	—	—	—	—	—	—	—
Standard Toll on I-5	–102.0	–1.9%	0	0.0%	–615	–6.0%	–186	–0.7%	–8.5	–1.8%
Standard Toll on I-5 and I-205	–186.2	–3.5%	0	0.0%	–1,256	–12.3%	–220	–0.9%	–1504	–3.3%

Source: Columbia River Crossing Project Team (2008).
Note: MOS = minimum operable segment. "—" indicates the highest amount of energy, electricity, fuel consumed, and CO_2e emitted, a "0" indicates no differences between alternatives, and a negative number indicates the difference (amount less).

TABLE A.31. ALTERNATIVES SUMMARY OF CONSTRUCTION-RELATED ENERGY USE AND CO_2E EMISSIONS, COLUMBIA RIVER PROJECT

Alternative	Energy Consumed (mBtu)	CO_2e Emissions (tons)
Alternative 2		
With 16th Street Tunnel	7,055,867	590,178
With McLoughlin Tunnel	6,997,372	585,536
Alternative 3		
With 15th Street Tunnel	7,281,549	608,224
With McLoughlin Tunnel	7,221,671	603,472
Alternative 4	5,903,553	494,010
Alternative 5	6,084,734	509,171

Source: Columbia River Crossing Project Team (2008).

INDIRECT EFFECTS AND INDUCED DEMAND

Overview

A transportation project or program may have indirect as well as direct effects on GHG emissions. Most notably for transportation analysis, GHG emissions can result from *additional travel* (induced demand) that would not have occurred in the absence of the proposed highway or transit project, corridor improvements, or proposed transportation system plan or program.

Indirect or Secondary Effects

In its regulation on the National Environmental Policy Act, the Council on Environmental Quality defines indirect effects as effects that "are caused by the action and are later in time or farther removed in distance," in contrast to direct effects, which are "caused by the action and occur at the same time and place." Indirect effects "may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density, or growth rate," as well as environmental and other effects related to these land use changes (Council on Environmental Quality 1986).

Induced Demand

In a general sense, induced demand can refer to increased travel by any mode that results from improved travel conditions (e.g., reduced travel times or costs). As used here, induced demand refers specifically to induced *vehicle* travel, because that is the impact of interest for GHG analysis. An increase in vehicle travel may be a result of greater trip making, longer trips, and/or shifts from other modes. In the short term, this primarily reflects a redistribution of trip-making patterns among the same spatial distribution of activities. Over the longer term, additional induced demand may result as land use patterns change in response to transportation system changes. For a particular transportation facility, an improvement may also result in more traffic due to route shifting from other facilities to the improved facility, or shifts in the time of day of travel. However, only *net new travel* (VMT) is truly characterized as induced demand. Induced demand is therefore largely an indirect effect.

Induced demand effects are significant in GHG analysis because they can partially offset the GHG emissions reduction benefits of capacity or operational improvements that reduce congestion. However, as discussed below, induced demand effects are difficult to measure and forecast accurately, and there is currently no consensus as to how the magnitude of these impacts compares with the benefits of capacity expansion and congestion relief over the long run. Also, there is little evidence regarding how induced demand effects might vary for operational improvements (such as signal synchronization) versus capacity expansion, or for strategies that primarily affect reliability (such as incident management) rather than average travel time.

Measurement and Forecasting of Induced Demand Effects

Induced demand is a widely recognized phenomenon, but its magnitude may vary considerably from context to context. Induced demand can be described in terms of elasticities, such as a change in VMT with respect to a given change in highway capacity or travel time. Induced travel elasticities are often expressed in relationship to highway capacity (e.g., lane miles) because it is easier to measure than travel time. However, it is preferable to determine elasticities in relation to travel time because reduced travel time (increased travel speeds) is generally the factor that leads to additional travel. Induced demand may result from people making more trips, shifting modes (from nonauto to auto), or making longer vehicle trips (because of shifts in routes and/or destinations). In the long term, land use patterns may disperse, leading to more increases in vehicle trip lengths as destinations become farther apart (and perhaps less transit accessible).

Attempts to measure induced demand elasticities, usually in terms of VMT with respect to lane miles, have produced widely varying estimates. The literature usually distinguishes short-term (less than ~5 years) from long-term elasticities, because response tends to be greater over the long term as people have more opportunities to shift their activity locations and travel patterns. Short-term estimates have ranged from about 0.1 to 0.7, with most clustering in the range of 0.2 to 0.5. An elasticity of 0.5 means that a 10% increase in lane miles for a region or corridor would result in a 5% increase in VMT. Long-term estimates have ranged from about 0.3 to 1.1, with most clustering in the range of 0.4 to 0.9. Elasticities of VMT with respect to lane miles will be positive, and elasticities of VMT with respect to travel time will be negative.

Only a handful of studies have examined elasticities of VMT with respect to travel time or speed, but the results tend to fall in the same absolute range (Cervero 2002). Cohen (2002) cautions that because of various methodological issues some of these studies have likely overstated actual elasticities; he concludes from a review of other studies and original analysis that travel time elasticities are probably in the range of –0.1 to –0.4.

Measurement of induced demand is complicated by the need to separate spatial or temporal *shifts* in traffic patterns (e.g., to the facility) from *net increases* in traffic, and over the long term, by the need to separate the effects of other trends (e.g., background population and employment growth) from the effect of the facility or program itself. The magnitude of induced demand is likely to vary widely from situation to situation.

Expansion of a highly congested freeway in Los Angeles is likely to result in a significant amount of induced demand, while expansion of a four-lane freeway in rural North Dakota is likely to have little, if any, effect on traffic volumes. Induced demand is likely to be greater over the medium to long term, but measuring induced demand becomes more difficult over a longer time frame.

Travel demand forecasting models can help to separate these various effects and predict induced demand. However, most models in practice today have limitations in their ability to accurately reflect induced demand effects. In particular,

- Many models do not include feedback from the traffic assignment to the trip distribution step. As a result, longer trips due to reduced congestion will not be modeled;
- Even fewer models include feedback to the trip generation or auto ownership steps (although evidence suggests that the primary impact of congestion is on trip lengths and mode choice, not total trip rates);
- Few travel models are integrated with a land use forecasting model, meaning that growth effects will not be captured. Furthermore, land use forecasting methods must accurately consider the effects of transportation infrastructure and accessibility improvements on development patterns if they are to capture induced travel effects;
- Time-of-day shifts are not reflected in many models. While time-of-day shifts themselves do not represent true induced travel, they may affect the amount of induced travel by changing the level of congestion in peak and off-peak periods;
- Static traffic assignment algorithms may not account for the impacts of queuing on route shifts; and
- The interpretation of the doubly constrained gravity model commonly used in the trip distribution step is unclear, even though the results may mimic the impacts of induced demand.

One study by Rodier et al. (2001) of the Sacramento, California, region suggested that about 50% of long-term induced travel is not captured by the use of travel demand models when they are used without land use feedback. In contrast, a review by the Metropolitan Washington Council of Governments (2001) found that the agency's travel forecasting process generally captures induced travel, although it does not separate induced travel from other increases in travel. The review notes that the travel forecasts were based on a cooperative land use forecasting process that addresses changes in development patterns predicted to occur as a result of major changes in transportation system capacity. DeCorla-Souza (2000) also concluded that travel models may adequately capture induced demand, based on the observation that relatively large travel time elasticities were imputed from the use of a regional travel demand model in Memphis, Tennessee (–0.7 without feedback, –1.1 with feedback). An assessment of three case study models by Rodier et al. (2001) found that when travel times are fed back to a land use model and/or the trip distribution step, then models "can represent induced travel within the range documented in the empirical literature."

Appropriate Situations in Which to Conduct Additional Analysis of Induced Demand

In some cases, the analytic tools used to estimate VMT and GHG emissions may already account, at least partially, for induced demand. As noted above, this is most likely to be the case when a regional travel demand model with appropriate feedback loops is being used. For projects that do not significantly affect the overall time and/or cost of travel (e.g., projects that primarily improve safety), induced demand effects are likely to be minimal. For small projects such as traffic signal timing, there is some debate as to whether there is any measurable induced demand effect, although it may be that an areawide collection of smaller projects adds up to improvements in conditions large enough to affect travel choices.

For major investment projects that significantly affect travel time and/or costs, it is desirable to specifically analyze potential induced demand effects and assess how they may affect the GHG emissions benefits of a project or program. Such situations may include

- Project-level analysis in which a travel demand model that includes feedback effects is not already being used;
- Project- or systems-level analysis in which the existing modeling system has limited or no ability to capture effects, including growth-inducing effects of transportation system improvements, and/or feedback from congestion to the trip distribution step;
- Projects that generate interest in induced demand and growth effects for GHG emissions, air quality, land use impacts, and/or other analysis purposes; and
- Projects for which resources are available to enhance modeling systems or apply sketch-level analysis methods.

Data Sources and Calculation Methods

Methods to account for induced travel and indirect effects include the following, listed in order of increasing level of effort:

- Direct application of induced demand elasticities;
- Sketch plan corridor-level models;
- Enhancements to travel demand models to better incorporate feedback from congestion; and
- Land use forecasting methods incorporating accessibility, with feedback to travel demand models.

Direct Application of Induced Demand Elasticities

Induced demand elasticities from the literature may be applied to changes in travel conditions to estimate changes in traffic volumes. For example, consider a 5-mile-long segment of a four-lane freeway with a 2-hour peak period, peak-direction traffic volume of 8,000 vehicles. This facility operates at an average of 30 mph under peak conditions. The total peak period congested VMT on this facility is 8,000 vehicles × 5 miles × 2 time periods (a.m. and p.m.), or 80,000 VMT.

The freeway is being expanded to six lanes, which is projected to increase the average peak period speed to 60 mph, representing a 50% reduction in travel time over this segment. Assuming the long-run elasticity of VMT with respect to travel time in this area is 0.4, this means that VMT will increase by 80,000 × 50% × 0.4, or 16,000 VMT per day within a 5- to 10-year period.

The GHG emissions impacts of this additional VMT can then be compared with the emissions benefits of reduced congestion, as analyzed using other methods such as a traffic simulation model or MOVES emissions factors by vehicle speed.

This is a crude assessment that does not account for factors such as the existing versus postproject level of congestion and travel times on the facility, differences in local versus regional traffic shifts, effects of traffic changes on nearby facilities, or feedback from changes in congestion to changes in VMT. When choosing an appropriate elasticity, the analyst must be careful to consider whether the elasticity value includes route diversions and time-of-day shifts that do not actually represent *new* VMT; that is, some of the additional VMT and GHG emissions calculated for the expanded facility are actually removed from other facilities or off-peak time periods. Nevertheless, the elasticity approach may be useful for determining an order of magnitude assessment of how induced demand effects are likely to compare with congestion relief benefits.

Sketch Plan Corridor-Level Models

FHWA has developed a spreadsheet-based model known as Spreadsheet Model for Induced Travel Estimation (SMITE). This model is useful for sketch planning analysis, especially when four-step urban travel models are either unavailable or are unable to forecast the full induced demand effects. SMITE can be used to provide useful information to assist policy makers in evaluating proposals for specific additions to highway capacity for corridor studies. An accompanying paper discusses the concepts underlying SMITE and describes an application of SMITE to the evaluation of a typical freeway capacity expansion project (Federal Highway Administration 2012f).

SMITE has the following notable features:

- It accounts for changes in traffic volumes and speeds on parallel arterials due to diversion, as well as the freeway corridor being improved;
- It uses speed relationships to estimate the effects of congestion on speeds;
- The speed estimates are sensitive to peak spreading and queuing under congested conditions;
- It allows the user to provide travel demand elasticity estimates to obtain estimates of induced travel; and
- It computes external costs of induced travel (mobility and other user and nonuser benefits and costs) using user-provided estimates of external costs per VMT and compares benefits and disadvantages over the life of the investment.

SMITE-ML, a variation of SMITE, was developed specifically to evaluate managed lanes (Federal Highway Administration 2012e). SMITE and SMITE-ML do not estimate GHG emissions directly, but they produce outputs of changes in freeway and arterial VMT and travel speeds that could be used to develop estimates of GHG emissions using emissions factors from MOVES or another model.

IMPACTS, another FHWA spreadsheet-based sketch plan model that incorporates induced demand, is a series of spreadsheets developed to help screening-level evaluation of multimodal corridor alternatives. The model is described in more detail above.

Enhancements to Travel Demand Models

Differences in parameters and methods make it difficult to generalize regarding how to ensure that travel demand models accurately reflect induced demand effects. However, it is apparent from the literature that the two most important enhancements are (1) feedback from traffic assignment to the trip distribution step and (2) feedback to land use patterns.

COMSIS (1996) provides a general discussion of the incorporation of feedback into travel demand models. Feedback to the trip distribution step can be incorporated within the framework of a typical four-step model. Feedback to land use may be more problematic, as the availability of land use models incorporating accessibility measures varies widely by metropolitan area, and few are integrated with the transportation model. Furthermore, today's land use models are suitable only for plan- and systems-level analysis and not for analyzing the specific impacts of individual transportation projects (Cambridge Systematics and Gliebe 2009). Consideration of the GHG emissions impacts of induced demand may therefore need to be modeled at a systems level (considering an overall systems plan) or done using a qualitative or sketch-level assessment of the likely land use impacts of a project, as described below.

Land Use Forecasting Methods

Land use forecasting methods span the range from qualitative, judgment-based assessments; to spreadsheet-based allocation models; to fully integrated travel demand and land use forecasting models. The most appropriate technique depends on a number of factors, including

- Specific information needs, and the level of accuracy and precision needed or desired for decision making;
- The magnitude of the transportation project and nature of its potential impacts; and
- Availability of data and analysis resources.

Several reports provide guidance on forecasting methods for land use and indirect effects of transportation projects. More recent publications include the *Desk Reference for Estimating the Indirect Effects of Proposed Transportation Projects* (Louis Berger Group 2002). This NCHRP report contains guidance and a framework for practitioners to use for defining the indirect effects of proposed transportation projects, identifying tools for estimating these effects, and analyzing these effects. Avin et al. (2007), in their report *Forecasting Indirect Land Use Effects of Transportation Projects*, provide more detailed guidance and information on selected land use forecasting methods and assist practitioners in selecting an appropriate methodology. FHWA's *Interim Guidance on the Application of Travel and Land Use Forecasting in NEPA* (2010) is intended to encourage improvement in how project-level forecasting is applied in the context of the NEPA process. It focuses on the procedural or process considerations in forecasting rather than on technical methods.

In order to complete the loop of incorporating indirect effects into GHG emissions analysis, there must be feedback between the land use forecasting process and the travel demand analysis. At a minimum, the revised land use forecast considering a project's effects must be used as a basis for redoing the travel demand forecast and obtaining updated VMT and speeds by facility type. Ideally, multiple iterations are conducted, so that the updated travel conditions are used to update the land use forecast, which is then used to derive new travel forecasts. This process should be repeated until the travel forecasts converge (i.e., until the difference between the previous forecast and the current forecast is small). GHG emissions under the final project scenario are then compared with GHG emissions projected under the no-build scenario with the baseline land use and travel forecasts.

Land use forecasting models and methods vary considerably in how transportation improvements are assumed to affect land development patterns. An ideal model will be based on a sound, empirically supported relationship between land development and accessibility, which is a measure of the number of potential destinations that can be reached from a particular location within a given travel time. Approaches that rely on judgment or unvalidated relationships may still provide useful insights, but should be subject to sensitivity testing to determine how a range of plausible assumptions may affect conclusions about induced demand and the resulting GHG effects.

USING MOVES TO ESTIMATE GHG EMISSIONS

Overview

EPA's Motor Vehicle Emission Simulator (MOVES2010) model was released in December 2009. On March 2, 2010, EPA provided notice in the *Federal Register* that MOVES2010 is officially approved for use in state implementation plans and for transportation conformity analyses outside of California (U.S. Environmental Protection Agency 2010c). MOVES allows the transportation planner to model GHG emissions from the project level to the regional level, and in a manner consistent with the way emissions of other pollutants would be calculated using MOVES for state implementation plans or transportation conformity analyses. The primary uses of MOVES for transportation planners include estimation of GHG emissions inventories from the project level to the regional level using typically generated local data, as well as evaluation of GHG emissions reduction policies affecting vehicle speeds, activity, or fleet mix, and some biofuels. The MOVES model software and documentation is available from the EPA website (U.S. Environmental Protection Agency 2012b).

MOVES can be used as either an inventory model or an emissions rate (factor) model. When used as an emissions rate model, MOVES provides only the emission rates; total emissions must be calculated using VMT and vehicle population outside of MOVES, likely in a spreadsheet lookup table or in an air quality postprocessor to a travel demand model. When used as an inventory model, however, MOVES uses VMT and vehicle population to calculate total emissions internally. In order to explain all of the MOVES inputs, this document assumes the use of MOVES as an inventory model. EPA provides technical guidance for which inputs are unnecessary when using MOVES as an emissions rate model.

This section summarizes the use of MOVES in three contexts:

- Using MOVES at a regional scale in areas without a travel demand model,
- Interfacing a state or regional travel demand model with MOVES, and
- Using MOVES for project- or corridor-level analysis.

Locally specific inputs, such as vehicle age distributions and characteristic ambient meteorology, are also discussed. Inputs to MOVES that are dependent on vehicle activity (e.g., VMT distributions by speed and road type) are discussed in the individual sections, because these can vary depending on the type of MOVES application. Finally, inputs that are common across all types of MOVES applications are discussed.

Methods to account for new fuel economy and/or low-carbon fuel standards are presented. Federal emissions and fuel economy standards that are proposed but not adopted or have been recently adopted may not be reflected in the emission rates built into the most current version of the MOVES model. MOVES will also not reflect any state-adopted GHG emissions or low-carbon fuel standards that go beyond federal requirements.

One of the first steps in any GHG emissions analysis should be to define a protocol that explains what will be studied, the spatial and temporal scale of analysis, inputs, and any limitations that would be applicable to the results.

Applying MOVES in Areas Without a Travel Demand Model

MOVES can be used to develop GHG emissions inventories by using regional VMT forecasts developed outside of a travel demand model as inputs. For this level of analysis, less detailed data are available than in the other scales of analysis discussed in this document. In this scale of inventory, emissions in MOVES are calculated based on the regional distribution of activity by speed, road type, and vehicle type (known as source type in MOVES).

MOVES users experienced with developing criteria pollutant emissions estimates for ozone or particulate matter analyses will note that the primary differences for GHG emissions analysis are the time scales needed and the pollutants to be modeled. GHG inventories are calculated at an annual level rather than the seasonal or daily level typically used for particulate matter or ozone inventories.

Areas without travel demand models that have previously developed criteria pollutant emissions estimates are more likely to have travel data in the form of annual average daily travel rather than annual VMT, although in some cases, annual VMT would have been necessary. Annual average daily travel can be scaled to the annual level by multiplying by 365.

The information below assumes that the practitioner has access to the MOVES2010 model, user's guide, and technical and policy guidance documents prepared by EPA. From the main MOVES screen, the following options should be selected for use in developing a GHG emissions inventory:

- **Scale:** County (shown in Figure A.13);
- **Calculation type:** Inventory (shown in Figure A.13);
- **Region:** County, then select appropriate state and county. An example of this selection is shown in Figure A.14;
- **Time aggregation level:** Year (automatically checks all months, hours, weekends, and weekdays) (Illustrated in Figure A.15);
- **Fuels and source use types:** Select all included in the inventory area, as shown in the example in Figure A.16;
- **Road types:** Select all road types, including off-network, that are included in the inventory area, as illustrated in Figure A.17; and
- **Pollutants and processes:** In order to calculate CO_2e emissions, all of the following must be selected from the pollutant list: total energy consumption, methane, nitrous oxide, atmospheric CO_2, and CO_2e. This screen is illustrated in Figure A.18.

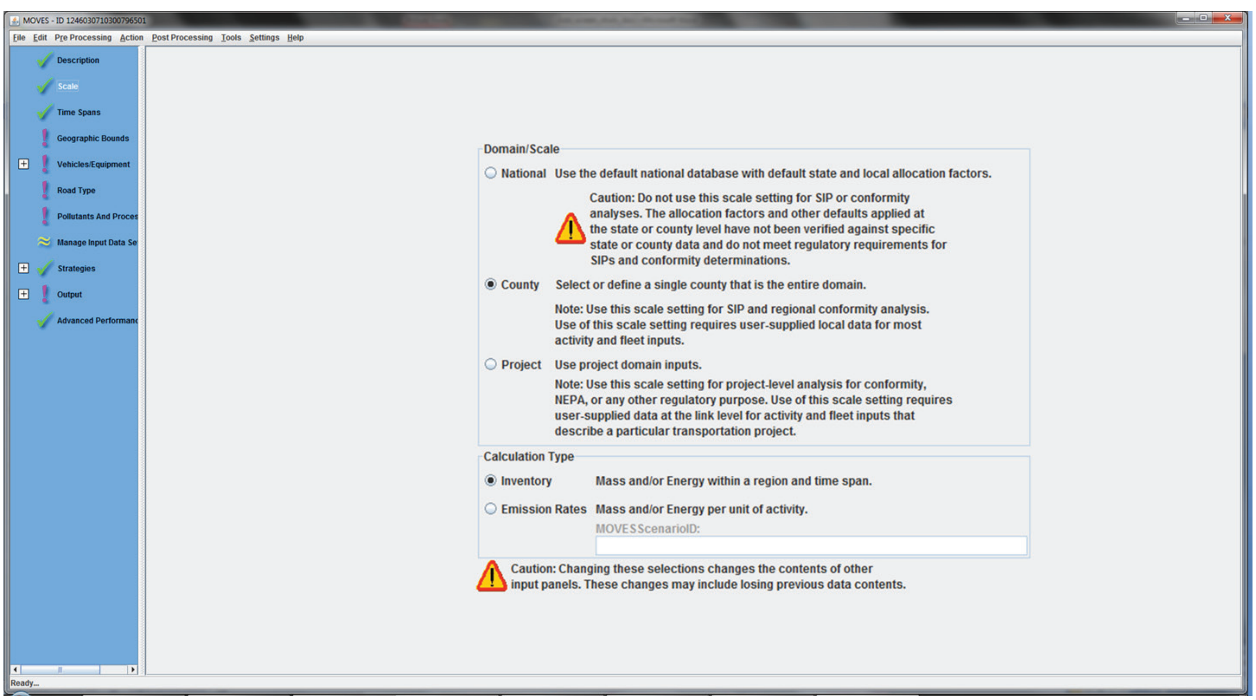

Figure A.13. *MOVES domain/scale screen.*

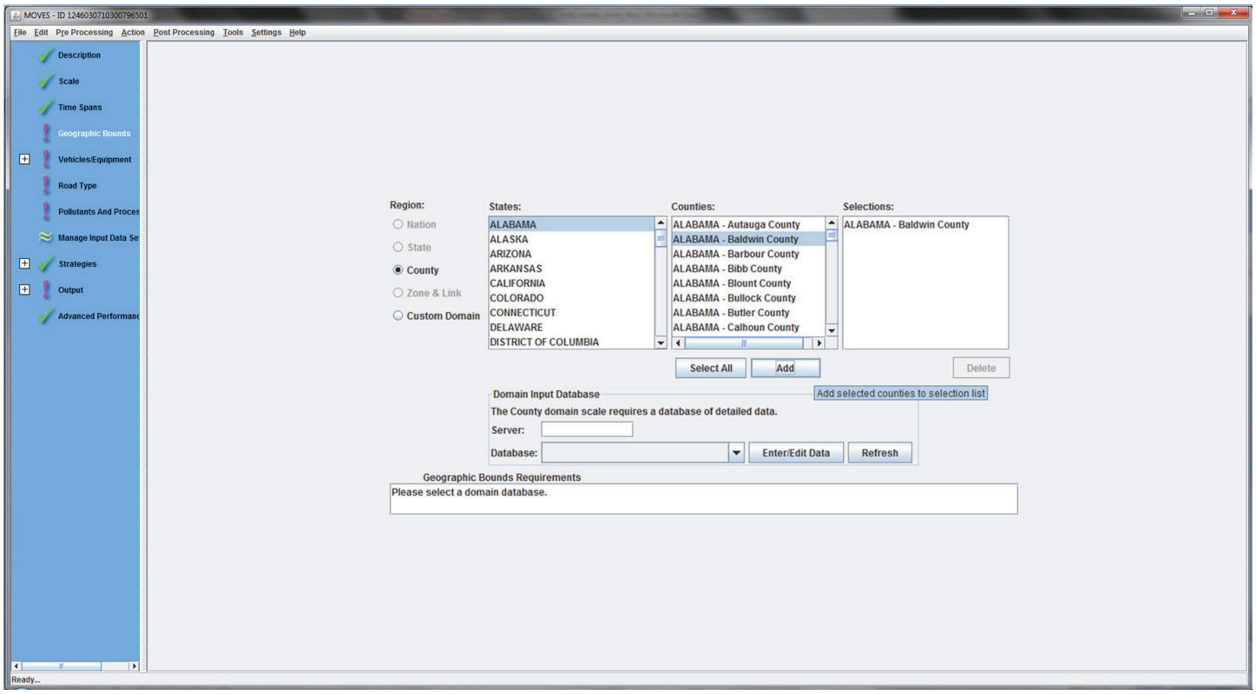

Figure A.14. *MOVES geographic bounds screen.*

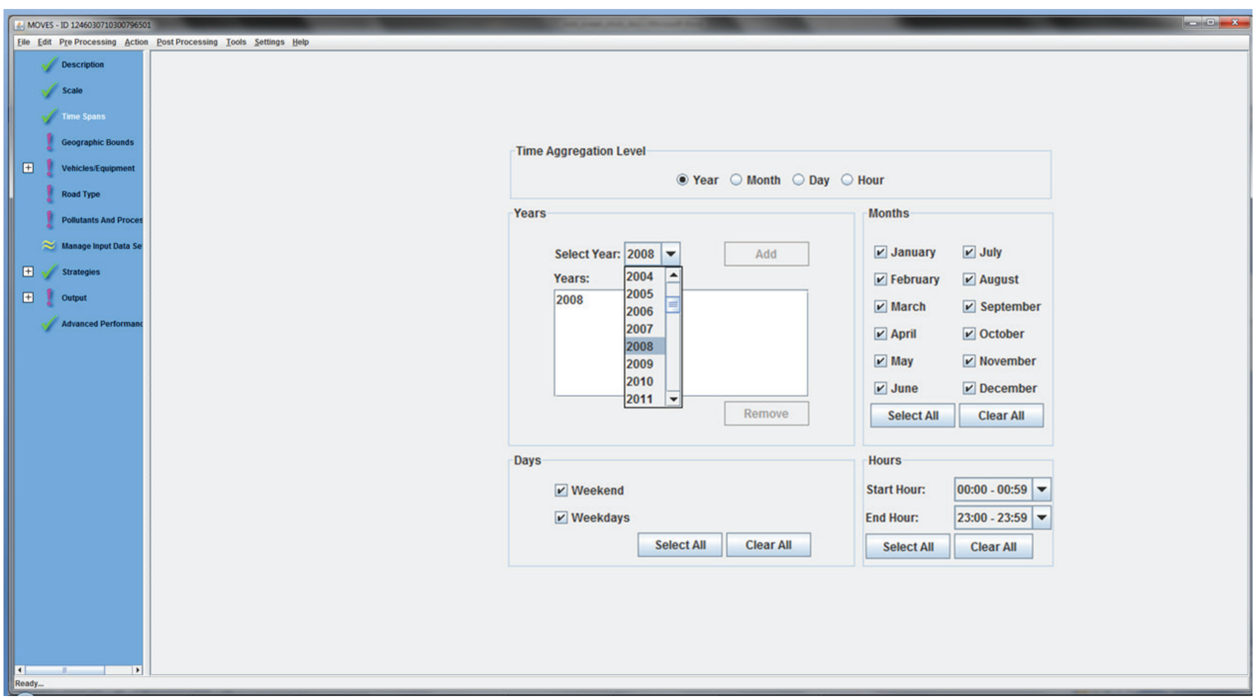

Figure A.15. *MOVES time span screen.*

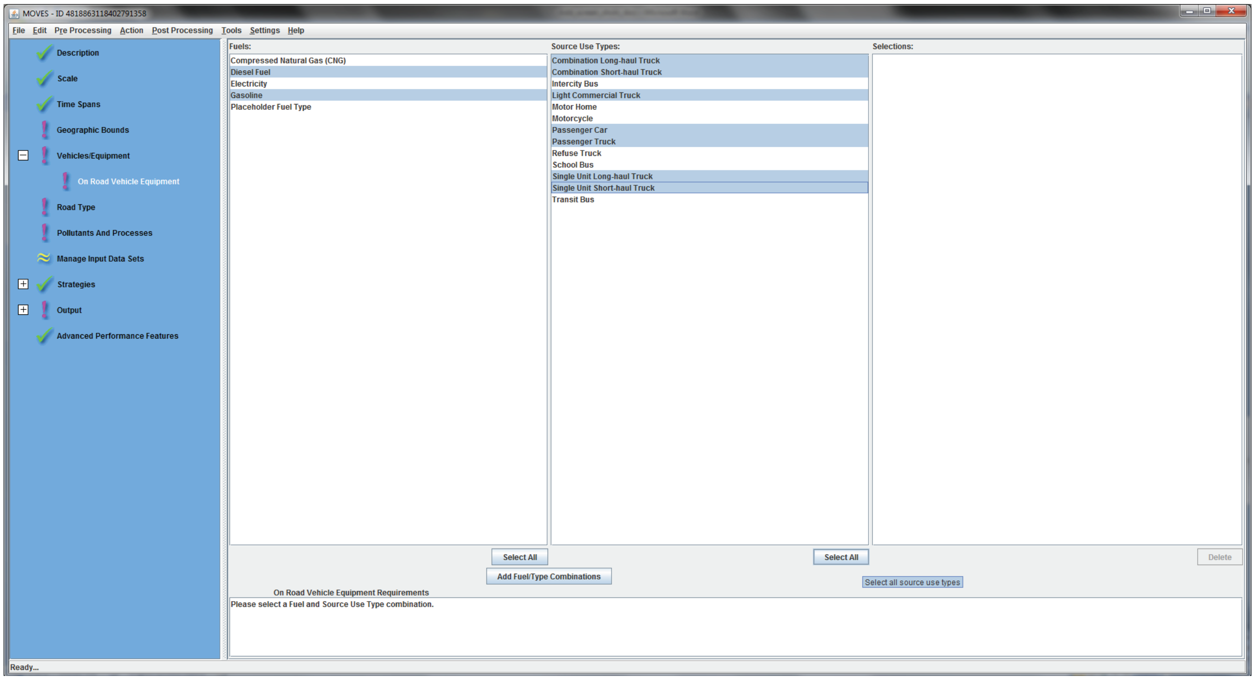

Figure A.16. *MOVES fuel and source types selection screen.*

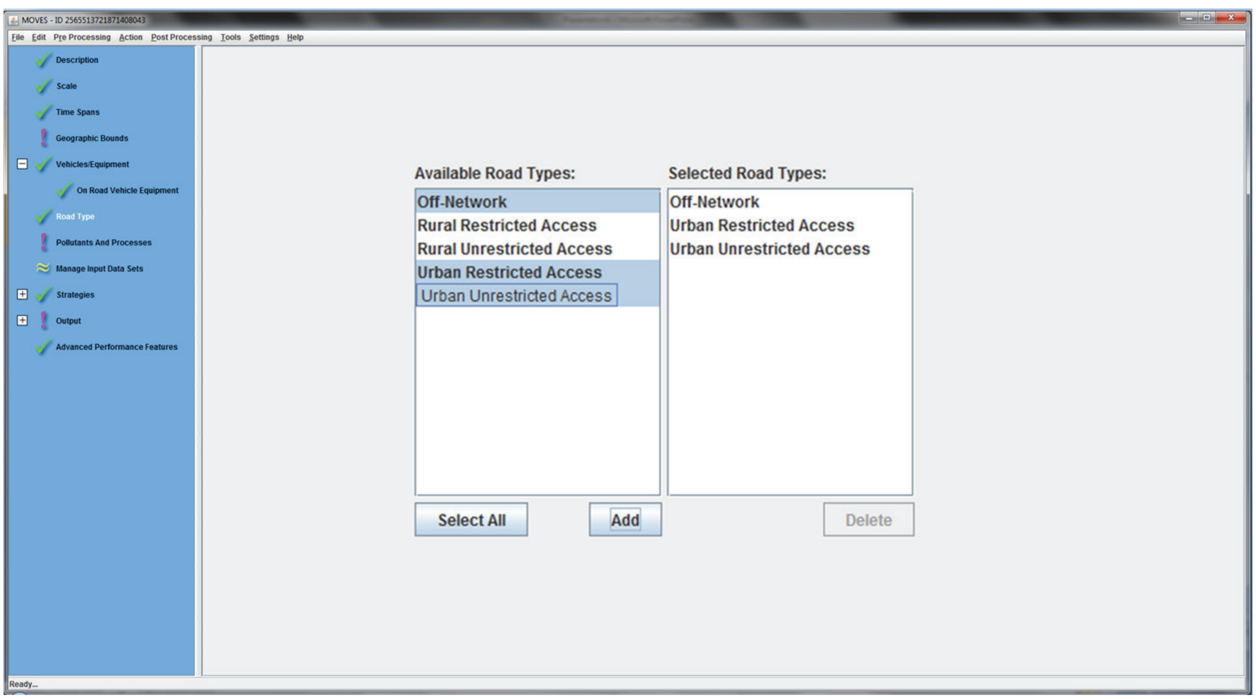

Figure A.17. *MOVES road type selection screen.*

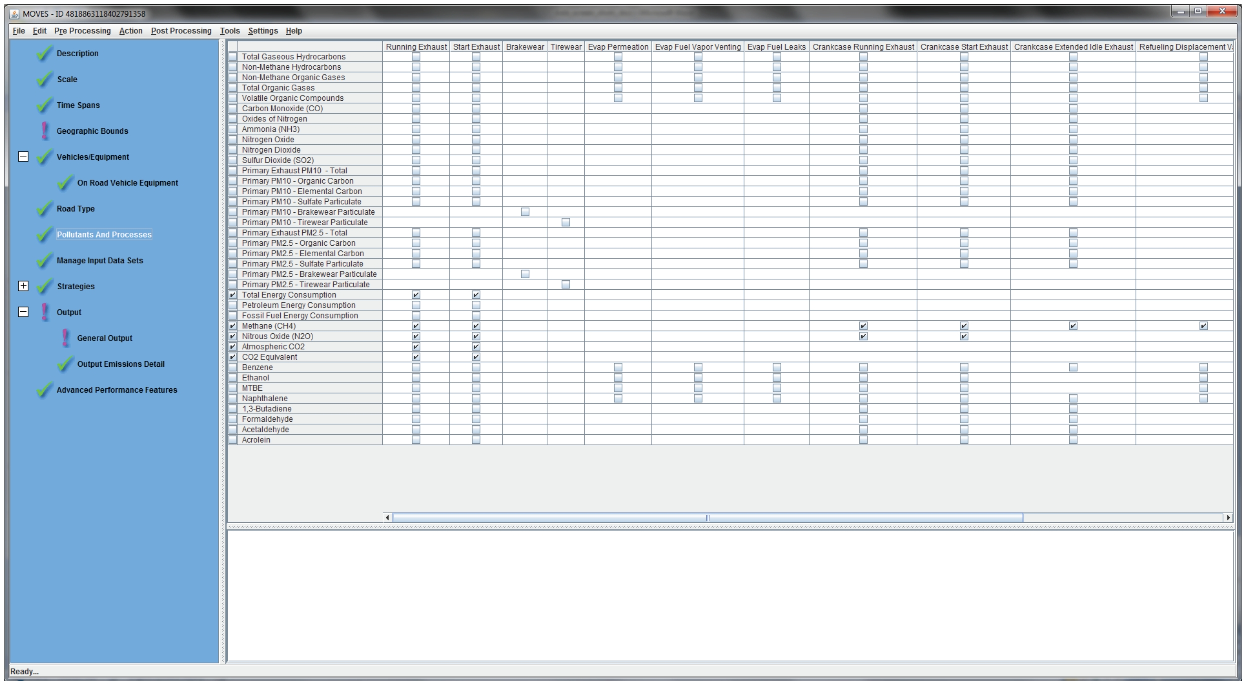

Figure A.18. *MOVES pollutants and processes selection screen.*

After the analyst has made the appropriate selections on the screens illustrated in the figures above, the MOVES County Data Manager is used to enter local data for the area. Local data inputs are required for various parameters for MOVES to run successfully. However, some of these inputs can be based on EPA default data if they are not important to the calculation of GHG emissions or if no locally derived data are available. The local inputs for which data are needed for a successful MOVES run include vehicle age distributions, average speed distributions, fuel information, temperature and humidity information, road type distribution, source type population, VMT data, and inspection and maintenance program information. Of these, accurate local data are most important for VMT, vehicle age distributions, and road type distributions in creating a GHG emissions inventory. These inputs are described in greater detail below.

From the MOVES County Data Manager, in most cases, a spreadsheet template can be exported that includes all combinations of the fields that need to be populated for use in MOVES. This template can then be populated by the user with local data and imported as part of the MOVES database for the selected county.

A separate database (and MOVES model run) would need to be developed if separate runs for each county in the area are to be performed. If only areawide GHG emissions data are needed, then the County Data Manager should be populated using data representative of the entire area (e.g., including all VMT in the area), but using a single county code to represent the area. Alternatively, the Custom Domain option in MOVES can be used to represent a multicounty area. However, several additional inputs are needed with this option. The inputs related to vehicle activity are discussed below, and other inputs that apply to all scales of analysis are discussed at the end of this document.

Local Area Vehicle Travel Inputs for MOVES in Areas Without a Travel Demand Model

VMT

For areas without travel demand models, it is expected that VMT will be available at the facility level for each county within the area. For other types of analyses, VMT would normally be collected at the annual average daily travel level (such as for an ozone analysis). However, for a GHG emissions analysis, VMT needs to be the estimated annual volume. The total VMT data input to MOVES must be broken down by Highway Performance Monitoring System (HPMS) vehicle types (i.e., passenger car; motorcycle; other two-axle, four-tire vehicles; single-unit and combination trucks; and buses).

In addition to total county- or area-level VMT by HPMS vehicle category, MOVES requires VMT fractions by hour, day, and month. For areas without travel demand models, it is recommended that the user export the default data for these inputs from the MOVES County Data Manager and use those as input. However, the total VMT data (in the HPMSVtypeYear table) must be populated with local data, as VMT defaults in this table are zero.

Speed Distributions

To calculate emissions inventories for areas without travel demand models, the speed inputs typically used would be an average speed by roadway type and would generally apply to the entire day rather than speeds developed for peak and nonpeak travel periods. If more detailed speed data are available for an area without a travel demand model, the section in this report on speed distribution inputs for areas with regional travel model outputs should be reviewed, and more specific speed distributions should be developed, as applicable. The average speed by roadway type data need to be entered in MOVES as speed distribution files via the MOVES County Data Manager. If the user has previously developed these speeds into speed distribution files for use with MOBILE6, EPA has provided a converter program, in Excel spreadsheet format, that can convert the MOBILE6 speed distribution files to the format needed by MOVES.

If no previous speed distribution files exist, the user will need to develop the MOVES speed distribution data directly by exporting a template for the Average Speed Distribution table through the MOVES County Data Manager. This will create a spreadsheet or text table that includes all combinations of the sourceTypeID codes (vehicle categories), roadTypeID codes, hourDayID codes, and avgSpeedBinID codes that are needed for input to MOVES with the avgSpeedFraction field blank for all records. Using this template, the user would then populate the speed bin or bins that represent the desired speed with 1.0 for all occurrences of this speed bin or bins for the selected road type.

The speed distribution data in MOVES represent the fraction of time that a specific vehicle (source) type spends within a specific speed range. For example, if it has been determined that the average speed on urban restricted access roads is 45 mph, then the user would populate the avgSpeedFraction field of the AvgSpeedDistribution table with 1.0 for avgSpeedBinID equal to 10 (speeds at least 42.5 mph and less than 47.5 mph) and for roadTypeID equal to 4 (urban restricted access) for all sourceTypeIDs and all hourDayIDs. The avgSpeedFraction field for all other speed bins on roadTypeID equal to 4 would be populated with 0. Note that in order to represent speeds that are not the average of the end points of one of the speed bins, speed distribution fractions will split between two adjacent speed bins to correctly model the selected speed. The procedure for estimating the fraction of hours of travel in each bin is explained in the MOVES technical guidance document.

Default speed distribution tables can be obtained from the MOVES County Data Manager. However, because the CO_2 emission calculations are sensitive to speed, the analyst is advised to use speeds representative of travel in the local area rather than the MOVES default data.

Road Type Distribution of VMT

The Road Type Distribution table also requires local data inputs through the MOVES County Data Manager. For each of the MOVES source type IDs, the fraction of VMT that occurs on each of the MOVES road types must be entered. This data set is relevant to a GHG emissions inventory because the speed data affecting the CO_2 emission rates are defined by road type. Thus, the assignment of VMT fractions to specific road types will determine the total amount of VMT that is represented at a specific speed. Again, a template can be exported that provides the necessary fields and combinations of data IDs.

Applying MOVES in Areas with a Travel Demand Model

Travel demand models are a commonly used tool to forecast traffic conditions based on future socioeconomic and demographic projections and alternative transportation networks. MOVES can be used in conjunction with travel demand model VMT output by vehicle type (light duty versus heavy duty), facility type (freeway, arterial, local street), and speed to estimate overall GHG emissions from on-road vehicle travel. Emissions for a particular plan alternative can then be compared with emissions for a no-build or existing + committed (E+C) forecast and/or base year emissions by applying emissions factors to link-level model output, stratified by speed, road type, and vehicle type. 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 transportation improvement program. E+C conditions typically represent the no-build scenario for comparison of long-range transportation plan alternative scenarios.

In using MOVES with a travel demand model there are often complications involving differences in vehicle and facility type definitions between the two modeling paradigms. The next three subsections discuss an approach to dealing with common interface issues.

Correspondence Between Travel Demand Model Facility Classifications and MOVES Roadway Type

Run the travel demand model for the no-build or E+C scenario; output link-level volumes and speeds by MOVES road type. The facility types within the travel demand model will likely not match up with the MOVES road types. However, an equivalency table of travel demand model facility type to MOVES road type can be created to append the MOVES road type code to each link in the model network.

Allocation of VMT by Vehicle Type

As a default, travel demand models do not output trips or VMT by the 13 MOVES source (vehicle) types. Typically, the models output VMT by passenger trips or passenger and truck trips. Sometimes truck trips are further disaggregated into light-, medium-, and heavy-duty truck trips. Because the 13 MOVES source (vehicle) types nest within the six HPMS vehicle types, HPMS data can be used to obtain the percentage of VMT by the six HPMS vehicle types, and the percentage distribution can then be applied to the travel model VMT. Although default vehicle type distributions from MOVES can be used, EPA encourages the use of local data for the six HPMS vehicle types and discourages the use of national defaults unless they are used to further break down the six HPMS types into the 13 MOVES vehicle types.

Mapping MOVES Emissions Factors to Travel Demand Model Link-Level Data

When running MOVES to get emissions factors by vehicle type and speed, 2.5- or 5-mph speed increments covering the range of speeds observed on the roads to be modeled should be used. If emissions factors will be applied for the six HPMS categories, the emissions factors output from MOVES for the 13 MOVES source (vehicle) type categories can be postprocessed using a weighted average. The emissions factors can then be mapped to links either by matching the link-level speed with the nearest incremental speed modeled in MOVES or by interpolating from a lookup table of emissions factors by speed increment.

Applying MOVES in Project-Level Analyses

MOVES can also be applied to estimate the GHG emissions associated with project- or corridor-level changes to the transportation system. As of 2010 there was limited EPA or FHWA guidance available for how to conduct a project-level GHG emissions analysis using MOVES. The EPA–FHWA MOVES training course (U.S. Environmental Protection Agency 2012d) presents information on project-level MOVES analyses that is consistent with the information in the EPA MOVES user's guide, but it has limited utility for GHG assessments. Similarly, the particulate matter hot-spot guidance (U.S. Environmental Protection Agency 2010f) has potential crossover information, but the scope of the assessments for criteria pollutants or mobile source air toxins would be expected to be considerably different from those for GHGs, both in geography and time scale.

Transportation projects in the context discussed here are generally road projects that do not directly cause new trip generation. In contrast, *development projects* result in the generation of new local trips. For example, a road-widening project or intersection improvement would be considered a transportation project. Such projects lead to changes in GHG emissions as a result of changes in speed, flow of traffic, or traffic volumes. Use of the MOVES model now enables transportation modelers to capture GHG emissions changes that result from such projects. These changes result from changes in fuel consumption with speed, traffic flow, and volume changes. In order for these changes to be captured in a GHG analysis, detailed information at the link level is needed.

Appendix G of the MOVES user's guide provides some information about how to set up a MOVES run for a project-level analysis. However, the example provided is directed toward criteria pollutant analyses and needs to be adapted to the larger scale of analysis that is likely to be typical of a GHG project study. The information below summarizes some of the information in the MOVES user's guide that is likely to be relevant to project-level GHG studies.

It is suggested that weekday and weekend day analyses be developed separately and then weighted to reflect the prevalence of weekday versus weekend travel patterns during a year.

For each roadway link, the user must specify the MOVES road type that best represents it. Any of the four road types may be chosen to represent each project link. A link length must be specified for each roadway link to be modeled.

Traffic volume estimates must be specified for each link. This is the total average traffic flow from all vehicle types on the link during the period being modeled. Any or all of the MOVES vehicle source types may be included at the same time in a project-level run.

The average speed on each link must be specified. The drive schedule inputs should match the overall average speed(s) of the individual drive cycles as submitted in the LinksDriveSchedule tab.

The average road grade must be specified for each link. This input represents the overall average grade of the entire link, not one specific link segment. It is used only if a drive schedule input is not provided.

MOVES can use second-by-second driving schedules to model vehicle operation, such as those that might be obtained from a traffic simulation model. If drive schedules are not provided, MOVES uses the average speed and average grade inputs plus default MOVES driving cycles to model the driving behavior.

The distribution of traffic by MOVES source type is another MOVES input. It is entered as the SourceTypeHourFraction in the LinkSourceType worksheet and the LinkSourceType input tab. If there is an expected difference in the distribution of traffic among source types, this difference should be reflected in the build versus no-build MOVES simulations.

Emissions that occur off the transportation network (e.g., in parking lots) can be included in a project-level MOVES run via the extended idle and parked vehicle fraction parameters. The operating mode distribution needs to reflect the soak times in parking lots or parking garages. The soak time is the time since the vehicle engine was turned off.

The source type age distribution for the vehicles in the project area needs to be input to MOVES. This age distribution would usually be expected to be the same as an area would use for any urban-scale analysis such as a state implementation plan emissions inventory. However, if the project is expected to attract a nonrepresentative vehicle age distribution (e.g., a football stadium might attract a newer fleet than average), then that age distribution should be used in MOVES. A younger fleet would be important for any forecast year analyses that will be affected by new fuel economy standards (i.e., lower GHG emission rates).

Link-Specific Driving Schedules

As discussed above, MOVES can use second-by-second driving schedules to model vehicle operation. This section addresses developing link-specific driving schedules using microscopic traffic simulation models as a preferred alternative to standard VMT with estimated average speeds. Microscopic transportation simulation models simulate the movement of individual vehicles at second or subsecond intervals through a representative travel network. In doing so, they keep track of the speed and acceleration of every second of the simulation. This approach offers a level of refinement beyond using average speeds, which does not capture the details of how congestion forms and dissipates in practice. Whether an analyst chooses to use a microsimulation model to prepare a GHG emissions analysis for a transportation project depends on whether there is expected to be a significant difference in the traffic delay characteristics with the transportation project, because GHG benefits accrue from reducing the excess fuel consumption that might occur without the project. If average speeds and times in modes (acceleration, deceleration, cruise, and idle) do not change with the project, then a microsimulation analysis may not be needed.

Vehicle activity is significantly different under different regimes of congestion, such as

- Queue-forming transitional flow, characterized by backward-forming shock waves;
- Movement within the queue; and
- Recovery from queuing conditions.

The output of each simulation run is a vehicle trajectory file that for every second of the simulation indicates the speed and acceleration of every vehicle in the network; that is, the output consists of instantaneous speed and acceleration. Such voluminous data require some summarization before being input to MOVES. Table A.32 provides an excerpt from a typical driving cycle for MOVES input.

There are other possible approaches to using the microsimulation model outputs than using the average speed by link. The average speed assumption is a reaction to long MOVES run times, which would be exacerbated by using the speed–acceleration trajectories for every vehicle.

Another user option is to sample the second-by-second individual vehicle trajectories and to then use that sample as MOVES inputs. If such an approach is considered, it is suggested that the microsimulation model results for each time period be reviewed to determine how much variability there is in the speed–acceleration–time traces in order to develop an appropriate sampling method. A significant amount of variability in the vehicle-to-vehicle speeds and accelerations during a time period suggests that a larger sample size is warranted. This approach is discussed in EPA's particulate matter hot-spot guidance: "For both free-flow highway and intersection links, users may directly enter output from traffic simulation models in the form of second-by-second individual vehicle trajectories" (U.S. Environmental Protection Agency 2010f). If this approach is used, then EPA recommends using data from a representative sample of links, in which each link represents an individual vehicle trajectory, as input to the MOVES model and then scaling the results based on the number of vehicles on the actual road links to the number of sampled vehicle trajectories modeled. The sampled vehicle trajectories should include idling, acceleration, deceleration, and cruise.

TABLE A.32. EXAMPLE FILE STRUCTURE OF DRIVING CYCLE FILES PRODUCED FROM MICROSIMULATION MODEL OUTPUT

SPEED (mph)	SECOND	TIME	LINK	HOUR
60.31	1	4:00:00	I-805 Lane 1	1600-1700
60.70	2	4:00:01	I-805 Lane 1	1600-1700
61.00	3	4:00:02	I-805 Lane 1	1600-1700
60.57	4	4:00:03	I-805 Lane 1	1600-1700
60.58	5	4:00:04	I-805 Lane 1	1600-1700
61.42	6	4:00:05	I-805 Lane 1	1600-1700
62.31	7	4:00:06	I-805 Lane 1	1600-1700
62.91	8	4:00:07	I-805 Lane 1	1600-1700
62.54	9	4:00:08	I-805 Lane 1	1600-1700
61.91	10	4:00:09	I-805 Lane 1	1600-1700
62.01	11	4:00:10	I-805 Lane 1	1600-1700
61.66	12	4:00:11	I-805 Lane 1	1600-1700
61.87	13	4:00:12	I-805 Lane 1	1600-1700
61.08	14	4:00:13	I-805 Lane 1	1600-1700
60.20	15	4:00:14	I-805 Lane 1	1600-1700
58.85	16	4:00:15	I-805 Lane 1	1600-1700
58.44	17	4:00:16	I-805 Lane 1	1600-1700
59.05	18	4:00:17	I-805 Lane 1	1600-1700
60.16	19	4:00:18	I-805 Lane 1	1600-1700
62.98	20	4:00:19	I-805 Lane 1	1600-1700
62.95	21	4:00:20	I-805 Lane 1	1600-1700
63.48	22	4:00:21	I-805 Lane 1	1600-1700
62.51	23	4:00:22	I-805 Lane 1	1600-1700
61.83	24	4:00:23	I-805 Lane 1	1600-1700
61.44	25	4:00:24	I-805 Lane 1	1600-1700
60.23	26	4:00:25	I-805 Lane 1	1600-1700
59.88	27	4:00:26	I-805 Lane 1	1600-1700
60.15	28	4:00:27	I-805 Lane 1	1600-1700
60.33	29	4:00:28	I-805 Lane 1	1600-1700
61.55	30	4:00:29	I-805 Lane 1	1600-1700

Yet another option is to select percentiles from the speed distribution for analysis using MOVES.

For practitioners without microsimulation modeling capability, an FHWA contract is underway in 2010 that will produce example vehicle-specific power profiles for MOVES under various congestion conditions. When these vehicle-specific power profiles are released by FHWA, users will be able to use the ones that best match their specific roadway configuration and will be able to perform a more complete analysis of their transportation project than would otherwise be possible.

Local Area Vehicle Travel Inputs for MOVES for Project-Level Analyses

This section discusses the individual input tables needed to model a project-level analysis in MOVES.

Links

The use of the Project Level within MOVES requires a complete definition of the project. All individual roadway links and the off-network area must be specified by the user. This can be done by exporting a template for the Links table through the MOVES Project Data Manager, which will create a spreadsheet or text table that includes all combinations of the linkID, countyID (only one county may be chosen for a given project-level run), zoneID, roadTypeID, linkLength, linkVolume, linkAvgSpeed, linkDescription, and linkAvgGrade that are needed for input to MOVES. The roadTypeID is required for each roadway link and can be chosen from the four available road types (unrestricted or restricted urban or rural roads). The linkLength is the length in miles of each of the road links. The user must also specify link volume for each modeled roadway link. Link volume is the total average traffic flow from all vehicle types on the link during the period being modeled (for the project level, the period can only be the hour). The average speed and average road grade represent the overall average of the entire link. If driving schedules are not provided, MOVES will use the average speed and grade inputs and default MOVES driving cycles to do the calculation. However, if a link driving schedule is provided, then the average speed and grade will be obtained through that input.

Link Driving Schedule

The Link Drive Schedules Importer defines the precise speed and grade as a function of time (seconds) on each roadway link. Exporting a template for the Link Drive Schedules table through the MOVES Project Data Manager will create a spreadsheet or text table that includes all combinations of the LinkID, secondID, speed, and grade that are needed for input. The speed variable is entered in miles per hour and the grade variable in percentage grade (i.e., vertical distance or lateral distance; 100% grade equals a 45-degree slope). For each MOVES run, only one driving schedule can be input by the user. It is important to note that for a given roadway link, a user-supplied driving schedule will take precedence over an average link speed or grade input.

Link Source Type

The Link Source Type Importer describes the distribution of VMT by MOVES source (vehicle) type. The percentage of the total traffic on each link needs to be allocated to specific source types. This can be done by exporting a template table through the MOVES Project Data Manager, which will create a spreadsheet or text table that includes all necessary combinations of the LinkID, SourceTypeID, and SourceTypeHourFraction.

Operating Mode Distribution

The Operating Mode Distribution Importer is used to import operating mode fraction data for source types, hour combinations, roadway links, and pollutant and process combinations. By exporting a template for the table through the MOVES Project Data Manager, a spreadsheet is created that includes all combinations of the SourceTypeID, HourDayID, LinkID, PolProcessID, OpModeID, and OpModeFraction that are needed for input to MOVES.

Operating modes are modes of vehicle activity that have distinct emission rates. For example, running activity has modes that are distinguished by their vehicle specific power and instantaneous speed. Start activity modes are distinguished by the time the vehicle has been parked prior to the start (soak time). For a given source type, hour and day combination, roadway link, and pollutant and process combination, the operating mode distribution must sum to one. The Operating Mode Distribution Importer is required for the Project Data Manager when modeling any nonrunning emissions-producing process (such as idling or start processes). It is also required for modeling running emissions processes when either the Link Drive Schedules Importer is not used, or the link average speed input is not entered in the Links Importer. It is important to note that Operating Mode Importer data will take precedence over data entered in the Link Drive Schedules Importer and the Links Importer if conflicting data are entered.

Off Network

The Off Network Importer provides information about vehicles that are not driving on the links, but still contribute to the project emissions (for instance, when starting or idling). Exporting a template through the MOVES Project Data Manager will create a spreadsheet that includes all combinations of the sourceTypeID, vehiclePopulation, startFraction, extendedIdleFraction, and parkedVehicleFraction that are needed for input.

For each source, vehicle population is the average number of off-network vehicles during the hour being modeled. The startFraction field, a number from zero to 1.0, specifies the fraction of this population that has a start operation in the given hour. The extendedIdleFraction field is also a number from zero to 1.0; it specifies the fraction of the population that has had an extended idle operation in the given hour. Finally, the parkedVehicleFraction field is a number from zero to 1.0 that specifies the fraction of the population that has been parked in the given hour.

Local Area Inputs for MOVES Not Related to Vehicle Travel

This section describes the local area inputs to MOVES that are needed for all analysis types.

Vehicle Age Distributions

It is important that the vehicle age distribution data be representative of the local area for a GHG emissions inventory (as it is for other emissions inventories). The data underlying the CO_2 emissions calculations differ by model year group. Thus, areas with newer vehicle fleets should have lower CO_2 emission rates (on a gram per mile basis) than areas with older vehicle fleets. For areas that have developed MOBILE6 registration distributions, EPA has provided a registration distribution converter that will take the MOBILE6-based registration data and format the data for use with MOVES. Otherwise, the MOVES County Data Manager can be used to create a template for preparing the age distribution data, and data from the state's Department of Motor Vehicles registration database can then be used to populate the template.

Fuel Data

For the fuel supply and formulation inputs, the primary concerns are obtaining the correct mix of gasoline and diesel and identifying the share of ethanol in gasoline. The MOVES defaults for these values should be exported from the MOVES County Data Manager for the selected county. The resulting values should be evaluated based on what is known about the area's fuel supply. Any necessary changes should be made to the values, and the resulting tables should then be imported via the MOVES County Data Manager.

Meteorology Data and Inspection and Maintenance Program Data

Temperature and humidity data are not important in developing a GHG emissions inventory. The user can export the MOVES default data for these parameters for the selected county to include in the MOVES GHG runs. The same is true of the inspection and maintenance program inputs.

Source Type Population

The total number of vehicles in the selected county or area is needed for each of the 13 MOVES source types. EPA's MOVES technical guidance document explains how the source type population data can be developed, because this is a new input for MOVES that was not required for MOBILE6.

Accounting for New Fuel Economy and/or Low-Carbon Fuel Standards

Data in the original (December 2009 release) MOVES2010 model represented in-use fuel economies based on the federal fuel economy standards through the corporate average fuel economy (CAFE) standards that were updated as a result of the Energy Independence and Security Act (EISA) of 2007. An update of the MOVES model released in August 2010, MOVES2010a, includes GHG emissions or fuel economy values representative of those included in the April 2010 joint EPA–National Highway Traffic Safety Administration (NHTSA) rulemaking that affected the light-duty vehicle

(LDV) GHG emissions standards and CAFE standards for model year 2012 through 2016 vehicles. These standards were developed to make the national standards equivalent to the California standards for those model years.

There may be times in the future when the most recent release of MOVES lags behind the adoption of federal fuel economy standards. There may also be situations in which states have adopted standards more stringent than federal standards (e.g., consistent with California) or in which planners wish to consider the effects of proposed, but not yet adopted, standards. There also may be situations in which state or regional low-carbon fuel standards are adopted or proposed that are not reflected in the MOVES emission rates.

The way that MOVES handles fuel economy and CO_2 emissions is fairly complex. No input or database of fuel economy or direct CO_2 emissions are included in the MOVES database. Instead, the MOVES EmissionRate table in the default MOVES2010 database includes energy consumption rates that vary by operating mode, model year group, engine size, and vehicle weight. These rates are then converted to the CO_2 emissions values output by MOVES. These energy consumption rates are based on tested in-use vehicle fuel consumption as opposed to EPA's vehicle fuel economy rating or CAFE standards.

The formula used within MOVES to convert energy per unit activity to fuel economy is essentially

$$\text{fuel economy (unit activity/gal)} = \text{fuel density (g/gal)} \times (\text{energy content (kJ/g)}/\text{emission rate (kJ/unit activity)})$$

Data on fuel density and energy content for gasoline and diesel fuel are contained in the MOVES Fuel Type table.

EPA is looking for ways to simplify the fuel consumption data within MOVES, but at present the complexity of the MOVES fuel consumption data means there is no easy way to directly model changes to fuel economy or GHG standards. However, EPA provides a work-around method for estimating changes in CO_2 emissions resulting from changes in fuel economy in Appendix F of the MOVES *User Guide*. Using this approach, the user would need to develop a table of the baseline MOVES fuel economy values compared with the fuel economy values of the scenario to be analyzed by model year and vehicle type. The values used for comparison should be expressed in terms of the equivalent CAFE standards (as opposed to the on-road fuel economy values). Based on the percentage reduction in the inverse of the fuel economy values, and factoring in the diesel vehicle market share for the model year of interest, the user would then develop a table to be modeled in MOVES via the Alternate Vehicle Fuels and Technologies strategy inputs. The percentage reduction in fuel economy is essentially modeled as an electric vehicle penetration value. Because electric vehicles are modeled assuming zero CO_2 emissions in MOVES, the end result, if modeled correctly, should give a reduced CO_2 emission value that would be the same as the value that would be calculated if a different fuel economy value were used. The basic equation used for calculating the Electric Vehicle fraction for a given model year is as follows:

$$\text{scenario fraction electric vehicle} = 1 - \{(1/\text{scenario fuel economy})/(1/\text{MOVES baseline fuel economy})\}$$

It may be possible to adjust output CO_2 emissions in a similar manner, without the need for making an additional MOVES model run. However, to do this, the output emissions would need to be at the model year level of detail.

The analyst may also consider a simpler option, which involves adjusting MOVES CO_2 emissions factors by the ratio of on-road LDV fuel economy with versus without the new standards in a given analysis year. Such information may be available from a regulatory impact assessment by a federal or state agency. It may be possible to interpolate results for interim years not analyzed. Similarly, a low-carbon fuel standard could potentially be modeled in a simplistic fashion by reducing CO_2 emission rates in proportion to the average reduction required by the standard (e.g., 10% in year *X*). This approach would maintain the ability to apply emissions factors specific to vehicle type, facility type, and speed to VMT forecasts, while adjusting overall emissions to be consistent with reductions expected from the fuel economy or carbon standard.

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