U.S. Department of Transportation
Federal Highway Administration

HANDBOOK FOR ESTIMATING

Transportation Greenhouse Gases for Integration into the Planning Process

Quality Assurance Statement

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Technical Report Documentation Page

1. Report No. FHWA-HEP-13-026	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Handbook for Estimating Transportation Greenhouse Gases for Integration into the Planning Process		**5. Report Date** July 2, 2013 **6. Performing Organization Code**
7. Authors Michael Grant (ICF), William Seth Hartley (ICF), Ron Milam (Fehr & Peers), Jerry Walters (Fehr & Peers), Laurence O'Rourke (ICF), Jennifer Brickett (ICF), Sonya Suter (ICF)		**8. Performing Organization Report No.**
9. Performing Organization Name and Address ICF International, Inc. 9300 Lee Highway Fairfax, VA 22031 Fehr & Peers 100 Pringle Avenue, Ste. 600 Walnut Creek, CA 94596		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-10-D-00006
12. Sponsoring Agency Name and Address United States Department of Transportation Federal Highway Administration 1200 New Jersey Ave. SE Washington, DC 20590		**13. Type of Report and Period Covered** June 2011 – December 2012 **14. Sponsoring Agency Code** HEPP
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16. Abstract

This publication is a handbook designed to provide information on how to analyze on-road greenhouse gas emissions at the state and regional level, and how to incorporate those analyses into transportation planning efforts. The handbook is intended to help state DOTs and MPOs understand the possible approaches, data sources, and step-by-step procedures for analyzing GHG emissions. It provides an overview of estimating GHG emissions in the planning process, and identifies and describes several key methodologies used to estimate emissions. It also provides a discussion of the strengths and weaknesses of each methodology, and includes a section designed to help users identify which methodology is best for their situation.

17. Key Words Transportation planning, greenhouse gases, emissions, inventory, forecasting, modeling, vehicle miles traveled, fuels, analysis methods, state DOT, metropolitan planning organization	**18. Distribution Statement** No restrictions. This document is available to the public from the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	120	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgements

This Handbook was developed with the assistance of practitioners from a range of agencies that were convened as a Greenhouse Gas Assessment in Transportation Team (GGATT) to provide input to the development of this document. Their input received during several peer exchanges and an in-person meeting was invaluable in shaping the Handbook. We would like to thank the following individuals who were part of the GGATT:

Laura Berry, U.S. Environmental Protection Agency

Gina Campoli and Costa Pappis, Vermont Agency of Transportation

David D'Onofrio, Atlanta Regional Commission

Garth Hopkins, California Department of Transportation

Ron Kirby and Erin Morrow, Metropolitan Washington Council of Governments

Chris Klaus, North Central Texas Council of Governments

Rich Perrin, Genesee Transportation Council

Doug Rex, Association of Central Oklahoma Governments

Howard Simons, Maryland Department of Transportation

Mark Smith, North Carolina Department of Transportation

James Worthley, San Luis Obispo Council of Governments

In addition, we would like to thank the many other staff from state DOTs and MPOs who also provided input to this document through discussions during a peer exchange and webinar that were held in November 2011 and March 2012.

Acronym & Definitions List

AADT – Annual Average Daily Traffic
ABAG – Association of Bay Area Governments
APTA – American Public Transportation Association
ARC – Atlanta Regional Commission
BAAQMD – Bay Area Air Quality Management District
BAU – Business as Usual
BCDC – Bay Conservation and Development Commission
BEA – Bureau of Economic Analysis
CAA – Clean Air Act
CAFE – Corporate Average Fuel Economy
CDTC – Capital District Transportation Committee
CH_4 – Methane
CNG – Compressed Natural Gas
CO_2 – Carbon Dioxide
DMV – Department of Motor Vehicles
DOE – Department of Energy
DOT – Department of Transportation
DTA – Dynamic Traffic Assignment
DVRPC – Delaware Valley Regional Planning Commission
EERPAT – Energy and Emissions Reduction Policy Analysis Tool
EIA – Energy Information Administration
EIIP – Emission Inventory Improvement Program
EISA – Energy Independence and Security Act
EMFAC – Emission Factors model (California)
EPA – Environmental Protection Agency
EV – Electric Vehicle
FHWA – Federal Highway Administration
FLEET – Freight Logistics Environmental and Energy Tracking model
FTD – Fischer-Tropsch Diesel
GAO – Government Accountability Office
GBNRTC – Greater Buffalo Niagara Regional Transportation Council
GGATT – Greenhouse Gas Assessment in Transportation Team
GHG – Greenhouse Gas
GIS – Geographic Information Systems
GPS – Global Positioning System
GREET – Greenhouse Gases, Regulated Emissions, and Energy use in Transportation model
HBO – Home-based Other
HBW – Home-based Work
HCM – Highway Capacity Manual
HCS – Highway Capacity Software

HFCs – Hydrofluorocarbons
HHDV – Highest Class of Heavy Duty Vehicle
HPMS – Highway Performance Monitoring System
IDAS – ITS Deployment Analysis System
I&M – Inspection and Maintenance
ICM – Integrated Corridor Management
ITE – Institute of Transportation Engineers
ITS – Intelligent Transportation System
kWh – Kilowatt Hours
LACMTA – Los Angeles County Metropolitan Transportation Authority
LCA – Lifecycle Analysis
Local level – county or municipal level
LNG – Liquefied Natural Gas
LPG – Liquefied Petroleum Gas
LRP – Long Range Plan
LRT – Light-rail Transit
LRTP – Long Range Transportation Plan
MAP-21 – Moving Ahead for Progress in the 21st Century
MDOT – Maryland Department of Transportation
MMBtu – Million Metric British thermal units
MOVES – Motor Vehicle Emissions Simulator
MOVES – RREGGAE – MOVES-Roadway and Rail Energy and Greenhouse Gas Analysis Extension
MPO – Metropolitan Planning Organization
MTC – Metropolitan Transportation Commission
MVSTAFF – Motor Vehicle Stock, Travel, and Fuel Forecast model
MWCOG – Metropolitan Washington Council of Governments
N_2O – Nitrous Oxide
NEPA – National Environmental Policy Act
NHB – Non-home Based
NHTS – National Household Travel Survey
NPS – National Park Service
NYSDOT – New York State Department of Transportation
O/D – Origin/Destination
PEL – Planning and Environment Linkages
PHEV – Plug-in Hybrid Electric Vehicle
PTW – Pump to Wheel
SB – Senate Bill
SCAG – Southern California Association of Governments
SCRITS – Screening for ITS model
SHA – Maryland State Highway Administration
SIPT – State Inventory Projection Tool
SIT – State Inventory Tool

STAPPA/ALAPCO – State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials
STIP – State Transportation Improvement Program
STS – Statewide Transportation Strategy
TDM – Transportation Demand Management
TEAM – Travel Efficiency Assessment Method
TERMs – Transportation Emission Reduction Measures
TIP – Transportation Improvement Program
TPB – National Capital Region Transportation Planning Board
TRIMMS – Trip Reduction Impacts of Mobility Management Strategies model
TSM – Transportation System Management
USC – United States Code
V/C – Volume to Capacity Ratio
VHT – Vehicle Hours Traveled
VIN – Vehicle Identification Number
VIUS – Vehicle Inventory and Use Survey
VMT – Vehicle Miles Traveled
VTDEC – Vermont Department of Environmental Conservation
VTrans – Vermont Department of Transportation
WSDOT – Washington State Department of Transportation
WTP – Well to Pump
WTW – Well to Wheel

Table of Contents

1. Introduction

1.1. Background and Purpose

Transportation sources are a significant contributor to greenhouse gas (GHG) emissions nationally and are often considered a key component of climate change mitigation efforts. State departments of transportation (DOTs) and metropolitan planning organizations (MPOs), together with transit agencies, local governments, and other partners, have the responsibility for transportation planning, which along with federal and state policies can affect GHG emissions patterns. Transportation planning requires comprehensive consideration of possible strategies and diverse viewpoints gathered, in part, through stakeholder and public engagement. It includes assessing a range of policy, investment, and system management and operations strategies, and their effects.

Recognizing that the transportation planning process plays a fundamental role in the state's, region's, or community's vision for its future, some states and metropolitan areas are incorporating GHG reduction goals into their planning efforts. While there is no Federal requirement for consideration of GHG impacts in statewide and metropolitan transportation planning, some agencies are moving ahead with efforts to quantify GHGs and explore transportation strategies to reduce these emissions.

For instance, in response to statewide climate change requirements or energy policy initiatives, MPOs in New York, California, and Washington have been incorporating GHG analyses into their metropolitan transportation plans, and MPOs in Oregon are in the process of incorporating GHG analyses into their regional planning processes. Even in states without any GHG requirements, some state DOTs and MPOs are beginning to analyze GHG emissions, including both past and current emissions as well as future forecasts, to help inform on-going climate change mitigation efforts and to make more informed transportation investment decisions. Many states also have produced GHG inventories and have identified potential transportation mitigation strategies through the development of climate action plans. These inventories and climate change action plans may be a foundation for states and regions to explore transportation policies and strategies in more detail through the statewide or metropolitan transportation planning process.[1]

This Handbook and other resources have been developed that provide information about GHG analysis tools. For example, the National Cooperative Highway Research Program (NCHRP) report *Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects*[2]

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[1] Transportation components of state climate action plans are often quite limited, and forecasts and strategy analyses may require updates. See: FHWA, "Review and Assessment of State Climate Action Plans," prepared by ICF International, 2009, http://www.fhwa.dot.gov/environment/climate_change/mitigation/resources_and_publications/action_plan/index.cfm. Also, NCHRP Report 20-24, Task 59, "Strategies for Reducing the Impacts of Surface Transportation on Global Climate Change: A Synthesis of Policy Research and State and Local Mitigation Studies," prepared by Parson Brinckerhoff, 2009, http://climatechange.transportation.org/pdf/nchrp_2024_59_final_report_031309.pdf

[2] NCHRP Project 25-25 Task 17, "Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects," prepared by ICF International, 2006.

identifies 17 tools or methods that can be used to analyze the GHG implications of transportation projects. The report *Greenhouse Gas Analysis Tools*[3] prepared for the Washington State Department of Commerce introduces a methodology to identify tools that can be used to estimate GHG emissions, and includes a description of available tools. Also, GHG emissions analysis may use the same tools and data as the emissions analysis for criteria pollutants that many MPOs currently conduct for Clean Air Act (CAA) transportation conformity.

Many state DOTs and MPOs are just beginning to explore how to analyze GHG emissions in relation to their transportation plans. They may have questions such as:

- How can GHG emissions analyses be applied in the transportation planning process?
- What are the most appropriate methods to use?
- What data are needed, and what are common sources?
- What are the strengths and limitations of different approaches?

This Handbook is intended to help state DOTs and MPOs of all sizes and capabilities understand possible approaches, data sources, and step-by-step procedures for analyzing GHG emissions for use in the transportation planning process. It is intended for use by individuals who are involved in deciding how their organization will perform a GHG analysis at a statewide or metropolitan level. This could include planning directors or other staff who would like to better understand available options for quantifying GHGs that can be implemented in their existing process. The Handbook is intended to be user friendly and informative, particularly for state DOTs and MPOs that have limited experience with emissions analysis. It provides an overview of the analytical process required and directs users to more detailed user manuals and technical resources regarding specific models and tools.

The Handbook addresses GHG emissions analysis within the context of statewide and metropolitan transportation planning, not at the individual project level. Although the intended audience is state DOTs and MPOs, some of the methodologies included in the Handbook can be appropriately applied to the local, meaning the county or municipal, level. Many counties and cities are developing GHG inventories or conducting analyses of GHG reduction strategies, and some local governments are partnering with their respective states and MPOs. In addition, some areas may be interested in transportation goals related to reducing fuel use or energy consumption. While this Handbook focuses on GHG emissions, many of the techniques and resources presented here apply equally to either analyzing GHG emissions or fuel use/energy consumption.

Handbook Supports Planning Level Analysis

Keep in mind that the methods described in this Handbook are designed for use at the statewide or regional levels. Some methods may also be applicable at a smaller area-wide level, such as a county or municipal level. Throughout this Handbook, the term "local" level is intended to mean the county or municipal level, not the project level.

[3] Washington State Department of Commerce, "Greenhouse Gas Analysis Tools," prepared by Fehr & Peers, 2009, http://www.commerce.wa.gov/site/1277/default.aspx.

1.2. Development of this Handbook

This Handbook was developed with input from state DOT and MPO practitioners from across the country, including a Greenhouse Gas Assessment in Transportation Team (GGATT) convened specifically to help shape this document. Developing the Handbook involved the following key steps:

- **Literature Review.** An initial literature review was developed to provide an inventory of existing tools, literature, and studies relevant to the identification of methodologies and data for analyzing GHGs at the statewide and metropolitan levels. The literature review served as an initial overview of existing resources to be used in the creation of the Handbook.

- **Case Study Interviews and Discussions.** Several interviews with state DOTs and MPOs were conducted to gather detailed information on methodologies and approaches used to estimate and forecast GHG emissions, as well as perceived strengths and limitations of these approaches. In addition, discussions were held with the GGATT and within an MPO peer exchange held in St. Louis in order to gather input on methodologies.

- **Documentation of Methodologies and Data and Modeling Needs.** An interim report was developed documenting procedures that may be used to analyze GHG emissions, including data sources, examples of use of these methods, and strengths and limitations. The report also identified gaps in data or modeling tools that many state DOTs or MPOs face in conducting GHG analysis and that may need to be filled to effectively conduct such analysis. This report served as the foundation for the Handbook.

Based on the documented information, and input from the GGATT and other transportation practitioners, the information was then organized in the form of this Handbook to provide a practical resource for state DOT and MPO staff.

1.3. Handbook Organization

This Handbook describes GHG analysis approaches and lays out steps associated with each of these methods, along with information on data sources, examples of their application, and resources for further information.

The Handbook is organized as follows:

Section 2: Overview: Estimating GHG Emissions in the Planning Process provides an introduction to GHG emissions, why an agency might be interested in analyzing GHG emissions, and the types of analyses that may be conducted in the context of statewide and metropolitan transportation planning. It also provides an overview of primary GHG estimation methods. This section may be particularly helpful for staff who have limited experience with emissions analysis and those who want a broad overview of different approaches.

Section 3: What Methodologies are Applicable for your Situation is designed to help the Handbook user identify an appropriate method or methods, based on the specific needs and situation of the agency.

Sections 4 through 8 focus on methodologies for estimating GHG emissions. For each methodology, the key steps and data options are reviewed, along with strengths and weaknesses of each approach and examples of agencies that have followed the approach. A summary table is included at the beginning of each section to help the user understand the basic requirements of the approach. These sections also provide references to additional resources, as well as tips to keep in mind in regard to these approaches.

> **Section 4: Fuel-based Methods** describes methods that rely on fuel consumption data, including both inventory and forecasting methods.
>
> **Section 5: Vehicle Miles Traveled (VMT)-based Methods** describes approaches that rely on vehicle travel data and connect this information to an estimate of emissions using emission factors or an emissions model. This section discusses methods relying on a range of data to estimate VMT and travel activity, including vehicle, household, and land use data, as well as data from the Highway Performance Monitoring System (HPMS), and network-based travel models. It also discusses various approaches to estimating emissions, including use of the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator (MOVES) model, the preferred tool for developing emissions estimates.
>
> **Section 6: Alternative GHG Estimation Approaches** describes two other types of approaches that do not rely directly on fuel consumption or VMT data: 1) commodity-flow based methods to estimate freight truck emissions and 2) use of the FHWA's Energy and Emissions Reduction Policy Analysis Tool (EERPAT) to analyze scenarios that include a range of policy and transportation system changes.
>
> **Section 7: Specific Transportation Strategy Analysis Methods** identifies additional tools and approaches that can be used to analyze specific types of transportation strategies, such as transportation demand management (TDM), land use, transportation system management (TSM), eco-driving, and freight strategies. These strategies are often not well accounted for in GHG forecasts and require separate analysis.
>
> **Section 8: Additional Considerations: Lifecycle Analysis and GHG Emissions from Transportation Construction and Maintenance** reviews 1) lifecycle emissions analysis (LCA), a type of analysis that aims to improve the understanding of GHG emissions from transportation and upstream sources, such as fuel processing and distribution; and 2) analysis of emissions from transportation infrastructure construction and maintenance.

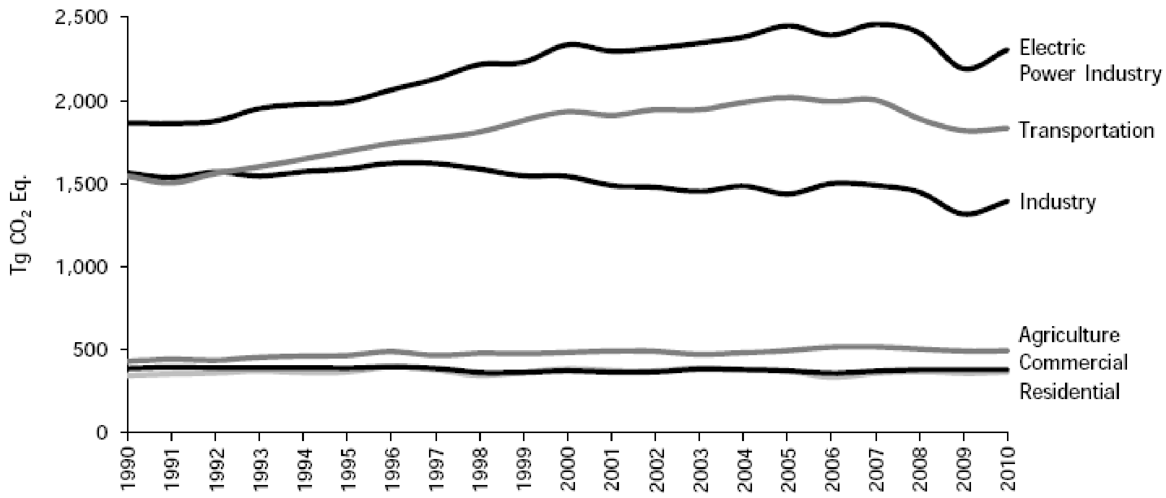
Section 9: References provides links to more detailed documentation of models, and information on additional resource documents.

2. Overview: Estimating GHG Emissions in the Planning Process

2.1. Introduction to Transportation GHG Emissions

The transportation sector is one of the largest sources of GHG emissions in the U.S., comprising 27 percent of U.S. GHG emissions in 2010.[4] In some states, transportation emissions comprise a significantly larger share of GHG emissions and in other states a smaller share. For example, in Washington State, transportation accounted for 45 percent of the state's total GHG emissions in 2008, not because transportation GHG per capita is higher than other states but because GHG emissions from the electricity sector are relatively low due to Washington's heavy reliance on hydroelectric power.[5] The graph below shows that nationally, transportation has historically been the second largest contributor of GHGs behind the electric power industry.

Figure 1. U.S. GHG Emissions Allocated to Economic Sectors, 1990 to 2010



Source: U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010,* Figure 2-12.
Note: Does not include U.S. territories

The focus of the Handbook is on on-road GHG emissions since they comprise the majority of transportation emissions and since the statewide and metropolitan transportation planning largely focuses on surface transportation. Nationally, on-road sources account for about 84 percent of transportation GHG emissions, as shown in Figure 2. However, it is important to note that off-road emissions sources (e.g., ports and airports) may be important contributors to transportation GHG emissions in some states and metropolitan areas.

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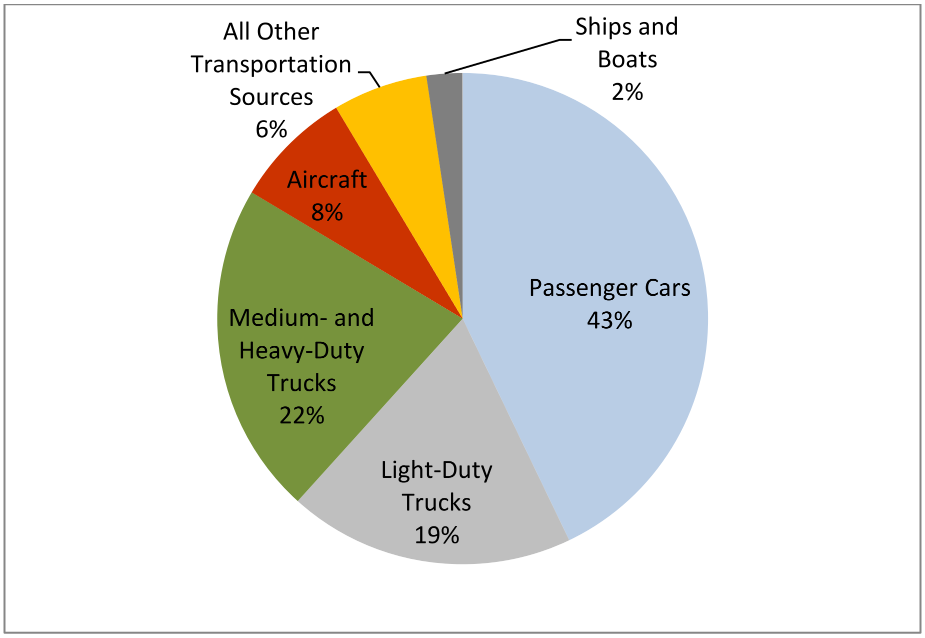
[4] U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, April 2012; EPA-430-R-12-001, http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

[5] Washington Department of Ecology, *Washington State Greenhouse Gas Emissions Inventory 1990-2008*, December 2010, http://www.ecy.wa.gov/climatechange/ghg_inventory.htm.

Figure 2. U.S. GHG Emissions from Transportation Sources, 2010 (CO_2 equivalent)



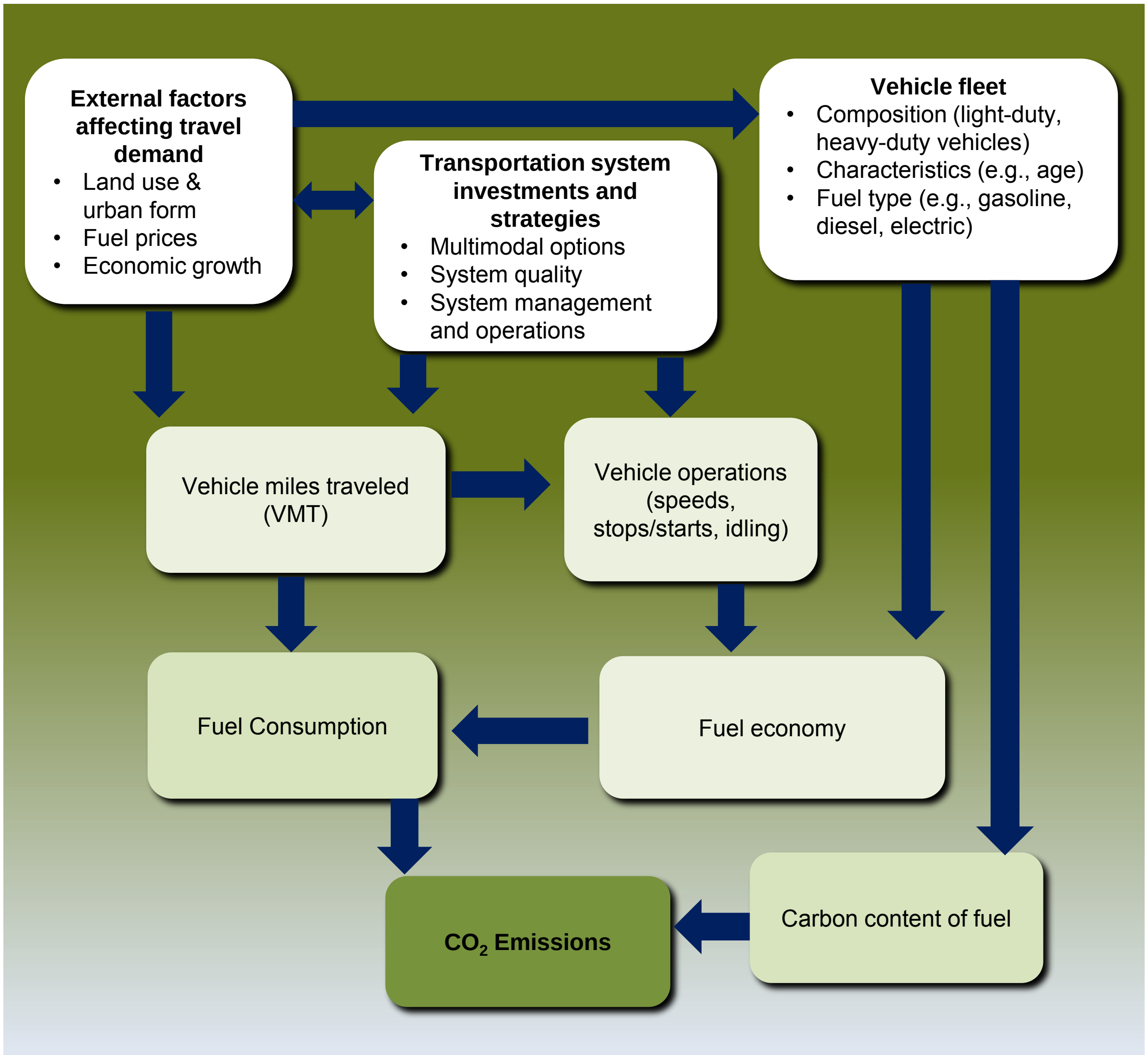
Source: Developed using data from U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010.*

Carbon dioxide (CO_2) is the primary GHG associated with the combustion of transportation fuels, accounting for over 95 percent of transportation GHG emissions based on global warming potential. CO_2 is emitted in direct proportion to fuel consumption, with different emissions levels associated with different fuel types.

Other notable GHGs include methane (CH_4) and nitrous oxide (N_2O), which together account for two percent of transportation GHG emissions, and hydrofluorocarbons (HFCs), which comprise approximately three percent of transportation GHG emissions. N_2O and CH_4 are not directly related to fuel consumption, but instead are dependent on engine operating conditions (i.e., vehicle speeds) and emissions control technologies. In addition, HFCs are emitted from vehicle air conditioners and refrigeration used in some freight shipments; these emissions do not come from the tailpipe, and depend on factors such as the age of the vehicle and how often air conditioners are used. Given the relatively small percentage of these gases in comparison to CO_2, these emissions are often not calculated in simple analyses. However, their potential global warming impact per unit of gas is many times that of CO_2 and therefore regions may want to calculate N_2O and CH_4 directly along with CO_2, particularly if they already have experience modeling emissions.

CO_2 emissions from transportation can be calculated based on the amount of fuel – gasoline, diesel, and other fuels – used by motor vehicles and other transportation sources. This simple concept becomes more complex though, when trying to capture the variety of factors that affect fuel consumption as generally depicted in the flow chart below.

Figure 3. Key Factors Influencing On-Road CO_2 Emissions



The amount of fuel consumed by vehicles depends on a wide range of factors, including the amount of vehicle travel and the fuel economy of those vehicles, which in turn depends on how they are operated and the vehicle characteristics. The type of fuel burned (e.g., gasoline, diesel, compressed natural gas, biofuel) also affects the amount of CO_2 that is emitted, based on the carbon content of the fuel. Extrapolating many of these variables into the future is challenging and requires numerous assumptions that can have a significant effect on forecasts. For GHG forecasts, vehicle and fuel assumptions have significant potential to affect results, so particular attention must be paid to these assumptions, by both analysts and the users of GHG forecasts.

Estimations of GHG emissions can rely on similar methods to those used for analyses of criteria air pollutant emissions. These methods include analyzing VMT with emissions factors, or using an emissions model, such as EPA's MOVES model, which is EPA's preferred tool for developing on-road GHG emission inventories at the state and local levels.[6]

2.2. Why Estimate GHG Emissions in Transportation Planning?

Transportation planning is a cooperative process to make decisions about transportation investments and strategies for operating, managing, maintaining, and financing the transportation system in such a way as to advance the area's long-term goals. Transportation planning involves many steps, from developing a vision and goals through developing a long range plan (LRP), sometimes referred to as a long range transportation plan (LRTP). The overall transportation decisionmaking process involves additional steps, including programming investments, project development, systems operations, and on-going monitoring of system performance (as shown in Figure 4).

Figure 4. The Transportation Decisionmaking Process

Source: FHWA/FTA, "The Transportation Planning Process: Key Issues – A Briefing Book for Transportation Decisionmakers, Officials, and Staff." FHWA-HEP-07-039, September 2007. Available at: http://www.planning.dot.gov/documents/briefingbook/bbook.htm#2BB

[6] U.S. EPA, "Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption: Public Draft," January 2012. http://www.epa.gov/otaq/stateresources/420d12001.pdf.

Although Federal regulations do not require analyzing GHG emissions as part of statewide or metropolitan transportation planning, many actions to address GHG emissions can be initiated at the state and regional level. Therefore, there are several reasons for state DOTs and MPOs to consider estimating GHG emissions as part of the planning process.

- **To better understand the environmental implications of LRPs** – Statewide and metropolitan transportation plans are designed to take a long-term view (20-30 years into the future) of transportation needs and to identify projects, strategies, and policies to achieve agreed-upon goals. Understanding the environmental effects of alternative transportation plan options is important in making informed decisions, and climate change is an environmental issue states and MPOs may wish to consider.
- **To address environmental sustainability within performance-based planning efforts** –To support informed transportation investment decision-making, states, MPOs, and transit agencies are increasingly incorporating performance measures in their transportation plans and analyzing the anticipated performance implications of alternative strategies or investment packages. Within these efforts, agencies may wish to inventory and forecast GHG emissions as a basis to establish performance measures to support environmental sustainability goals. [7]
- **To complement Planning and Environment Linkages (PEL) efforts** – GHGs can be analyzed at several points in the transportation decision-making process. While GHG analysis is possible for individual projects, analyzing GHGs during the planning process can be more meaningful, given their system-wide impacts, broader geographic scope, and longer time scale. Incorporating GHG emissions analysis in the planning process can complement the Planning and Environment Linkages (PEL) approach, which encourages collaboration and integration between transportation and natural resource agencies on the planning and environmental review processes. The PEL approach encourages planners to analyze data and consider the costs and benefits of decisions in a comprehensive way. It can also help eliminate potential duplication of planning and National Environmental Policy Act (NEPA) processes, creating one cohesive flow of information. In addition, by encouraging resource and regulatory agencies to get involved in the early stages of planning, it provides them an opportunity to help shape planning decisions, instead of just reacting to project proposals, thereby improving outcomes and the efficiency of decision-making.[8]
- **To support state and/or local climate action planning efforts** – A number of states and municipalities have developed climate action plans that identify targets and key strategies for GHG emissions reduction. These climate action plans typically have been developed with limited input from transportation agencies. By considering GHG emissions as part of the transportation planning process, transportation agencies can provide better information to help decision-makers understand the expected level of GHG emissions from transportation in the future and the potential reductions that may be feasible from transportation investments and operations and transportation demand management strategies. This information can be particularly important in determining

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[77] 23 USC 150(b)(6).

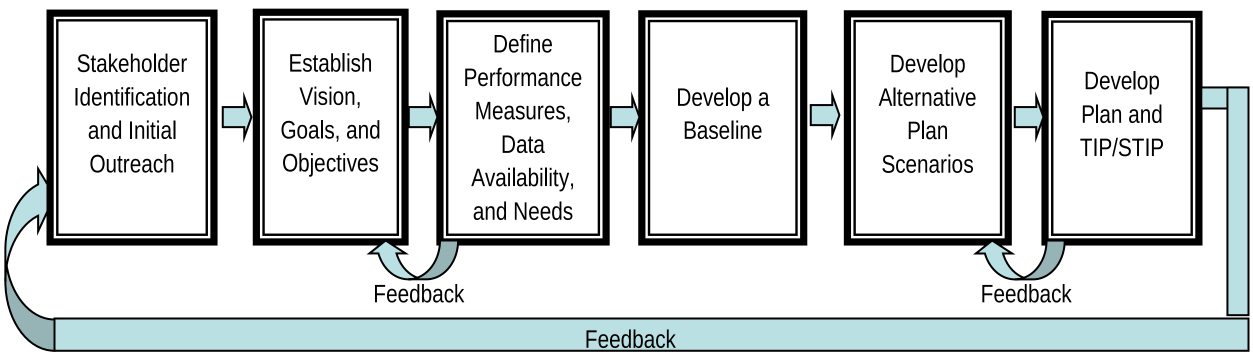
[8] Additional information on the PEL approach is available through the FHWA website, "Planning and Environment Linkages: Program Overview," http://environment.fhwa.dot.gov/integ/index.asp.

what range of strategies may be applied, and in estimating credible reductions from transportation within multi-sector efforts.

Incorporating GHG Emissions in the Planning Process

GHG consideration can be incorporated into the transportation planning process at numerous points, as shown in Figure 5, and described below.

Figure 5. Potential Points for Addressing GHG Emissions in the Planning Process



Source: Adapted from: FHWA, “Integrating Climate Change into the Transportation Planning Process,” July 2008.

- **Stakeholder identification and outreach.** Transportation planning is a cooperative process designed to foster involvement by all users of the system, such as the general public, public transportation providers, the business community, community groups, environmental resource agencies, pedestrians and bicyclists, and freight operators and shippers, through a proactive public participation process. Transportation agencies can actively engage with state and local environmental agencies and other organizations involved in climate action planning.
- **Establish a vision, goals, and objectives.** State DOTs and MPOs can include GHG reduction as part of their vision for outcomes of the transportation system, as well as within goals or objectives in long-range plans. The public and other affected stakeholders need to be actively involved in the establishment of a vision, goals, and objectives, as they are developed through the transportation planning process, and these may involve consideration of GHG emissions.
- **Define performance measures and data availability and needs.** Within a performance-based planning process, agencies will develop performance measures to measure progress towards stated objectives. In addition to the performance measures required as part of performance management pursuant to 23. U.S.C. 150(c), a GHG performance measure may be selected to support goals related to environmental sustainability. Developing such a measure requires consideration of existing data that can be used to estimate emissions levels.
- **Develop a baseline.** As States and regions attempt to understand GHG emissions levels associated with on-road sources, transportation planners may be called upon to provide information on current, past, and projected future levels of emissions. For many

states, a GHG inventory is usually the first step (described further in section 2.3), since understanding the scope of GHG emissions is key to identifying trends and sources of increase.

A greenhouse gas inventory is a past and present accounting of greenhouse gases emitted to or removed from the atmosphere over a period of time. Many state air agencies have developed an inventory that becomes a baseline for GHG analysis, working with other regional and state stakeholders. This includes all major emission sources, including the transportation sector, but may not have involved detailed analyses of travel-related trends and factors. Policy makers use inventories to track emission trends, develop mitigation strategies and policies, and assess progress.[9] Within the transportation planning process, a baseline inventory may be developed focusing on on-road sources, as well as a "business as usual" forecast of expected emissions under existing policies and trends.

- **Develop alternative plan scenarios.** In this step, utilizing the GHG baseline, as well as any targets that are set, agencies identify alternative strategies or approaches for achieving objectives, and typically define a number of alternative packages of investments, accounting for fiscal constraints that will be incorporated in the long range transportation plan. This step can include identification of one or more alternative scenarios, which may include specific strategies intended to reduce GHGs, such as by reducing vehicle miles traveled and improving traffic flow..
- **Evaluate alternatives, select preferred alternative, and develop the LRP and transportation improvement program (TIP).** Agencies analyze alternative scenarios using the established goals, performance measures, and targets, to understand implications and select the alternative that best addresses system performance objectives and community goals. In this process, GHG emissions effects can be considered along with a wide range of other performance measures in order to assess tradeoffs, develop priorities for investments, and prioritize related policies and strategies. The two major products of this planning process are:
  - A LRP: Develop and update a long range transportation plan for the state or metropolitan area covering a planning horizon of at least twenty years.
  - A TIP: Develop a short-range (four-year) program of transportation improvements based on the long-range transportation plan; the STIP (statewide transportation improvement program) and the metropolitan area TIP and should be designed to achieve the area's goals, using investments, management and operations strategies, and financial tools.
- **Monitor and evaluate effectiveness (feedback).** Monitoring system performance over time and evaluating the effectiveness of implemented strategies across the various performance metrics, including ongoing analysis of the levels of GHG emissions, provides an important feedback that helps to inform the next cycle of transportation planning.

The public should be actively involved throughout the process, including in selecting a preferred "vision" for the community and defining preferred outcomes of that vision. If that vision includes reducing GHG emissions from transportation, the public and other stakeholders have important

[9] U.S. EPA, State and Local Climate and Energy Program, http://www.epa.gov/statelocalclimate/state/activities/ghg-inventory.html

roles in helping to achieve them. Involving the public up front and gaining their acceptance of the benefits of programs to mitigate climate change can provide continued support for policies and programs to address GHGs.

Examples of Areas Integrating GHGs in Planning

A number of states and metropolitan areas are including climate change considerations in their transportation plans and programming documents, and have integrated GHG emissions analysis in the planning process. Just a few examples are highlighted below.

State of Maryland. The 2009 Maryland Transportation Plan notes that,

> "Maryland is beginning to address climate change through its Climate Action Plan, which sets Statewide goals for reducing GHG emissions. Reducing transportation GHG emissions will likely require a range of transportation and land use policy options, including increasing the use of cleaner fuels, transitioning State vehicle fleets to high efficiency vehicles, providing robust transit service, promoting land use options that reduce the need for single occupant vehicle use, and considering road pricing strategies to both help offset the environmental costs of transportation and to address congestion. MDOT and its Modal Administrations are implementing key policies aimed at reducing GHG emissions described in the Climate Action Plan. Maryland Transit Authority prepared the MARC Growth and Investment Plan to expand and improve commuter rail service in Maryland, and is working to increase transit ridership across the State. State Highway Administration is working to ensure safe walking and bicycling conditions whenever highway facilities are being improved, and promotes ridesharing through its provision of park-and-ride facilities. MDOT programs aimed at reducing GHG emissions include Travel Demand Management (TDM) strategies to reduce VMT growth, implementing transit-oriented development, and MTA is also promoting work trip reduction alternatives through Commuter Choice Maryland. In addition to reducing GHG emissions, these policies also help relieve transportation system congestion, improve quality of life and access to jobs, and stimulate community reinvestment." [10]

Philadelphia Region. The Delaware Valley Regional Planning Commission (DVRPC), the MPO for the Philadelphia region, has included a key plan principle to "Build an Energy Efficient Economy" in in its long range land use and transportation plan, called "Connections: The Regional Plan for a Sustainable Future." The plan sets a goal to "Reduce GHG Emissions" by 50 percent from 2005 levels by 2035 (across all sectors) while building an energy efficient economy. The document notes that DVRPC's regional GHG emissions inventory estimates that in 2005 the region produced just over 90 million metric tons of CO_2, roughly 1.5 percent of the U.S. total. It states, "Recent studies identify the need to reduce global GHG emissions by 80% by 2050 to keep climate change within an acceptable range. A 50% reduction by 2035 would put us on track to achieve this goal." It also notes that

[10] Maryland Department of Transportation, *Maryland Transportation Plan 2009*, http://www.mdot.maryland.gov/Office%20of%20Planning%20and%20Capital%20Programming/Plans_Programs_Reports/Reports/MTP/2009MTP.pdf

"More than simply an environmental imperative, the act of reducing greenhouse gas emissions is also an economic opportunity… Building an energy-efficient economy will: Create a steady supply of sustainable jobs in emerging, high-growth industries; Provide new green collar jobs for those currently underemployed; Reduce airborne pollutants to acceptable levels; and Save residents on household energy and transportation costs; Save local governments in reduced energy expenditures."[11]

San Francisco Bay Area. *Plan Bay Area* is an integrated long-range transportation and land-use/housing plan for the San Francisco Bay Area. It includes the Bay Area's Regional Transportation Plan, which the Metropolitan Transportation Commission (MTC) updates every four years, and the Association of Bay Area Governments' (ABAG's) demographic and economic forecast, which is updated every two years. Taken together, the land use patterns and transportation investments aim to reduce GHG emissions for cars and light-duty trucks in the nine-county region. Due for adoption in spring 2013, Plan Bay Area covers the time period through 2040. MTC used the EMFAC (California Emissions Factors) model in conjunction with its regional travel demand model to generate GHG estimates. MTC has been motivated to estimate regional GHG emissions for several reasons. The public values this information, and California state law requires that MPOs demonstrate per capita GHG reductions in their regional transportation plans. MTC has been calculating GHG emissions for nearly a decade. As Plan Bay Area is being developed, performance targets have been selected against which to measure and evaluate various land use scenarios and transportation investments and policies. After consulting with experts, stakeholders and the public, ABAG and the MTC adopted 10 targets. The first is a GHG reduction target required by Senate Bill 375, "The California Sustainable Communities and Climate Protection Act of 2008." MTC must demonstrate that its long range plan will reduce per-capita CO_2 emissions from cars and light-duty trucks 7% by 2020 and 15% by 2035, compared to 2005 levels.[12]

For more information about integrating GHG considerations into transportation planning, see: Transportation for Communities: Advancing Projects through Partnerships, "Integrating Greenhouse Gases into Transportation Planning", available at: http://www.transportationforcommunities.com/shrpc01/ghg_application_kdps/26/0

- FHWA, "Integrating Climate Change into the Transportation Planning Process," July 2008, available at: http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/integrating_climate_change/climatechange.pdf.
- FHWA, "Climate Change - Model Language in Transportation Plans," FHWA-HEP-11-002, May 2010, available at: http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/model_language/index.cfm

[11] DVRPC, *Connections: The Regional Plan for a Sustainable Future (The Long-Range Plan for the Greater Philadelphia Region)*, http://www.dvrpc.org/reports/09047.pdf.

[12] ABAG, the Bay Area Air Quality Management District (BAAQMD), the Bay Conservation and Development Commission (BCDC) and MTC, *One Bay Area*, http://onebayarea.org/regional-initiatives/plan-bay-area/measuring-progress.html.

2.3. Types of GHG Analyses in the Context of Statewide/Metropolitan Transportation Planning

As states and regions attempt to understand GHG emissions levels associated with on-road sources, transportation planners may be called upon to provide information on current and past levels of emissions and their sources as well as information on what future emissions are likely to be under multiple scenarios. The understanding of GHG emissions levels can help states and MPOs achieve performance goals and targets by addressing emission reductions strategies through a comprehensive process in a consistent, coordinated manner. Strategic implementation of investments in the multimodal transportation system can reduce GHG emissions while achieving a balanced, environmentally responsible transportation network.

This information can be important in the transportation planning process, since one of the factors to be considered in both statewide and metropolitan transportation planning is: "protect and enhance the environment, promote energy conservation, improve the quality of life, and promote consistency between transportation improvements and State and local planned growth and economic development patterns."[13] Moreover, states and MPOs must consider including appropriate environmental mitigation activities in their long range transportation plans. Many areas have developed goals related to environmental quality within their transportation plans, or have developed goals for GHG reduction as part of separate climate action plans that can be references in the long range transportation plan.

GHG analysis falls into three broad categories based on the analysis purpose and timeframe of interest:

- **Inventory development** – estimates past or current emissions levels;
- **Forecasts / analyses of alternative scenarios –** makes predictions about future emissions, potentially under different transportation investment or policy scenarios; and
- **GHG strategy analysis –** specifically analyzes the emissions effects of transportation strategies or sets of strategies, including policies and projects which enhance the integration of land use and transportation planning and development, either to document the impact of existing programs or to forecast the potential impacts of alternative strategies.

These types of analyses are closely related, and some states or MPOs engaged in GHG analysis will perform all of them in order to assess past and current emissions levels, to identify anticipated trends in emissions in the future, to explore the impacts of plans and programs, and to examine the potential impacts of alternative strategies.

[13] 23 USC §134 (metropolitan) and 23 USC §135 (statewide).

Note on Terminology: What is meant by an emissions "inventory"?

As used in this Handbook, an emissions "inventory" refers to the level of emissions in a current or past year, while a "forecast" refers to the level of emissions in a future year, either under a "business as usual" scenario or under any number of alternatives.

It is important to note that air quality planners often use the term emissions "inventory" to refer to any analysis quantifying a total amount of emissions for any calendar year, in contrast to an emissions "rate" or "factor" (such as grams per mile). Under this definition, an inventory could be for 1990, 2010, or 2020, and could include multiple scenarios (e.g., a 2030 "business as usual" inventory and a 2030 alternative scenario inventory). Transportation planners, on the other hand, may prefer to think of "inventories" as present or past, and "forecasts" as future predictions, given the differences in data sources that may be used and levels of uncertainty with each. Regardless of how the terms are typically used, it is important for individuals and agencies to have a clear understanding of terms when discussing their analyses.

Inventory Development

An inventory of GHG emissions from transportation (or on-road specific) sources provides information on the magnitude of emissions and their sources. An inventory is usually performed for a recent year, depending on data availability. Inventories may also be calculated for a more distant-past baseline year specified in legislation or executive mandates or policies, and as such can be critically important in developing strategies and measuring progress over time to meet those mandates. The level of detail and accuracy that an inventory provides is determined by the methodology used and by the accuracy of key input data (e.g., vehicle fleet characteristics in the inventory year, VMT, speeds, operating conditions, etc.). General steps for developing a GHG inventory are noted below.[14]

[14] Adapted from U.S. EPA, State and Local Climate and Energy Program, "Developing a Greenhouse Gas Inventory." Available at: http://www.epa.gov/statelocalclimate/state/activities/ghg-inventory.html.

General Steps for Developing a GHG Inventory

- *Set boundaries* – Define the geographic boundaries of analysis.
- *Define scope* – Decide which emissions source categories (e.g., on-road sources only, or all transportation sources) and subcategories (e.g., light-duty vehicles, heavy-duty vehicles, buses), as well as which specific GHGs (CO_2 only, or also N_2O and CH_4) should be included. Also determine how to account for GHGs from travel that starts or ends outside the geographic boundaries.
- *Choose analysis method* – Depending on the data available and purpose of the inventory, choose a top-down (fuel-based), bottom-up (VMT-based), or hybrid approach.
- *Set a baseline year* – Select a baseline year to provide a benchmark to compare progress going forward, considering whether data for that year are available, the chosen year is representative, and the baseline is coordinated with baseline years used in other inventories. (Note: In some cases, legislation or executive direction will specify the baseline year.)
- *Collect input data and conduct analysis* – Gather necessary data and use appropriate tools for the analysis. If necessary data are incomplete or have limitations, as will often be the case, make appropriate assumptions.
- *Document results and how they were derived* – Having complete documentation of methodologies used is critical when comparing inventories or forecasts conducted in future years to the current estimate. Document all assumptions, caveats and limitations.

For more information, EPA's State and Local Climate and Energy Program provides technical assistance, analytical tools, and outreach support; available at http://www.epa.gov/statelocalclimate/state/activities/ghg-inventory.html.

Forecasts / Analyses of Alternative Scenarios

As states and MPOs try to understand the potential impact of their decisions on the transportation network and the natural and human environment, they may want to identify anticipated trends in GHG emissions levels or assess potential effects of different long range transportation plan scenarios on GHG emissions. To do this, they will need to estimate future emissions. These estimations can take the form of forecasts analyzing future alternative scenarios. In the case of a forecast, the organization will typically analyze emissions under a business-as-usual scenario. This can reflect anticipated changes in fuel economy, fleet composition, travel patterns, and other variables likely to impact emissions.

In order to identify ways to reduce emissions, the agency may choose to analyze alternative scenarios that estimate the anticipated impact of various policy choices or implementation strategies. For example, an MPO creating its metropolitan transportation plan might forecast emissions for a twenty-year planning horizon under current trends and also forecast what would happen under different implementation strategies being explored as part of the metropolitan transportation plan. In addition, the MPO could provide alternative analyses using different assumptions about future vehicle technology and fuels.

General Steps for Developing a GHG Forecast

- *Determine forecast year(s)* – Select one or more milestone years in the future. The selection of milestone year(s) may be influenced by: (a) legislative or executive branch GHG targets and laws and (b) the need to synchronize with planning timeframes of the state or area. Also, consider whether to analyze GHGs on a cumulative basis, rather than for a specific forecast year, since climate change impacts are based on cumulative GHGs, over decades.
- *Choose analysis method* – Depending on the data available and purpose of the forecast, select a method that matches the appropriate level of detail and accuracy for the analysis purpose.
- *Collect input data and conduct analysis* – Gather necessary data and use appropriate tools for the analysis.
- *Conduct additional strategy analyses* – Depending on the sophistication of the analysis method and existing modeling tools (e.g., the level of sophistication of the travel demand model), conduct additional "off-model" analyses to adjust the forecast, if needed.
- *Document the results* – Clearly document the results, including assumptions and any limitations or caveats. Identify key areas of sensitivity affecting results.

GHG Strategy Analysis

Analyzing the effects of GHG strategies may be part of the overall forecasting process, particularly if different scenarios for the future are being explored. It is important to note, however, that standard travel forecasting approaches are not well geared toward analyzing certain types of strategies, such as strategies that reduce non-recurring delay, reduce heavy-duty vehicle idling (e.g., truck stop electrification), introduce a low carbon fuel standard, and many others. Consequently, it may be important to conduct specific analyses of GHG reduction strategies or packages of strategies as part of the planning process. Moreover, as agencies move toward more performance-based planning and programming approaches, they may wish to analyze the GHG effects of different projects and programs in order to help prioritize investments for funding. A state DOT or MPO also may wish to analyze the GHG emissions benefits of existing projects or strategies, based on collected data on impacts, in order to help understand their effectiveness and to help inform future decisionmaking.

General Steps for Conducting GHG Strategy Analysis

- *Identify the specific strategies to be analyzed* – The analysis may be for one or more strategies and policies.
- *Select appropriate analysis tools* – These tools typically will focus on estimating the changes in vehicle technology and fuels, VMT, vehicle operating conditions, or vehicle fleet in response to the strategies. One tool may be able to analyze a set of strategies simultaneously, or separate analyses using multiple tools may be needed.
- *Consider the effects of combinations of strategies* – It is important to consider the effects of different combinations of strategies, since some strategies may be synergistic while others are antagonistic.
- *Collect or develop input data and conduct analysis* – Gather necessary data and use appropriate tools for the analysis. Convert changes in travel characteristics (such as changes in travel demand, speeds, congestion) or other factors (such as changes in vehicle technologies) to changes in emissions.
- *Document the results and how they were derived* – Document the methodology used, assumptions about strategies and baseline conditions, and caveats and limitations.

2.4. Overview of Primary Methods

Most efforts to estimate transportation GHG emissions fall into the following primary categories of methods:

- Fuel-based Methods;
- VMT-based Methods;
- Alternative GHG Estimation Approaches; and
- Specific Transportation Strategy Analysis Methods.

Each type of method serves certain needs better than others and has strengths and weaknesses in application, due to data requirements, outputs produced, and sensitivity to different factors. Fuel-based inventories and forecasts are typically best for state-level analysis due to the availability of state fuel sales data, while VMT-based methodologies may be used at multiple levels. Both state DOTs and MPOs generally have methods to estimate VMT, and most MPOs have travel demand models to forecast future VMT under different scenarios for use in the planning process. Each type of method can typically be applied at different levels of sophistication, based on the amount and quality of data available and the purpose and needs of the analysis.

Table 1 highlights the primary types of methods and approaches that can be used, along with key strengths and limitations. A summary of each general type of method follows.

Table 1. Methods and their General Strengths and Limitations

Methods for Estimating and Forecasting GHG Emissions			
Type of Method	**Approach**	**Strengths**	**Limitations**
Fuel-based Methods	*Simple spreadsheet inventory or forecasts:* Collect fuel data and multiply by emissions factor (based on carbon content of fuel) or use EPA's State Inventory Tool; for projections use State Inventory Projection Tool or simple growth factor	• Simple • Data generally accessible • Can be used for all modes (to the extent that state or MPO-specific data are available)	• Only produces estimates by fuel type, not vehicle type • Fuel sales may not match well with actual travel activity, particularly in smaller geographic areas • Projections for future years are not as precise if based on simple growth factors • Method only addresses CO_2, not other GHGs (e.g., nitrous oxide, methane)
	More refined inventory or forecasts: Disaggregate by vehicle type or geography; account for multiple factors in forecasts	• Relatively simple • Provides more detailed breakdown	• Fuel sales may not match well with actual travel activity, particularly in smaller geographic areas • Many assumptions need to be made to develop projections • Method only addresses CO_2, not other GHGs (e.g., nitrous oxide, methane)

VMT-based Methods	*Simple approach:* Develop estimates/forecasts of VMT relying on vehicle, household, economic activity, pricing, and land use data and apply simple emissions factors*	• Relatively simple • VMT estimates are generally available • Well-geared toward areas without network travel models or experience with emissions analysis	• Does not account for impacts of congestion, speeds, or eco-driving behavior of motorists • May not account for significant variation in vehicle fuel efficiency and fuel types across the passenger and freight fleets
	More sophisticated: Rely on HPMS data and/or a network-based travel model to develop estimates/forecasts of VMT broken out by major facility type and/or speed bin and apply emissions factors based on look-up tables*	• Relatively simple but provides more robust analysis (accounting for impacts of speed changes) • Well-geared toward areas with or without network travel models	• Does not account for full range of factors that may be addressed in emissions models (although emissions factors typically will be developed using an emissions model, but applied using simplifying assumptions) • Requires extra effort to attribute VMT shares to different vehicle/fuel types, to reflect variations in GHG/mile for both passenger and freight vehicles
	Emissions Modeling: Develop estimates/forecasts of VMT and use MOVES (or EMFAC in California) *Simple approach:* Rely on model's defaults for inputs other than VMT *Most sophisticated:* Customize inputs for the specific area being modeled*	• Most robust ability to address all of the factors that influence GHG emissions • MOVES is EPA's preferred tool for developing on-road GHG emission inventories at the state and local level	• Local data will need to be assembled, unless the emissions model has already been used for SIP or conformity analysis, or relying on default data (note: default data reduces precision of analysis)

	Commodity Flow-based Methods	• Enhances an existing inventory that does not include freight	• Difficult to forecast since emissions are often driven by factors that are external to a state or region
Alternative GHG Estimation Approaches	FHWA's Energy and Emissions Reduction Policy Analysis Tool (EERPAT)	• Provides policy sensitivity for different GHG mitigation measures • Can evaluate future changes in land use and is sensitive to external changes in the price of fuel • Can incorporate changes in technology • Can be used to assess the overlapping effects of bundles of GHG mitigation strategies • Is relatively well-suited to statewide transportation GHG analysis	• There are a large number of model inputs and some may be difficult to obtain • Model applies to statewide analysis only • Model's VMT estimates are not as accurate as a network-based model
Specific Transportation Strategy Analysis Methods	These approaches include off-model tools that capture the effect of GHG mitigation strategies that cannot be analyzed through travel demand models (e.g., Commuter Model) – EPA has developed an approach called the Travel Efficiency Assessment Method (TEAM), which encompasses use of these types of methods	• Relatively easy to use • Some tools and approaches (e.g., COMMUTER Model, TRIMMS) can analyze the impacts of TDM and TCM strategies in one package • TEAM builds directly on outputs from existing travel demand models and uses existing modeling tools	• These approaches generally require application of emissions factors. Lack of familiarity with MOVES by some users could be a limitation. • Some methods involve simple calculations or rely on relationships drawn from national literature, which may not be accurate in all locations

Additional Considerations in GHG Analysis	Lifecycle analysis methods: using Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model or other approaches	• Provides a fuller understanding of the net impact of strategies (accounts for emissions associated with tailpipe and upstream emissions) • GREET allows the user to compare the lifecycle emissions attributable to conventional and alternative fuels	• For GREET, units of grams of CO_2 equivalent per mile (gCO_2e/mi) limit the user to a pre-determined fuel economy • The GREET tool does not capture the emissions from so-called indirect land use change attributed to sources such as corn and soybeans
	Construction and maintenance emissions methods – spreadsheet tools can be used to estimate GHG emissions associated with materials and equipment used in construction and maintenance of roadways	• Allows transportation agencies to consider the GHG impacts of roadway planning and construction, rather than just considering tailpipe emissions from vehicles using roadways	• Existing tools work best to analyze individual projects using detailed engineering data. Tools are not well equipped for system level analyses of construction and maintenance in long range planning

* Within these general VMT methods, there are a number of different approaches available to estimate VMT as well as to develop inputs for calculating emissions factors; each of these approaches has its own strengths and limitations, depending on data availability and modeling capability. Refer to Chapter 5 for more details.

Fuel-based Methods

Fuel-based methods typically rely on estimates of fuel sales, and directly convert fuel use estimates into CO_2 emissions estimates based on the carbon content of each fuel. The basic equation for estimating CO_2 emissions is:

$$\text{Fuel Consumed} \times \text{Emission Factors} = CO_2 \text{ Emissions}$$

Note: The emissions factor will depend on the fuel type (e.g., motor gasoline, diesel). Fuel consumption is often expressed in gallons and emissions factors in CO_2/gallon.

Fuel-based methods are most applicable where fuel data are available and fuel purchased in the geographic area is used by vehicles operating within the same area. This tends to be the case at a larger scale such as at the state level for developing GHG inventories based on historical data on fuel consumption.

> **Fuel-based Methodologies Reviewed in this Handbook**. Fuel-based methods can be used to develop:
>
> - Inventories (Section 4.1) and
> - Forecasts (Section 4.2).
>
> For both fuel-based inventories and forecasts, a basic approach produces estimates of CO_2 by fuel type. More refined approaches involve additional steps to allocate emissions to vehicle types or geographic areas, or incorporate additional factors into forecasts.

A challenge with fuel-based methods includes the potential that fuel sales may not match directly with travel activity (they may differ due to interstate trucking, through traffic, and other factors). This often raises a policy question about whether GHG should be measured based on where fuel is sold, where travel occurs, or based on the generators of trips (e.g., households and businesses). Moreover, forecasting fuel consumption is often a challenge as the cost of oil fluctuates, and fuel-based methods often are not sensitive to economic development, demographic, and land use allocation policies, transportation investments and strategies, and non-highway transportation user costs (e.g., transit fares and parking costs).

VMT-based Methods

VMT-based methods focus on quantifying the amount of vehicle travel and then connecting this information to an estimate of emissions using emission factors or an emissions model. The basic equation for estimating emissions is:

$$\text{VMT} \times \text{Emission Factors} = \text{GHG Emissions}$$

Note: The emissions factor (typically presented in grams per mile) will depend on vehicle type, classes within vehicle types, technology/fuel type, speeds, and operating conditions. Different emissions factors are available for CO_2, N_2O, and CH_4.

There are many different techniques and levels of sophistication that can be used both for estimating VMT and for developing emissions factors.

VMT can be estimated based on a range of data sources such as data from the HPMS, vehicle odometer readings, household travel survey data, or land use-based vehicle trip generation estimates. VMT forecasts can be developed using network-based travel forecasting models, in which a range of factors such as transportation investments, land use, and modal options affect estimates of future VMT. In non-network based methods, simplified approaches may be used to forecast future travel demand, such as applying simple growth factors. Non-network methods are sometimes referred to as ‘sketch’ planning models although these methods may include relatively robust models of travel behavior to reflect a wide range of variables.

Emissions factors, meanwhile, also can be estimated at various levels of sophistication, ranging from simply applying an average GHG emissions factor to VMT (based on average vehicle fuel economy), to more sophisticated methods accounting for other variables (e.g., vehicle speeds and fleet mix), to use of emissions models like EPA's MOVES model and the Emission FACtors model (EMFAC), developed by the California Air Resources Board and used by agencies within the State of California. MOVES and EMFAC account for a wide range of factors (including vehicle age, road type, drive cycles, and other factors). Policy analysts may wish to match the level of sophistication of the emissions analysis to be somewhat commensurate with the level of sophistication in the VMT analysis.

VMT-based Methodologies Reviewed in this Handbook. All VMT-based methods involve estimating vehicle travel and applying emissions factors or an emissions model. This Handbook identifies several different sources of VMT estimates, as well as different approaches to developing emissions estimates. The Handbook is divided into the following sections:

- Relying on vehicle, household, economic, pricing, and land use data to estimate VMT (Section 5.1)
- Relying on HPMS data and/or a network-based travel model to estimate VMT (Section 5.2)
- Developing emissions factors and emissions inventories (Section 5.3) – This section discusses various ways to estimate emissions, ranging from use of simple look-up tables of emissions factors to use of EPA's MOVES model.

Handbook users are advised to look both at sections discussing VMT estimation and emissions estimation.

Alternative GHG Estimation Approaches

Although fuel-based and VMT-based methods are most common for developing GHG inventories and forecasts, other emissions estimation techniques may be applied. Specifically, emissions from freight trucks, as well as other freight modes, can be difficult to forecast since they are often affected by economic factors not accounted for in travel demand forecasting models, which tend to focus on household travel. As a result, one approach profiled in this Handbook is to develop GHG emissions estimates based on commodity flow data.

Alternative GHG Estimation Approaches Reviewed in this Handbook.

- Commodity Flow Based Methods to Estimate Freight Truck Emissions (Section 6.1)
- Energy and Emissions Reduction Policy Analysis Tool (EERPAT) (Section 6.2)

In addition, most of the traditional travel and fuel forecasting methods do not easily enable the user to account for a full range of transportation GHG reduction strategies, including policies such as pricing, incentives for energy efficient vehicles, and land use policies. The Energy and Emissions Reduction Policy Analysis Tool (EERPAT) was designed specifically to help agencies conduct a screening-level analysis of a wide range of emissions reduction strategies.

Specific Transportation Strategy Analysis Methods

Most travel forecasts, whether through a network-based travel demand model or non-network based approaches, lack the capability to evaluate many GHG reduction strategies such as changes in small-scale land use density, land use mix, pedestrian environment, and transit accessibility; parking price changes, pay-as-you-drive auto insurance; and most other pricing strategies; employer trip reduction programs and other transportation demand management (TDM) strategies; and eco-driving programs and transportation system management and operations strategies, such as improved incident management and traffic signal coordination. A range of tools and approaches can be used to analyze the effects of GHG reduction strategies that cannot be directly accounted for in standard travel forecasting methods. These "off-model" analyses often use simple spreadsheet calculations. Similar approaches are widely used in the transportation conformity process to calculate the emissions benefits of strategies that cannot otherwise be accounted for in the travel forecasting process.

Specific Transportation Strategy Analysis Methods Reviewed in this Handbook.

- Transportation demand management strategies (Section 7.1)
- Land use strategies (Section 7.2)
- Transportation system management and eco-driving strategies (Section 7.3)
- Freight strategies (Section 7.4)

Additional Considerations in GHG Analysis: Lifecycle Analysis and GHG Emissions from Transportation Construction and Maintenance

While most of the methodologies discussed in this Handbook focus on GHGs emitted directly from motor vehicles, analysts should be aware that transportation activities also generate other emissions. The field of LCA (also known as lifecycle analysis) is concerned with understanding the full environmental impacts associated with all the stages of a project or product life. Within the transportation planning context, lifecycle GHG analysis includes not only direct emissions from motor vehicles but also emissions associated with upstream activities, such as fuel production and distribution. These can be important issues, particularly when examining strategies related to alternative fuels or electricity use in transportation, since powering motor vehicles or rail with electricity will generate some GHG emissions at the powerplant source of electricity.

Additional Considerations Reviewed in this Handbook.

- Lifecycle Emissions Analysis Methods (Section 8.1)
- Construction and Maintenance Emissions Analysis (Section 8.2)

In addition, some state DOTs and MPOs are interested in considering the emissions associated with transportation infrastructure construction and maintenance activities. These activities produce emissions, and there are strategies available to reduce these emissions (for instance, reduced roadside mowing, use of low emissions construction equipment, use of warm-mix asphalt).

2.5. A Note on Travel Demand Models

A number of GHG estimation techniques rely (especially for future estimates) on the availability of a suitable network-based travel demand model. Such models are built to evaluate long term regional changes in travel activity due to socio-economic changes (economic development, population shifts) and modifications of the transportation system. They are frequently used by MPOs and State Transportation Agencies in cost/benefit analysis for major highway or transit investments (e.g. through the FTA New Starts program), for alternative analysis and prioritization in long range transportation plans, and for air quality conformity analysis.

Evaluating the suitability of an existing travel model will require due diligence to determine the resolution of the travel demand model, its ability to generate consistent aggregate estimates of future travel, and the compatibility of its modeling and scenario assumptions with the policy goals of the GHG analysis. Using an existing travel model is not guaranteed to support a "better" GHG analysis if the model's assumptions and limitations do not coincide with the needs of the GHG analysis. For example, evaluating multiple scenarios for a rapid analysis of many possible policy initiatives may be prohibitively expensive and time consuming if attempted with a complex travel model, and may not yield substantially better results for the purposes of initial screening than a well-developed strategic model such as FHWA's EERPAT.

Analysts who are considering using travel demand model outputs to support greenhouse gas analysis should make an effort to understand the available travel model - what its inputs are (and what they are not), what the model does with them, and how the model outputs are intended be interpreted. The remainder of this section reviews the structure of travel demand models, how they are applied, and what kind of information they generate. This overview is necessarily brief; additional resources that provide more in-depth discussions of the travel demand modeling process are discussed in Chapter 5 (page 63).

For decades, the standard technology for travel demand modeling has been what is called a trip-based model, or a "four step" (or sometimes "three step") model, and most regions that do travel demand modeling still operate such a model for regional planning purposes. The four "steps" include trip generation (how many people are traveling for different purposes), trip distribution (where and how far those trips go), mode split (which classifies the trips by mode of travel, including various transit modes or carpooling) and trip assignment (identifying the highway and transit facilities on which those trips occur). In a 3-step model, the mode split step is eliminated or simplified. Trips are typically analyzed by purpose (for example, home-to-work, or home-to-shopping, or even heavy trucks), reflecting the observation that people typically travel different distances and at different times of day for different purposes.

Trip-based models originally focused on reproducing summary vehicle counts (and transit ridership), often in the form of average annualized daily traffic or average weekday traffic (from which VMT estimates are derived). Trip-based models depend heavily on statistical analysis of regional traffic patterns. Because these models treat trips as independent statistical events, they rely heavily on implicit assumptions about the correlations between trips in different zones and for different purposes. Such assumptions are often insensitive to various types of demographic shifts (e.g. changes to travel patterns shrinking household size, or due to reduced vehicle ownership), and to certain changes in the transportation system (e.g. peak-period tolling which may induce shifts to different time periods as well as changes to vehicle occupancy).

Over the years, various enhancements to the basic four-step model have been applied, such as adjusting trip assignment estimates due to congestion (so trips will accrue on alternate routes when the most direct route is congested), and altering the distribution of trips to reflect the undesirability of destinations that are relatively inaccessible by any mode or that require traversal of highly congested facilities. In addition, such models are often split into time periods to permit more refined analysis of "within day" daily travel patterns (peak versus off-peak travel).

In addition, trip-based models (as well as the more complex tour- and activity-based models) have been used with dynamic traffic assignment (DTA) approaches to examine the dynamics of rush-hour congestion in more detail. But DTA outputs are not typically presented in the form of traffic or VMT summaries at the aggregate level required for GHG analysis and may require post-processing to generate consistent traffic estimates for GHG analysis.

Over the last two decades, new techniques for improving travel model sensitivity to linked trips and household dynamics have emerged. Commonly referred to as "tour-based" or "activity-based" models, the distinctive feature of such models is their focus on analyzing the joint behavior of individual travelers (tour- and activity-based models are thus collectively referred to here as "traveler based" models). Traveler-based models explore more detailed demographic impacts of system changes, by comprehensively linking trips to the characteristics of travelers and their local environment so that better account can be made of the influence of household interactions, variations in travel choice among individuals within a various demographic groups, and linked constraints on travel.

Such models often include considerably finer detail about the travel network and the local environment that individual travelers experience. They may also support detailed analysis of bicycle or pedestrian modes (and shifts to those modes due to system enhancements, which may be relevant for GHG analysis). Traveler-based models are often also implemented as "simulation models" , computing outcomes by mapping out likely sequences of correlated trips taken by synthesized individuals and households over a certain period of time. The simulation approach can be very useful for evaluating operational performance and correlated effects of related transportation system enhancements, but simulation increases the model runtime considerably compared to trip-based models. More importantly, such models may have statistical limitations with respect to estimating cumulative statistics such as average daily or annual VMT. For example: since simulations represent a snapshot of activity in a period of time and do not intrinsically develop estimates of cumulative activity - one day is not necessarily the same as another due to statistical variations in the inputs, and thus adding up a year's worth of days based on a one-day snapshot may magnify small statistical errors. Consequently, it may be desirable to perform multiple model runs with different "random seeds" (starting points) in order to develop an accurate estimate of total annual travel. Analysts contemplating the use of a simulation-based model should carefully consider the implications of the model's statistical assumptions and the intended uses of the model outputs.

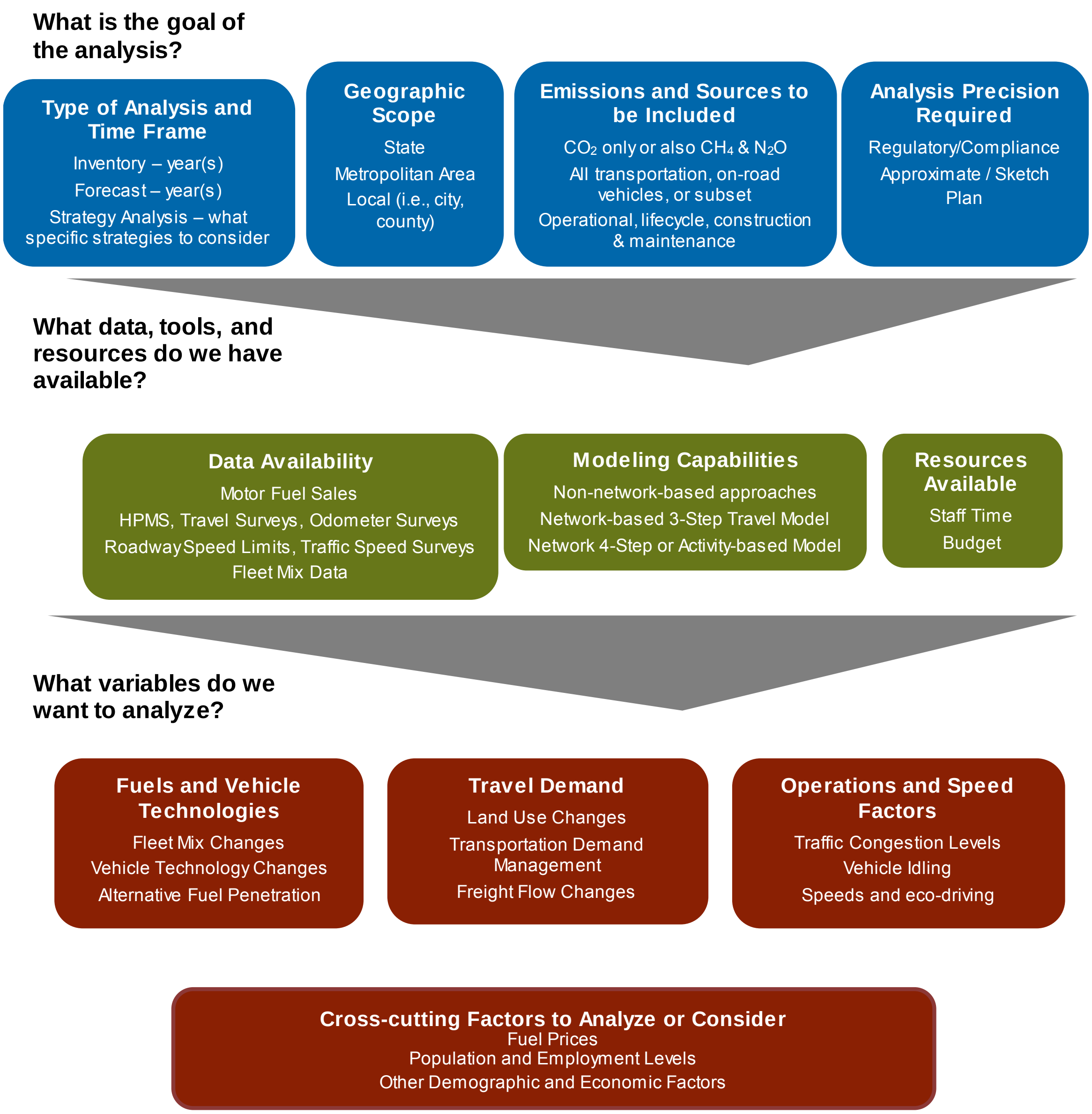
The question of statistical assumptions (and more broadly, the statistical uncertainty of any travel model) is by no means unique to simulation models. In important respects, traveler-based models using a simulation framework are expected to perform better than trip-based models, for example by being less susceptible to errors in core assumptions about trip linkages and the receptiveness of different elements of the population to improved performance on various system elements. But there is still little accepted science about how to estimate the uncertainty of forecasts. Though traveler-based models reduce the effect of hidden assumptions about trip linkages and response to system changes, they introduce a potential additional statistical burden of requiring multiple model runs in order to evaluate uncertainties in constructing detailed synthetic populations and in computing aggregate measures of the travel activity of such populations.

3. What Methodologies are Applicable for your Situation?

Given the variety of methods available for GHG analysis, it is important to recognize that not all methods are applicable in all circumstances. There are a number of key factors that affect the appropriate selection of a methodology. As shown in the figure below, key questions that the analyst should consider are:

- **What is the goal of the analysis?**
- **What data, tools, and resources do we have available?**
- **What variables do we want to analyze?**

Figure 6. Key Factors to Consider in Selecting a GHG Estimation Method



These factors are discussed below.

3.1. Analysis Purpose

The first question to consider is, "What is the goal of the analysis?" Answering this question will typically include several components, addressing:

- The type of analysis (a historical or current inventory, forecasts of future emissions, or analysis of specific strategies); tied into this issue is the time span of analysis (a single future year or cumulative emissions; a near-term forecast or long-term forecast).
- Geographic scope (state, regional, or local, as well as considerations regarding how emissions will be allocated);
- Emissions and sources included (light-duty vehicles only, total on-road sources, all transportation sources; direct travel-generated emissions or a full lifecycle of sources).
- Analysis precision required (this can range from extremely detailed for regulatory purposes to simply developing an initial estimate).

A state DOT or MPO might also want to consider whether it is interested in measuring the transportation activity of residents living within its jurisdictional boundaries or in all travel that occurs within its boundaries – including "through traffic" that does not originate or stop in the area. This can be a particular issue for areas that would like to allocate emissions to particular jurisdictions within their planning area (e.g., allocating transportation emissions to each county within a state), since allocating emissions between origins, destinations, and pass through areas can become complicated.

Type of Analysis

One of the most important factors in deciding on a methodology is to determine what type of analysis is to be conducted. As noted in Section 2, there are three common types of analyses, which often are conducted in combination.

- **Inventory** – Developing a GHG inventory generally relies upon measured or estimated data for a given base year or set of years. An inventory can be developed for different purposes, requiring different levels of sophistication. For instance, an inventory may simply be developed to estimate total GHG emissions for a state or region to understand baseline emissions. Alternatively, an inventory may be broken up into subcomponents, such as emissions by types of sources (e.g., light-duty vehicles, heavy-duty vehicles), different trip purposes (e.g., work-trips, non-work trips), or geographic levels (e.g., the county, city, or

Reconciling Fuel-based and VMT-based Estimates

At the state-level, GHG estimates may be developed by different state departments using different data. For example, an environmental department may develop a fuel-based inventory and projections as part of a multi-sector inventory, whereas a state DOT may develop estimates and projections using VMT-data. These methodologies may produce different results, and some areas have struggled to reconcile fuel-based inventories and VMT-based inventories/forecasts of GHG emissions. It is important to keep these concerns in mind early on so that agreement is made on a common approach, or procedures are developed to reconcile estimates developed using different methodologies.

neighborhood or traffic analysis zone level) to develop a more detailed understanding of sources and potential mitigation approaches. The specific purpose and intended use of the inventory will influence the types of methods to be used. For example, fuel consumption data methods may be sufficient for a basic inventory, but likely cannot be used to develop detailed inventories that break down emissions into sub-components, such as small geographic areas.

- **Forecasts** – Forecasting GHG emissions involves making assumptions about the future. The forecast year may be dictated by state legislation or executive level policy or associated with the final year of a long-range transportation plan or climate action plan, or the analysis may include several milestone years. Forecasts may be conducted to develop a baseline ("business as usual") projection or to analyze scenarios, such as alternative transportation plan options or different assumptions about future fuel prices and economic growth. If forecasts are required, then the approach used for the inventory and the forecasts normally should be compatible (e.g., using similar geographic boundaries, types of approaches and inputs) to allow for direct comparisons to isolate changes or to accurately assess GHG reduction strategies.

Recognize uncertainties associated with forecasts

Forecasting by nature involves more uncertainties than developing an inventory where "real world" data (e.g., on fuel consumption or vehicle travel, speeds, and other characteristics) are collected as inputs to calculating emissions. The further away the time horizon for analysis, the more uncertainty is typically introduced into the analysis, particularly as it relates to future fuel prices and vehicle technologies. GHG emissions are often analyzed using a long time horizon (e.g., 2050), and consequently, it may be useful to examine multiple scenarios for some of the key factors, such as vehicle technologies, which will affect emissions levels.

- **Strategy Analysis** – While standard transportation forecasting models often account for the effects of transportation investment and land use strategies, there typically will be the need for analyses of specific transportation strategies or packages of strategies, separate from the standard forecasting approach. These strategy analyses are conducted for transportation measures that can affect VMT, vehicle operations, or vehicle fleet characteristics, such as:
    - Pricing policies, including parking pricing, road pricing, carbon or mileage fees, vehicle feebates, or pay-as-you-drive insurance
    - Eco-driving training and educational programs
    - Compact development or other "smart growth" strategies
    - Expansion of the transit service area and frequency/quality of operations
    - Changes in transit fare policies
    - TDM or commute trip reduction
    - Intelligent transportation systems (ITS)
    - Investments in bicycle and pedestrian infrastructure and amenities
    - Truck stop electrification

- Alternative/low-carbon fuels purchases or incentives
- Reduced energy use and GHG emissions in transportation construction, maintenance, and agency operations

If a state DOT or an MPO wants to consider VMT reduction strategies or changes in congestion levels and speeds as part of forecasting GHG emissions, then understanding the level of accuracy and sensitivity of any model and assumptions they are using is essential. More sophisticated models will do a better job of accounting for factors like land use, urban form, and transit, bicycle, and pedestrian investments than simple travel forecasting models. If the model is not sensitive to certain factors, then separate analyses of strategies may be required.

Consider relationships among strategies

Different transportation strategies may have effects that are synergistic or antagonistic with each other, so it is important to consider a combination of factors when analyzing transportation strategies. However, if reduced fuel costs result in increased desire to drive then there may be a negative impact on VMT reduction strategies.

Geographic Scope

The geographic scope tends to influence the type of method that is selected for GHG modeling, based on data availability. At the state level, fuel-based methods are often used given the availability of state-level fuel consumption data; at the MPO level, fuel sales data may not be available.

Most MPOs have access to data and travel models that allow them to use a VMT-based method for estimating and forecasting GHG emissions. For those MPOs with conventional or advanced network-based models, VMT forecasting is often routine and built into existing regional transportation planning or air quality conformity processes.[15] However, GHG analyses can entail a much longer timeframe – e.g., out to forty or more years from the present year – which is inherently less certain than predicting VMT for the shorter timeframes required for conformity and transportation planning. Network-based travel models are typically not available at the state level. Absent a model, HPMS data are available for base year estimates and forecasts can be made using extrapolation based on past trends and population growth, and can be applied at both the MPO and state levels.

[15] It should be noted that most MPO models are based on a typical weekday and do not include weekend travel. Typically, a factor decided by the MPO is used to convert weekday VMT to annual VMT, including weekends, based on available travel data. It is good practice to account for weekend travel in GHG analysis, since emissions are affected by factors that differ between weekday and weekend conditions.

What GHG emissions should be "counted"?

In developing GHG inventories and forecasts, an important policy question to consider is "what emissions should be 'counted' or assigned to a state or region?" There are a couple of options:

- **Emissions associated with fuel sold within the boundaries**. This is the approach commonly used within fuel-based inventories; however, it raises some questions about whether a state or region should be responsible for fuel that is sold in an area but is used outside of it.
- **Emissions from all travel on the transportation system within the boundaries.** This is the approach that is applied for transportation conformity purposes – emissions from all travel on the roadway network, whether due to local traffic or interstate through trips, are analyzed and reported.
- **Emissions generated by households and/or businesses within the boundaries.** A state DOT or MPO might instead be interested in focusing on GHG emissions due to the transportation activity of residents living or working within their jurisdictional boundaries (possibly including business and freight travel, as related to household goods consumption), excluding the effect of "through trips." This can be useful for areas that would like to allocate emissions to particular jurisdictions within their planning area (e.g., allocating transportation emissions to each county within a state). In this case, it is necessary to understand trip origins and destinations, and assign a portion of emissions to each, while removing the effect of trips that entirely pass through an area.

There are some advantages and challenges to each approach, so it will be important to agree upon what is the most desired way of counting emissions.

Emissions and Sources Included

Those conducting a GHG analysis need to determine whether their analysis will incorporate all GHGs or only CO_2. Not all methodologies presented in the Handbook consider all GHGs – for instance, fuel-based methods are limited to only considering CO_2 emissions, while VMT-based methods can account for all major transportation emissions sources. If an agency would like to or is required to consider all GHGs, this may determine which methodology is selected or whether additional analysis is required.

In addition, it is important to consider what sources of emissions are included: all transportation sources, all on-road vehicles, or only certain types of motor vehicles, such as light-duty vehicles (e.g., automobiles and light-duty trucks, such as pick-up trucks, sport utility vehicles, and minivans). Finally, while this Handbook is primarily concerned with emissions from fuel combustion during vehicle operation (pump-to-wheel emissions), it is important to acknowledge that all transportation fuels and modes have some sort of upstream emissions associated – notably, the energy used to produce, refine, and transport fuel. However, there is not currently an accepted or widespread methodology for quantifying lifecycle emissions from the transportation sector. Two options applicable to particular strategies -- the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model for alternative fuels and the American Public Transportation Association's (APTA) for electric emissions from transit -- are presented in Section 8.1.

Analysis Precision/Accuracy Required

An agency that requires a precise and accurate analysis (e.g., an area subject to GHG reduction targets or under regulatory requirements to analyze GHG emissions and strategies) will select a more sophisticated methodology (e.g., a methodology that requires a robust and detailed analysis or forecast of VMT, estimates vehicle fleet mix, and uses an emissions model such as MOVES or EMFAC.) As a case in point, California's Senate Bill (SB) 375 requires the use of model-based VMT forecasts in combination with EMFAC to estimate GHG emissions. The VMT estimates in this example must be stratified by speed bin and include special trip type accounting to isolate internal versus external trips. An agency that wants to have a general sense of GHG emissions in their region outside of any regulatory context may select a less precise methodology. For example, a less precise approach could be to use simple spreadsheets to generate GHG emissions (e.g., use vehicle, household, and land use data to generate VMT and apply emissions factors). Another option could be to use VMT estimates with MOVES, relying on default information and other flexibilities within the model to streamline the analysis, as described in EPA guidance.[16]

3.2. Availability of Data, Tools, and Resources

The availability of data, existing tools that are being used, and the resources available for analysis, including technical expertise with models, are also important considerations in selecting a method to use and deciding how to apply that method. For instance, a simple spreadsheet analysis may be selected by smaller agencies with limited staff, resources, and modeling experience, whereas a sophisticated model may be utilized by agencies that have experience in modeling and the resources to run the model.

Available Data or Ability to Collect Data

As noted earlier, fuel data are most often readily available at the state level, but often not available at the MPO level. As a result, using a fuel-based methodology is much more common at a state level than at a metropolitan area level. Moreover, MPOs are more likely to select a VMT-based methodology, particularly because many large MPOs already have experience using VMT data to generate emissions levels through conformity experience. Those MPOs that have experience with conformity will likely already have VMT as well as fleet data available – although predictions of future VMT and fleet characteristics – especially over long timeframes – is still necessary. States and smaller MPOs that do not have a travel demand model to generate VMT or information on factors such as vehicle speeds may opt to choose a method that relies on vehicle, household, or land use data, or HPMS data.

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[16] Refer to EPA's latest guidance on using MOVES to estimate GHG emissions, found at: http://www.epa.gov/otaq/stateresources/ghgtravel.htm.

Understand Data Quality

In addition to knowing what data are available, it is important to consider the quality of data and what the data represent. For instance, in most areas, data on the activity of heavy-duty trucks is limited, and it is often not possible to distinguish between light commercial and passenger trucks based on data available from vehicle registration data, even though this distinction can have a major impact on vehicle activity and emissions. Since estimates of VMT from the Highway Performance Monitoring System (HPMS) are derived from traffic counters on sample segments, these estimates are subject to sampling error. Moreover, standard methods are used to factor traffic counts for a number of days to represent an average annual daily traffic count for a roadway segment, and these adjustments have some level of error associated with them.

Existing Travel and Emissions Modeling Capabilities

Another key factor in selecting a method for analyzing GHG emissions is what modeling capabilities either already exist within the agency or could be easily obtained and applied. Nearly all large and mid-size MPOs (those with population greater than 200,000) use a network-based travel model. However, most state DOTs do not have a statewide travel model, and some smaller MPOs (those with population less than 200,000) may not. In a 2004 survey, 15 percent of small MPOs reported no modeling capabilities at all.[17] According to a recent Government Accountability Office (GAO) survey, about half of the MPOs do their own travel modeling, while the rest rely on consultants or their state DOT.[18]

In general, larger MPOs are more likely to develop and operate models in-house, and smaller MPOs, if they use a model, are more likely to require outside technical assistance. Some of the most sophisticated MPOs are using or developing more advanced activity-based travel models. The capabilities of existing travel models will determine the ability to conduct GHG scenario analyses and whether off-model approaches are needed to analyze strategies.

In addition, experience with transportation conformity and emissions analysis can be a key factor in selecting a method to use. Areas conducting conformity analysis typically will be able to apply the same methods they use for criteria pollutant analysis for analyzing GHG emissions, and rely upon most of the same data sources and models; however, some additional analyses may be conducted specific to GHGs. For instance, conformity methods are commonly based on a typical weekday, and additional analyses could be conducted to account for weekend travel. Areas not subject to conformity likely will have limited experience collecting data inputs used in emissions models, and may rely on simpler approaches.

[17] Transportation Research Board, "TRB Special Report 288: Metropolitan Travel Forecasting – Current Practice and Future Direction." October 2007.

[18] U.S. Government Accountability Office, "Metropolitan Planning Organizations: Options Exist to Enhance Transportation Planning Capacity and Federal Oversight," Report GAO-09-868, September 2009.

MOVES Model Preferred

It should be noted that beginning in March 2013, MOVES will be required for all new regional conformity analyses. Many states and regions are currently in the process of transitioning to MOVES from previously used models. For this reason, and other advantages discussed below, ***MOVES is the preferred model for estimating GHG emissions***, but it is not mandatory for GHG estimation. Additional explanation of the preferred role of MOVES in GHG emissions estimates is provided in Section 5.3.

Time and Budget Resources

The time and budget available for GHG analysis will influence the type of analysis selected. Developing a GHG inventory and forecast can be time intensive and may require a significant level of effort depending on the method selected and the experience of the agency. Some MPOs only have a few staff on hand and limited budgets for GHG analysis, whereas other MPOs and state DOTs have a larger staff base available to perform a GHG analysis. As noted above, experience with conformity is a factor that may influence the time and budget resources necessary for GHG analysis. MPOs that have experience with conformity may already have the modeling capabilities and familiarity with emissions modeling tools such as MOVES for GHG analysis, which will reduce the time and budget necessary for GHG analysis. However, MPOs that do not have conformity experience may have to spend more time learning, developing, or using tools for GHG analysis, or may need to reach outside the agency for assistance.

3.3. Variables and Strategies of Interest

It is important to consider whether the methodology enables analysis of all the variables or factors of interest when considering any given transportation strategy.

Fuel and Vehicle Technologies: Strategies that influence the future fleet mix, vehicle technologies, and alternative fuels are important because they have a significant impact on emissions. Although these factors are largely dependent upon national and state policies outside of the transportation planning process (such as federal Corporate Average Fuel Efficiency standards), states and MPOs have some opportunities to support and advance strategies, such as incentives for purchasing fuel efficient vehicles. Moreover, assumptions made about future vehicle and fuel technologies will affect the GHG reduction effectiveness of VMT reduction strategies.

Travel Demand: For strategies aimed at reducing VMT, it is important to understand how the VMT forecasts are developed, since most travel forecasts, whether developed through a network-based travel demand model or non-network based approaches, lack the capability to evaluate many travel strategies. Specifically, many travel models are unable to address strategies such as neighborhood-scale land use and urban design, and employer site-based TDM strategies.

Vehicle Operations and Speeds: Transportation operations and congestion relief strategies, and eco-driving programs, affect emissions through changes in vehicle operations, speeds, and/or congestion-related delays. In order to assess the effects of these changes on GHG emissions, the approach needs to account for changes in vehicle speeds or idling, and the emissions factors need to account for these factors as well (e.g., not just applying a simple emissions factor to all VMT without regard to speeds).

Cross-cutting Factors: Exogenous factors related to the economy, fuel prices, and demographic and societal factors can impact transportation emissions, particularly when developing long-range forecasts. For instance, while states can influence fuel prices through taxation, fuel prices are largely driven by global market forces. They are subject to high levels of uncertainty, and have effects on both vehicle travel and vehicle purchase decisions.[19] Therefore, when strategies are analyzed, it would be appropriate to conduct sensitivity analyses for these variables (e.g., using high and low values for future fuel prices).

3.4. Identifying an Appropriate Methodology

In order to identify appropriate methods for your circumstances, it may be helpful to review several sections of the Handbook. Since most sections discuss a range of different levels of sophistication for each type of methodology, there are often multiple options to consider in terms of data inputs and applications of the approach. Each section begins with a summary table highlighting applicability at different geographic levels and key attributes. The table below provides a high-level summary, which may be helpful to provide an initial starting point for selecting a methodology. Each methodology begins with a summary box that highlights key considerations.

[19] According to data from the U.S. Energy Information Administration, *Annual Energy Outlook 2011:* light-duty vehicle CO_2 emissions in 2030 would range from 15 percent below to 13 percent above its baseline ("reference case") forecast under a high oil price and low oil price scenario, respectively.

Table 2. Summary Table to Assist Users in Identifying Appropriate Handbook Sections

Type of Method	Methodology (Handbook section)	Purpose	Geographic Scope	Sources Included	Travel Model Required	Data, Tools, and Resources Required	Strategies Considered
Fuel-based Methods	*Fuel-based inventory (Section 4.1)*	Inventory	State (typically)	May include all transport sources	No	Fuel sales data, fleet mix (optional)	N/A
	Fuel-based forecasts (Section 4.2)	Forecast	State (typically)	May include all transport sources	No	Fuel projections	May account for economic and vehicle technology factors, including effects of fuel prices and regulations. (Not designed to address individual transportation investments or strategies.)
VMT-based Methods: Estimating VMT	*Relying on Vehicle, Household, or Land Use Data (Section 5.1) to estimate VMT*	Inventory, forecast, or strategy analysis	State, MPO, local	On-road vehicles	No	*Vehicle data*: odometer data, vehicle stock data *Household travel data*: results from household travel survey *Land use data*: land use areas, trip generation rates, demographic and socioeconomic data	May account for land use, demographic changes, and vehicle ownership changes. (Not designed to address individual transportation investments or strategies.)
	Relying on HPMS data and/or a network-based travel model (Section 5.2) to estimate VMT	Inventory, forecast, or strategy analysis	State, MPO, local	On-road vehicles	Applicable with or without a model	*HPMS*: HPMS VMT data, VMT by vehicle type and within vehicle type groupings *Network Model*: network model output	Travel model forecasts may account for changes in transportation investments, land use, and pricing. (Not typically able to address some types of TDM measures, operational strategies, and eco-driving.)

VMT-based Methods: Estimating Emissions	*Developing Emissions Factors & Emissions Inventories (Section 5.3)*	Inventory or forecast	State, MPO, local	On-road vehicles	Applicable with or without a model	*Simple Factors*: VMT *Look-up Tables*: VMT, fleet characteristic s, speed bins (optional) *MOVES or EMFAC model*: VMT by vehicle type, vehicle population and age distribution, VMT by speed bin	MOVES and EMFAC can account for effects of changes in vehicle travel and congestion and speeds. MOVES or EMFAC can be used with VMT estimates from any source; can account for any transportation strategy that is incorporated in the VMT estimate although it may not always be possible to distinguish the distinct impacts of individual strategies.
Alternative GHG Estimation Approaches	*Commodity Flow Based Methods to Estimate Freight Truck Emissions (Section 6.1)*	Inventory or forecast	State, some regions, possible at county-level	Freight trucks	No	Commodity flow estimates, truck survey data (optional) May require development of OD truck trip table	Largely designed for basic inventories or forecasts, accounting for changes in goods movement. (Not designed to address strategies affecting time or location of truck travel (e.g., peak hour restrictions).
	Energy and Emissions Reduction Policy Analysis Tool (EERPAT) (Section 6.2)	Scenario/strategy analysis	State	On-road vehicles	No	Demographic, land use, and strategy-related data required as inputs.	Land use, transportation demand, vehicle technology, fuels, and price changes.

Specific Transp. Strategy Analysis Methods [note: many of these tools estimate travel or fuel consumption effects, and must be combined with methods to estimate GHGs]	*Transportation demand management strategies (Section 7.1)*	Scenario/strategy analysis	State, regional, county-level	On-road vehicles	Applicable with or without a model	Sample tools and approaches include: COMMUTER, TRIMMS, and BAAQMD tool	VMT-reduction and travel time shift strategies, such as transit improvements, ridesharing, bicycle and pedestrian improvements, transit and parking pricing, and employer trip reduction.
	Land use strategies (Section 7.2)	Scenario/strategy analysis	Regional or county-level (typically)	On-road vehicles	Applicable with or without a model	Sample tools and approaches include: INDEX, PLACE3S, URBEMIS, Sustainable Communities Model, MetroQuest, and CommunityViz	Land use changes, including land use mixing, increased density, and pedestrian accessibility. Impact of “4 Ds” (density, diversity, design, and destinations).
	Transportation system management and eco-driving strategies (Section 7.3)	Scenario/strategy analysis	State, regional, county-level	On-road vehicles	Applicable with or without a model	Sketch planning tools, deterministic tools, and traffic simulation tools. Sample tools include the ITS Deployment Analysis System (IDAS) and Screening for ITS (SCRITS).	Traffic surveillance, work zone management, electronic toll collection, traffic incident management, road weather management, emergency management, and traveler information services.
	Freight strategies (Section 7.4)	Scenario/strategy analysis	State and regional	Freight trucks	Applicable with or without a model	Sketch analyses, US EPA SmartWay Transport Partnership tools	Idle reduction programs and policies, mode shift strategies, and strategies affecting pricing and time or location of truck travel.

Additional Considera-tions in GHG Analysis	*Lifecycle Emissions Analysis Methods (Section 8.1)*	Inventory or forecast	State, regional, possible at the county-level	On-road vehicles and related up-stream sources (e.g., fuel processing) and electric utilities	Applicable with or without a model	*Alternative fuels using GREET model*: fuel mix, inventory results *Electric Transit Emissions*: ridership, passenger load	Fuel and vehicle technology strategies.
	Planning Level Analysis of Construction and Maintenance Emissions (Section 8.2)	Inventory or forecast	State, regional, possible at the county level	Infrastructure construction and maintenance emissions	Applicable with or without a model	Type and length of activity (e.g., lane miles constructed)	Alternative construction materials and techniques.

4. Fuel-based Methods

This section describes fuel-based methods for developing inventories (past and current estimates) and forecasts of future emissions. These methods generally are most applicable at the state level, are designed to provide only estimates of CO_2 (not other GHGs), and may be used to provide estimates for both on-road and off-road sources.

4.1. Fuel-based Inventory Methods

This section describes fuel-based inventory methods. Two variations of this methodology are shown - a basic approach that simply calculates CO_2 emissions by fuel type and a more refined approach that involves additional steps to allocate those emissions by vehicle type or geographic area.

Table 3. Selection Criteria for Fuel-based Inventory Methods

Selection Criteria	Fuel-based Methodologies	
	Basic Approach (e.g., EPA SIT)	Refined approach (e.g., allocation to vehicle types)
Analysis Type	Inventory	Inventory
Geographic Scope Covered	State*	State*
Analysis Precision	Approximate (lower precision for smaller geographic areas) – does not directly account for location of travel activity	Approximate, but includes more detail – does not directly account for location of travel activity
Data Needed	Motor Fuel Sales	Motor Fuel Sales, Activity Mix by vehicle types and corresponding fuel economy
Necessary Analytical Capabilities	Limited – existing spreadsheet tool	Moderate – some data manipulation required
Level of Resources Required (i.e., staff/budget)	Limited – existing spreadsheet tool	Moderate – some data manipulation required
Capable of Addressing Vehicle Technology/ Fuels Changes	N/A	N/A
Capable of Changes in Travel Demand	N/A	N/A
Capable of Addressing Changes in Vehicle Speeds and Operations	N/A	N/A

**Note: While fuel-based methods can also be applied at the regional or county level in some cases, the applicability of fuel-based methodologies at a regional or county level depends on the level of geographic detail provided in state fuel sales data and the assumption that such fuel is used in the same area in which the sales occur or, at least, are attributed to the sales location. Some states provide a regional breakdown, but most do not.*

Description

A fuel-based inventory involves calculating CO_2 emissions based on fuel data. This relies on a direct relationship between fuel carbon content and emissions of CO_2 during combustion, and is not applicable for other GHGs. Fuel-based inventories are typically developed at the state level since state-level fuel sales data are generally available from fuel tax records; analysis at a state or larger level also minimizes errors due to any mismatch between fuel purchase and use locations. This method includes an implicit assumption that emissions can be attributed to purchase location. Most often, fuel-based inventories have been developed as part of a multi-sector GHG inventory, which may be developed in connection with a state climate action plan. Fuel-based methods may be used at a county or regional level if fuel sales data are available, but are less appropriate at those levels because it may not be reasonable to assume that fuel use and purchase locations coincide.

What is a State Climate Action Plan?

A state climate action plan identifies strategies that a state will use to reduce GHG emissions and address climate change. As part of a climate action plan, a state will often develop a GHG inventory that includes emissions from multiple sectors, including: residential, commercial, industrial, transportation, electric utilities, waste management, etc.

To develop a fuel-based inventory, states typically estimate CO_2 emissions by obtaining historic fuel use data by fuel type (e.g., motor gasoline, diesel, etc.) and then applying emissions factors to convert fuel use into CO_2 emissions, which are directly proportional to fuel consumption for each fuel type.

The EPA's State Inventory Tool (SIT) utilizes this approach, and is a useful tool for states interested in developing such an inventory. If additional data are available, the analyst may also take the resulting estimates of CO_2 emissions by fuel type and develop estimates of emissions by source, such as vehicle type, or to assign emissions to specific geographic areas.

As noted above, since N_2O and CH_4 are not directly proportional to fuel consumption but depend on engine operating conditions and emissions control technologies, fuel-based methods are not used to calculate emissions of these gases.

Strengths and Limitations

Fuel-based inventory methods tend to be most useful for developing a simple GHG inventory, given limited data requirements and analysis techniques, particularly for state-level analysis. Key strengths and limitations of the approach are noted in Table 4.

Table 4. Strengths and Limitations of Fuel-based Inventory Methods

Strengths	Limitations
• Relatively simple and requires limited inputs – Data on fuel consumption are generally available at a state level. • Can account for all transportation modes – Data on fuel consumption for aviation (at the location where fueling occurs) and other modes can be included[20], and these estimates are available in the SIT. • The SIT was developed specifically for state-level emissions inventory development and provides an easy to use tool for calculating state-level emissions.	• Fuel sales data may not accurately reflect fuel consumption within a state or region due to factors such as interstate freight movements, cross-border traffic, and development patterns along boundaries. • Emissions estimates are provided by fuel type, but these figures may not be comparable to other data used in the transportation planning process, including projections that are based on travel data. • Additional steps are required to develop estimates by vehicle type (e.g., autos, light-duty trucks, heavy-duty trucks, buses). Analyses to apportion fuel consumption to each vehicle type or to lower geographic levels generally rely on VMT data and vehicle fleet information, but this adds additional complexity.

As noted in the table above, one of the key limitations of a fuel-based inventory is the potential disconnect between the place of fuel sales and the location of the travel activity and/or generators of emissions. For example, the Portland metro region has developed a fuel-based GHG inventory, but the inventory misses emissions from some of the travel generated by the region's households and businesses where fuel is purchased outside the region.[21]

Even at the state level, this can be an issue, particularly for smaller states that have a lot of cross-state traffic or where fuel tax rates differ significantly across state boundaries. For instance, given its size and the significant amount of through-traffic it experiences, Maryland DOT has found that fuel sales do not provide as accurate a basis for estimating GHG emissions as VMT-based methods, given the amount of cross-border traffic.[22] Similarly, New York State discovered discrepancies between developing GHG estimates based on fuel sales data and VMT data in its 2003 GHG Inventory. Working with data from the Energy Information Administration (EIA) and FHWA, New York found that VMT had grown 20% between 1990 and 2000 while fuel sales had declined 4%. The discrepancy suggested that fuel being consumed in New York was being purchased out of state. A review of regional VMT and fuel sales data for

[20] This approach, attributing to trip origin, will be consistent with ACRP and IPCC guidance (ACRP, 2009) if aircraft fuel at each departure location.

[21] Information obtained from interview with Mike Hoglund of Portland Metro, 2011."

[22] This information was obtained from personal conversation with Howard Simons, Maryland Department of Transportation. For more information, see the "Maryland Climate Action Plan: Maryland Department of Transportation Draft 2012 Implementation Plan – Appendix," Maryland Department of Transportation, April 11, 2011. http://www.mdot.maryland.gov/Planning/Plans_Programs_Reports/Documents/Climate_Change_2011_Appendix.pdf.

New Jersey found the opposite in that state: fuel sales overestimated VMT. New York therefore concluded that the discrepancies were caused by vehicles driven in New York that refueled in New Jersey.[23]

Key Steps and Data Options

Step 1: Estimate transportation fuel consumption. For on-road vehicles, the most common fuel types are gasoline and diesel, although compressed natural gas (CNG), liquefied petroleum gas (LPG), and other fuels may also make up a portion of energy used in transportation. Fuel consumption data are typically based on state fuel tax records, but may be taken from various sources, including:[24]

- FHWA's Highway Statistics Report (for on-road fuel use),
- The U.S. EIA's State Energy Consumption, Price, and Expenditure Estimates (for all transportation modes),
- EPA's State Inventory Tool (for all transportation modes), or
- State energy reporting systems or fuel tax records.

Output: *Fuel consumption by fuel type.*

Step 2: Multiply by emission factor to estimate emissions. Fuel consumption of each fuel type is multiplied by the emission factor, based on the carbon content of each fuel type, to estimate emissions. Emissions factors are available from the EIA and the U.S. EPA.[25] Nationally, because of the use of reformulated gasoline and seasonal fuel blends by some regions, the carbon content of motor gasoline differs over time and among different locations based on the different mandated oxygenate content of gasoline. Carbon dioxide emissions factors from EIA for transportation fuels are listed in the table below. Emission factors can be presented in different formats (CO_2 per unit of volume, CO_2 per million Btu), so the user must take care to apply the correct emission factors.

Be aware: Emissions Factors for Ethanol and Other Biofuels

Commonly used emission factors show zero CO_2 emissions from ethanol and other biofuels, since the carbon released during combustion of these fuels is assumed to be offset by the atmospheric carbon consumed during growth of feedstocks. However, it is important to note that there are upstream emissions associated with the production and transport of biofuels, as from fossil fuels, which would be considered as part of a more comprehensive lifecycle assessment of GHG emissions.

23 Center for Clean Air Policy, *Recommendations to Governor Pataki for Reducing New York State Greenhouse Gas Emissions,* Washington, DC, 2003, pp. 162-163.

24 All national (and generally other state) sources depend on state fuel tax records.

25 EPA's Office of Transportation and Air Quality provides information on GHG emissions per gallon of fuel consumed by a typical passenger vehicle, available at: http://www.epa.gov/otaq/climate/documents/420f11041.pdf.

Table 5. EIA Carbon Dioxide Emission Factors for Transportation Fuels

Transportation Fuel	Emission Factors		
	Kilograms CO_2 Per Unit of Volume		Kilograms CO_2 Per Million Btu
Aviation Gasoline	8.32	per gallon	69.19
Biodiesel			
-B100	0	per gallon	0
-B20	8.12	per gallon	59.44
-B10	9.13	per gallon	66.35
-B5	9.64	per gallon	69.76
-B2	9.94	per gallon	71.80
Diesel Fuel	10.15	per gallon	73.15
Ethanol/Ethanol Blends			
-E100	0	per gallon	0
-E85	1.34	per gallon	14.79
-E10 (Gasohol)	8.02	per gallon	66.30
-M100	4.11	per gallon	63.62
-M85	4.83	per gallon	65.56
Motor Gasoline	8.91	per gallon	71.26
Jet Fuel, Kerosene	9.57	per gallon	70.88
Natural Gas	54.60	per thousand cubic feet	53.06
Propane	5.74	per gallon	63.07
Residual Fuel	11.79	per gallon	78.80

Source: U.S. Energy Information Administration, Emissions Factors, available at: http://www.eia.gov/environment/data.cfm

Most areas use ethanol as an oxygenate in gasoline. In the development of a multi-sector GHG inventory, the carbon content of ethanol and other biofuels is typically assumed to be zero, since the carbon released during combustion of these fuels is assumed to be offset by the atmospheric carbon consumed during growth of feedstocks. Thus, CO_2 emissions factors can be estimated based on the percentage of ethanol in gasoline, and by calculating a weighted average.[26] Note that, as with fossil fuels, the "upstream" emissions associated with biofuel production and transport can be significant, so any comparison of GHG emissions among transportation fuels done on a lifecycle basis can provide additional insight (see Section 8.1). Alternatively, data on fuel consumption can be entered into the SIT (see text box below).

Output: *CO_2 emissions by fuel type*.

[26] For instance, the emissions factor for E10 (gasohol), which is 90 percent motor gasoline and 10 percent ethanol is calculated by multiplying the motor gasoline emissions factor by 0.90, and assumes zero emissions from ethanol. See p. A-63 of Annex 2 of the 2011 U.S. Greenhouse Gas Inventory for the carbon content of oxygenates. http://epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Annex_Complete_Report.pdf.

Common Tool - EPA's State Inventory Tool

The most commonly used tool for developing a fuel-based inventory at the state-level is EPA's State Inventory Tool (SIT). The SIT is a spreadsheet model that helps states to estimate their GHG emissions from all sectors (e.g., on-road gasoline, on-road diesel, aviation, rail, marine, and natural gas/other). The SIT provides the option of using state-specific data or using default data that is generated by Federal agencies and some other sources. This tool uses fuel sales and default data to estimate CO_2. Based on its structure, the SIT approach is most appropriate for developing a transportation GHG inventory as part of a broader statewide inventory development process for all sectors, and for statewide analyses that do not require detailed breakdowns of transportation GHG emissions by transportation mode or by local jurisdiction.

The basic steps for using the SIT model include:

1. Select a State. Once the state is selected, the SIT tool will automatically reset for the state default data and assumptions that may be used in subsequent steps.

2. Fill in the Variables Used Throughout the Model. Users must select appropriate factors for several key variables used to estimate CO_2 (e.g., combustion efficiencies, carbon contents). Default data may be selected, or user-specific data may be entered. For defaults, consumer efficiencies are assumed to be 100 percent for petroleum fuel and the carbon content coefficient defaults are from the Greenhouse Gas Reporting Program.

3. Complete the Bulk Fuel Consumption Data Worksheet. Default data will automatically populate by fuel type, but can be overwritten with state-specific fuel consumption data.

4. View Emission Estimates on Sector Worksheet. The basic equation for estimating emissions in this model is:

Emissions (million metric tons of CO_2 Equivalent) =
Consumption (BBtu) x Emission Factor (lbs C/BBtu) x 0.0005 short ton/lbs x Combustion Efficiency (% as a decimal) x 0.9072 (Ratio of Short Tons to Metric Tons) ÷ 1,000,000 x (44/12) (to yield $MMTCO_2E$)

5. Review Summary Information. Provides total carbon emissions in million metric tons of CO_2 equivalent ($MMTCO_2E$) by fuel type.

For more information about the U.S. Environmental Protection Agency State Inventory Tool, see: http://www.epa.gov/statelocalclimate/resources/tool.html

Step 3: Disaggregate Emissions by Vehicle Type (optional). To develop a more refined CO_2 emissions estimate, an agency could disaggregate collected fuel sales data by vehicle type (e.g., automobiles, heavy-duty trucks). This could be useful for inventories that want to attribute emissions to household vehicles versus commercial vehicles and public transportation, for example.

One approach is to assume that a state's vehicle fleet is distributed like the national fleet. In this case, national data on the percent of each type of fuel consumed by vehicle type can be used to disaggregate the data. Data on fuel type shares for each type of vehicle are available from the U.S. Department of Energy's Transportation Energy Databook, Appendix A, at: http://cta.ornl.gov/data/index.shtml. By multiplying the quantity of fuel sold for each fuel type by the share of each fuel used by each vehicle type, the user can estimate fuel use by vehicle type. If the user has more detailed data available on the makeup of a state's vehicle fleet by vehicle type and/or fuel type, then these data could also be used. For instance, detailed data on a state's vehicle fleet can be obtained from a Department of Motor Vehicles (DMV) registration file. These data could be combined with estimates of mileage accumulation by vehicle type from MOVES to estimate a distribution of fuel by vehicle type.

Output: *CO_2 emissions by vehicle type*

Step 4: Disaggregate Emissions by Geographic Area (optional). An agency also may attempt to disaggregate emissions by geographic area (e.g., county or local area). Data may be available from fuel tax records to estimate fuel sales at this level, or data on travel patterns from a travel model, household travel survey, or HPMS may be used as a basis for allocating emissions to different geographic areas.

Output: *CO_2 emissions by county or other geographic area*

Example: Vermont statewide GHG inventory using SIT

The Vermont GHG inventory includes estimates of emissions for 1990 through 2008,[27] and was developed using SIT software and methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the transportation sector. EIIP is a jointly sponsored effort between EPA and the National Association of Clean Air Agencies (formerly State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO). Among other initiatives, the EIIP has developed preferred methods for collecting data and calculating emissions and developing more consistent documentation.[28] In Vermont, CO_2 emissions factors for on-road vehicle fuel in units of pounds (lb) per million British thermal units (MMBtu) were used. The default data for motor gasoline within SIT were replaced with gasoline consumption estimates from state tax data provided by the Vermont Department of Motor Vehicles and Legislative Joint Fiscal Office.

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[27] Vermont Greenhouse Gas Emissions Inventory Update: 1990 – 2008. http://www.anr.state.vt.us/anr/climatechange/Pubs/Vermont%20GHG%20Emissions%20Inventory%20Update%201990-2008%20FINAL_09272010.pdf.

[28] U.S. EPA, "What is the Emission Inventory Improvement Program?" http://www.epa.gov/ttn/chief/eiip/whatis.html.

4.2. Fuel-based Forecasting Methods

This section describes fuel-based forecasting methods. Two approaches are noted: a basic approach that forecasts CO_2 emissions by fuel type, and a more refined approach that involves forecasting fuel consumption by vehicle type.

Table 6. Selection Criteria for Fuel-based Forecasting Methods

Selection Criteria	Fuel-based Methodologies	
	Basic Approach (e.g., EPA SIPT)	Refined approach (e.g., by vehicle type)
Analysis Type	Forecast	Forecast
Geographic Scope	State*	State*
Analysis Precision	Limited – based on national trends and does not include state-specific vehicle/fuel parameters	Limited, depending on level of sophistication in approach
Data Needed	Fuel sales forecasts	Fuel sales forecasts, VMT by vehicle type projections
Necessary Analytical Capabilities	Limited – simple spreadsheet analysis or use of existing tool SIPT	Moderate – some data manipulation required for SIT outputs or to disaggregate fuel sales data
Level of Resources Required (i.e., staff/budget)	Limited – use of SIPT or spreadsheet analysis with available data	Moderate – additional data processing required
Capable of Addressing Vehicle Technology/ Fuels Changes	No	Yes
Capable of Addressing Changes in Travel Demand	Limited – Only if incorporated in VMT projections	Limited -- Only if incorporated in VMT projections
Capable of Addressing Changes in Vehicle Speeds and Operations	No	No

**Note: While fuel-based methods can also be applied at the regional or county level in some cases, the applicability of fuel-based methodologies at a regional or county level depends on the level of geographic detail provided in state fuel sales data and the assumption that such fuel is used in the same area in which the sales occur or, at least, are attributed to the sales location. Some states provide a regional breakdown, but most do not.*

Description

Fuel-based GHG forecasts can be developed based on historical trends or forecasted variables. These forecasts can be very simple, relying largely on national forecasts and historic al trends, or can involve more detailed analysis. EPA's State Inventory Projection Tool (SIPT) is an option for developing simple forecasts of GHG emissions. Projections are based in part on projections of fuel consumption reported in EIA's *Annual Energy Outlook* by sector and region.[29] Other characteristics – such as fleet composition, the state's proportion of national transportation fuel use, and control technology distribution – are assumed to remain constant in the future. It should be noted that this assumption reduces the accuracy of forecasts, particularly for long-term forecasts.

Given the extent to which national and state-level strategies, fuel prices, and other factors may affect vehicles and travel in the future, more accurate forecasts of fuel consumption would require use of a more refined forecasting approach that accounts for VMT-based growth factors (e.g., population, economic growth) and changes in driving conditions and behavior (e.g., congestion/speeds/eco-driving), as well as information on changes in vehicle fuel economy and the carbon content of fuels.

Many states that have developed a statewide GHG inventory and forecast have used statewide VMT projections (usually taken from the state DOT) together with vehicle fuel economy projections (usually taken from DOE's *Annual Energy Outlook*) to calculate growth factors for on-road gasoline and on-road diesel. The growth factors are multiplied by the fuel-based GHG emission inventory for the base year to forecast statewide vehicle GHG emissions out to 2020 or beyond.

Consider Existing Fuel Forecasts and Needed Enhancements

Some states have developed vehicle fuel forecasting methods or tools, which can be used for GHG forecasts. Although state DOTs often estimate future fuel sales as part of their fuel tax revenue projections, in many cases, these methods are simplistic and do not account for many factors that influence GHG emissions. Other states have relatively sophisticated methods. For example, Washington State DOT (WSDOT) has developed a new VMT forecasting model in response to state climate change regulations. The previous WSDOT VMT forecasting tool was simplistic and used for revenue forecasting. WSDOT assessed its VMT forecasting method and determined that it was inadequate for long-term VMT forecasts, in part because the model did not capture the flattening of VMT per capita that has been observed. As a result, WSDOT developed an econometric VMT forecast model that accounts for the state's employment, motor vehicle registrations, and gas prices.

For more information, see: *http://www.wsdot.wa.gov/NR/rdonlyres/380A1F61-EC09-478D-990C-4AA9B9292AFE/0/VMTForecastWorkGroupSummaryMay2010final.pdf*

[29] U.S. Energy Information Administration, "Annual Energy Outlook 2011 – Transportation." http://www.eia.gov/forecasts/aeo/sector_transportation.cfm.

Strengths and Limitations

Fuel-based forecasting methods are most useful for developing a simple GHG forecast in order to understand anticipated trends. They typically are based on VMT projections and estimates of future fuel economy, but do not account for the nuances associated with land use patterns, transportation investments, or other strategies. Key strengths and limitations of the approach are noted in the table below.

Table 7. Strengths and Limitations of Fuel-based Forecasting Methods

Strengths	Limitations
• Can account for all transportation modes. • Can incorporate varied levels of detail depending on available forecasts of VMT growth, fuel economy, fleet mix, and state or regional population growth. • Relatively simple; limited data inputs for EPA's State Inventory Projection Tool.	• Fuel sales projections may not accurately reflect fuel consumption within a state or region due to factors such as interstate freight movements, cross-border traffic, and development patterns along boundaries. • Methods that account for state-level VMT growth forecasts or fleet changes require more effort to forecast emissions. • The State Inventory Projection Tool relies largely on linear or national trends, and does not account for factors such as state or local population and employment growth, freight travel activity growth, congestion, state-level vehicle mix changes, alternative fuel/technology policies and new fuel economy standards, and land use patterns. It does not include estimates broken out by vehicle type, and is not designed to predict the impacts of transportation policies and investments. Therefore, it cannot be used to examine alternative transportation plans or statewide policies.

Key Steps and Data Options

Step 1: Forecast transportation fuel consumption (typically will be based on estimates for individual modes or vehicle types). Forecasting fuel consumption typically relies on projections of fuel sales. This information can be either based on national-level predictions for all fuel or may be broken out by fuel type, vehicle type, an estimate of the state or region's VMT growth, or other relevant

Advanced State Models to Forecast Vehicle Fuel Use

Some states have developed relatively advanced models to forecast vehicle fuel use. For example, California's Motor Vehicle Stock, Travel, and Fuel Forecast (MVSTAFF) model is used to forecast vehicle fuel use as well as vehicle travel and vehicle population. The model relies on forecasts of the following independent variables: population, personal income, prime lending rate, fuel price, licensed drivers, and new vehicle fuel economy.

For more information about the California MVSTAFF model, see: http://www.dot.ca.gov/hq/tsip/smb/mvstaff.html variables. As a complement to the SIT, EPA also provides the SIPT, which provides a basic projection of a state's emissions by fuel type (see the SIPT box below). Other options include developing fuel-based forecasts by vehicle type taking VMT growth and future fleet characteristics into account. Possible sources for data include:

Basic: Fuel consumption projections

- Forecasts of fuel consumption in the Energy Information Administration's *Annual Energy Outlook,* broken down by region and sector
- State fuel-sales projections (generated for tax revenue purposes)
- EPA's State Inventory Tool (for all transportation modes)

Variations: Fuel consumption projections by vehicle type incorporating VMT projections, fuel economy projections, and state population growth

- State or regional VMT projections
- State fuel-based inventory's fuel sales data by vehicle type
- Fuel economy projections for light-duty vehicles, commercial light trucks, buses, and freight trucks, from EIA's *Annual Energy Outlook*, available at: http://www.eia.gov/forecasts/aeo/
- EPA's estimated changes in vehicle fleet parameters, such as increased fuel economy in future years, or shifts between fuel types used. These could be obtained from the MOVES model, or from projections based on the Corporate Average Fuel Economy (CAFE) rulemakings; it is important, however to note that the CAFE standards apply to new vehicles, and do not correspond directly to real-world driving patterns, so the CAFE requirements should not be assumed as future fleet fuel economy.

Output: *Forecasted fuel consumption*

Step 2: Multiply by emission factors to estimate emissions. Apply the appropriate emission factors based on carbon content of fuel to generate a forecast of future emissions. Note that carbon content varies based on the fuel blend and so can change over time and by region. For a list of the carbon content of specific fuels, see Table 5.

***Output*:** *CO_2 by fuel type (and vehicle type, if broken out)*

Common Tool: State Inventory Projection Tool

Much like the State Inventory Tool, EPA has also developed a tool to help states forecast future GHG emissions. The State Projection tool relies upon national fuel consumption growth forecasts, and does not account for many state-specific factors that may influence GHG growth, such as state population growth. Moreover, it does not output CO_2 by vehicle type, only fuel type, and does not allow for varying assumptions on other key transportation variables.

For more information about the U.S. Environmental Protection Agency State Inventory Projection Tool, see: http://www.epa.gov/statelocalclimate/resources/tool.html

Example: Vermont statewide GHG projections

In Vermont, on-road vehicle CO_2 emissions were forecast by applying VMT projections, along with adopted changes in vehicle technology and use of biofuels. The VMT projections were developed by Vermont's Department of Environmental Conservation (VTDEC) using historical road type growth curves from the state DOT (VTrans). The data suggested that VMT would grow at an average rate of 1.3 percent per year between 2002 and 2009, 1.4 percent from 2009-2012, and 1.2 percent from 2012-2018. An assumption was made that the 1.2 percent growth rate would apply through 2030.[30] Gasoline and diesel emissions were adjusted to reflect the effects of California's light-duty vehicle GHG standards, which Vermont adopted in 2005. The standards apply to new vehicles beginning with model year 2009.

The projected fuel consumption for new vehicles without the California standards was estimated by applying the projected new vehicle fuel economy from EIA's *Annual Energy Outlook* to the estimated VMT. SIT CO_2 emission factors for diesel and gasoline consumption were then applied to calculate CO_2 emissions. Per-mile emissions factors from SIT were also used to estimate CH_4 and N_2O emissions. VMT for model year 2009 and newer vehicles was estimated for each year using a default percentage of VMT for the model year from the SIT tool. Emissions for the phased-in vehicles under the standards were estimated by applying the emission levels set by the standards to the estimated VMT. The emission reductions resulting from the standards were estimated by subtracting estimated emissions for phased-in light-duty vehicles from the estimated emissions for these vehicles without the standards.[31] The Vermont Biofuels Association provided the projections for biodiesel consumption. The biodiesel projections were subtracted from the diesel consumption projections. Ethanol consumption in Vermont is very low and was not forecasted.

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[30] As a result of major uncertainties, no attempt was made to update the projections used in Vermont's 2007 inventory in their most recent inventory. This section thus refers to the most recent projections that were developed. See "Final Vermont Greenhouse Gas Inventory and Reference Case Projections", 1990-2030, http://www.anr.state.vt.us/air/Planning/docs/Final%20VT%20GHG%20Inventory%20&%20Projection.pdf.

[31] ICF International, "VTrans Greenhouse Gas Modeling: Evaluation of Existing Inventory Data." July 2010.

5. VMT-based Methods

This section discusses VMT-based inventory and forecasting approaches. All of these approaches involve two main components:

1) **Developing VMT estimates** – which tend to rely upon travel and land use forecasting tools. Section 5.1 describes relatively simple options relying on vehicle, household, and land use data where a network-based travel forecasting model is not available. These methods may be most applicable for areas seeking to develop a GHG inventory in a relatively quick manner. Section 5.2 describes expanded options based on HPMS data and the use of a network-based travel forecasting model, which tend to be more robust and allow for more sophisticated analyses of speeds and other factors
2) **Estimating emissions–** which can range from applying a simple emissions factor (in grams per mile) to the VMT estimate, or may involve use of sophisticated emissions models in order to calculate emissions from travel (options are described in Section 5.3).

5.1 Estimating VMT Relying on Vehicle, Household, and Land Use Data

VMT is a key factor that influences transportation GHG emissions because the level of travel activity is a determinant of fuel consumption. While there are many sources of VMT data available, this section focuses on relatively simple methods of obtaining VMT data based on odometer data from vehicles, household travel surveys, and land use information. These VMT methods are generally intended for calculating passenger GHG emissions -- not freight. They also are largely intended for developing inventories, although extrapolations of historical trends can be made to develop forecasts, recognizing a high degree of uncertainty in these results. A brief description of each of these methods is provided.

Using Simplified Methods

Each of the methods described in this section are relatively simple and may be defined as “sketch planning” approaches. In general, it would be better to use calibrated and validated travel forecasting and emissions models. These simplified methods can be used when more sophisticated tools or the resources to apply those tools are not available. As such, it is important for the analyst to recognize the limitations of these approaches.

Table 8. Selection Criteria for Methods of Estimating VMT that Rely on Vehicle, Household, and Land Use Data

Selection Criteria	Methods		
	Odometer Data	Household Travel Data	Land Use Data
Analysis Type	Inventory; forecast possible	Inventory; forecast possible	Inventory; forecast possible
Geographic Scope	State, regional, or county	State, regional, or county	Regional or county (particularly suited for smaller geographic areas)
Analysis Precision	Approximate – appropriate for simple calculation, largely for personal vehicles; may lack data for certain vehicle types and speeds.	Approximate, due to limitations in sample size – appropriate for simple calculation, largely for personal vehicles; typically does not account for speed and other factors.	Approximate, based on trip generation factors that may not be applicable in all areas, and lack of application of speeds and other factors.
Data Needed	Odometer data, vehicle stock data	Results from household travel survey – e.g., miles traveled, trip purposes	Land uses (including square footage and/or employment levels), trip generation rates (from Institute of Transportation Engineers, or local study)
Necessary Analytical Capabilities	Moderate – although the calculation is relatively simple, there may be complexities in analyzing the odometer data. Analysis is more complex for forecasts, to account for changes in vehicles/fuels.	Limited for inventories – relatively simple calculation. More complex for forecasts, to estimate changes in travel patterns.	Limited to moderate – generally need fairly substantial amount of land use data and calculations across each land use type.
Level of Resources Required (i.e., staff/budget)	Limited to moderate for inventories. Higher for forecasts as knowledge about future vehicle/fuel trends is required.	Limited, assuming existing survey data; conducting a new survey would require additional resources.	Limited to moderate – depending on quality of existing land use databases, and extent of geographic area.
Capable of Addressing Vehicle Technology/ Fuels Changes**	Yes; odometer data should be matched with vehicle information	No; needs supporting vehicle/fuel data	No; needs supporting vehicle/fuel data
Capable of Addressing Changes in Travel Demand	Limited – depends on extent to which changes are captured in odometer data but generally not designed to assess.	Limited – depends on the extent to which the effects of these changes are captured in household travel data but generally not designed to assess.	Limited – depends on the extent to which the effects of these changes are captured in land use data
Capable of Addressing Changes in Vehicle Speeds and Operations	No	Limited – depends on extent to which survey data account for time of day and speeds.	Limited – depends on whether trip generation data are applied by time of day and associated with speeds.

*** Requires combination with other models and methods such as MOVES to address vehicle technology or fuels changes.*

Description

Vehicle Inventory/Odometer Data

One way to determine VMT for inventories is to directly observe the number of miles driven through periodic odometer readings. In some areas, odometer data are collected as part of vehicle safety inspections, air pollution vehicle inspection and maintenance (I&M) programs[32], or as part of the vehicle registration process. One important value of these data are that they can typically match information on miles traveled with specific types of vehicles (e.g., make and model), which when combined with fuel economy information, can be used to calculate fuel consumption and GHG emissions.

A sample website from the State of Delaware at the link below shows how odometer data are collected and used by consumers: http://www.dmv.de.gov/services/vehicle_services/titles/ve_title_odometer.shtml. Delaware is one of the many states that contribute to the National Motor Vehicle Title Information Service, which also collects and stores odometer data for consumer protection: (http://www.vehiclehistory.gov/index.html).

Some insurance companies also collect odometer data from drivers, which can be either self-reported or verified by a certified third party. Despite the collection of this data, its availability is often a limitation to using this method to estimate GHG emissions. Unlike many other government data sources, odometer data cannot simply be accessed from a government website. In addition, information on heavy-duty trucks is limited since these vehicles often operate outside of the state where they may be registered and few states individually track heavy-duty truck odometer data.

Where available, vehicle odometer data must be requested from state licensing departments, there may be a fee to access this information, and confidentiality agreements may also be necessary. The reliability of odometer data may also pose an issue. Newer cars and some very old cars may not be included in state I&M program emissions checks and therefore no data are collected. Based on information from the National Household Travel Survey (NHTS), newer cars are driven more than older cars. Additionally, the odometer data may not be available for all geographic areas. Small counties may be excluded because of confidentiality reasons, and many rural counties do not have air pollution inspection and maintenance programs. Lastly, vehicle odometer data are typically recorded at annual or biennial intervals. While this type of data could be useful for estimating long-term vehicle-related GHG emissions, the data can be challenging to use to estimate daily VMT or GHG emissions.

Household Travel Survey Data

Household travel surveys represent another source of VMT data. The most commonly available types of household travel surveys are the NHTS, statewide household travel surveys, and MPO household travel surveys. For the most part, these travel surveys recruit a socioeconomically and geographically diverse range of volunteers to have their travel activities monitored. As part

[32] Emissions testing was first done in California in 1966 and now there are currently 32 states that require some form of vehicle emissions testing. Information on state I&M programs is available at: http://www.emissions.org/category/state-emissions/.

of the travel survey, respondents are asked to report information such as the age of their car(s), odometer readings, and to estimate their annual mileage driven. In addition, daily mileage driven is estimated for the survey days by either directly estimating mileage using a GPS device or by using self-reported mileage from the respondents. Post-processing the survey data may also be possible to estimate VMT if physical addresses or parcels associated with trip ends are recorded.

Household surveys are often viewed as one of the most reliable sources of data for daily travel and VMT estimates; however, it is important for the analyst to understand limitations of the data as it relates to key issues such as sample size, selection bias, and limited time period. Travel surveys may have underreporting errors due to discrepancies between self-reported daily VMT and actual VMT and may focus on travel time instead of distance unless GPS tracking is used.

While household surveys are fairly accurate for daily travel and VMT estimates, their ability to generate annual VMT estimates has limitations. The potential inaccuracy relates to the short (typically one or two-day) survey periods, the reliance on self-reported data, and small sample sizes. The average person does not have a good sense about their annual VMT, yet this is a common question on household travel surveys. In addition, reporting errors can occur in households with multiple drivers, since they are more likely to report the annual mileage driven by the car as opposed to the mileage driven by each driver (which can lead to overestimates).

MPOs often take steps within their travel model development processes to correct for these potential errors. If these data sources are used to estimate VMT for GHG emissions reporting purposes, it may be prudent to validate the household travel survey results against other data sources such as fuel consumption, or HPMS data. For calculating GHG emissions, it will be important for surveys to capture information on vehicles, so that VMT by vehicle type (e.g., automobile, light-duty truck) is produced.

Land Use Data

Methods that rely on land use data to estimate VMT typically use land use-based trip generation factors to estimate vehicle trips and then multiply the trips by average trip lengths to calculate VMT. These approaches are often used at a small scale, such as for a municipality or to report GHG emissions at a small geographic scale across a metropolitan region where accurate and complete land use data are available. Many local jurisdictions have complete and relatively accurate inventories of land uses based on comprehensive plans, building permit data, or for local tax purposes. These land use inventories can be used to estimate passenger vehicle and truck VMT if adequate information is known about the number and length of vehicle trips generated. Some newer land use inventory and planning tools have travel embedded in the programs to provide for a direct estimate of VMT.

Of the three methods highlighted in this section, land use data are probably the most problematic for generating large-area (regional or statewide) VMT and GHG emissions data, and tend to be geared toward lower levels of analysis (e.g., a city, county, or sub-area of a county). The geographic area issue relates to the complex nature of travel between different land uses. For example, it is fairly simple to develop rough estimates of vehicle trip generation for a given land use based on trip rates from the Institute of Transportation Engineers (ITE) *Trip Generation* report. Combining the information on generated trips with trip lengths from a household survey, odometer readings, or data from the regional travel demand model can be used to estimate VMT for a given land use type.

The challenge is how to combine the information for a large area. Trips go between land uses and if one is not careful, it is easy to double count VMT and therefore GHG emissions. To help illustrate this point further, consider a spreadsheet tool developed by King County, Washington to help estimate GHG emissions. The tool has VMT and transportation GHG estimates for a wide variety of land uses from residential, to retail, to office and manufacturing. If one were to apply the King County tool on a citywide basis, there would be no way to account for the travel *between* workplaces and homes. Since both types of land use have a VMT and GHG estimate, both land uses are counting the same trip (and therefore VMT/GHG emissions) twice. More complex tools like travel demand forecasting models were developed to help untangle the mix of trips between different land uses to provide accurate estimates and forecasts of performance measures such as VMT. While there are significant drawbacks to using land use data for large-area planning efforts, these tools can be useful at the parcel level. In fact, the King County tool mentioned above was developed for just this purpose and is effective for isolating the VMT generated from individual land uses.

Strengths and Limitations

The main strengths of these VMT-based methods relying on vehicle, household, and land use data are quickness and low cost because they rely on existing and available data. As mentioned earlier, these methods are primarily applicable where a network-based travel demand forecasting model is not available. The following table highlights some of the strengths and limitations of the different methods.

Table 9. Strengths and Limitations of Methods of Estimating VMT that Rely on Vehicle, Household, and Land Use Data

Method	Strengths	Limitations
Using vehicle odometer data	• For purposes of GHG inventories, data on travel can be matched directly with information on vehicle type to develop estimates of fuel consumption by each vehicle type, if needed.	• Odometer data are not readily available in many locations. • Only provides data on the mileage traveled by vehicles, no information on where the travel occurred or under what conditions. • Data are often limited to light-duty vehicles so no freight vehicle data are available. • Measures current travel only. Forecasts rely on extrapolation that are unlikely to be sensitive to changes in the transportation network, fuel type, travel cost, or other important variables. This insensitivity would be magnified the further out the extrapolation goes.
Using household travel survey data	• Survey data can provide more detail on travel behavior, trip purposes, travel times, and other characteristics that are useful for more detailed analysis.	• Household surveys do not address freight traffic. • Measures current travel only. Forecasts rely on extrapolation that are unlikely to be sensitive to changes in the transportation network, fuel type, travel cost, or other important variables. This insensitivity would be magnified the further out the extrapolation goes. • Surveys typically do not provide information on operating conditions (speeds, congestion).
Using land use data	• Land use-based approaches can be useful for analyzing GHG emissions at small geographic scales or for distributing GHG emissions within a region to origins and destinations. • If future land use forecasts are available, then this method can also be used to forecast VMT and GHG emissions.	• Land use data at regional or state levels may be incomplete. • Double counting of trips and VMT may occur when including residential and non-residential land uses in a VMT estimate or forecast. • Trip generation rates from ITE are based on a limited sample and may not be reflective of actual travel behavior in all areas, so the estimates need to be calibrated to study area conditions/sources. • Forecasts are unlikely to be sensitive to changes in the transportation network and travel cost.

The different methods for estimating VMT may be useful for different purposes. For instance, while HPMS-based VMT estimates (which are described in a subsequent sections) are very detailed, and provide information on where travel is occurring (e.g., on specific roadway links), the data lack information on the origin and destination of trips, which may be useful for certain types of analysis. For some states and regions, pass-through travel can account for a large portion of VMT. Since transportation agencies have limited ability to influence travel generally, and intercity travel in particular, some may wish to report intercity travel or “through” trips separately in their GHG inventory, or exclude this travel altogether from the analysis. This is the current practice in California, which focuses on the emissions that a DOT or MPO can most directly influence through its transportation and land use planning efforts. Some MPOs have taken the approach of using HPMS data to establish a regional total VMT and then subtracting through-trip VMT, using regional cordon point license plate surveys to estimate through trip VMT.

Moreover, the odometer-based, household survey, and land use based methods only capture travel for a defined population of vehicles or households: generally passenger travel, not freight. Odometer-based estimates in particular, are not able to provide information on where the vehicles travel, and so these estimates are less useful in developing a detailed inventory accounting for travel speeds.

Key Steps and Data Options

This section describes how to obtain the VMT data and calculate GHG emissions from each of the three data sources above.

Option 1: Use Vehicle Data

As described above, directly reported vehicle odometer data is collected by most states through their motor vehicle departments. This data is often available for individual vehicles during sales or registration transactions. Odometer data usually contains the annual miles driven for passenger vehicles but the data are not readily available, particularly to non-government parties. While there are many limitations (as described above), vehicle odometer data are one of the few directly measured indicators of vehicle travel. These data may be particularly useful as a way to check VMT estimates from other sources or methodologies.

When these data are available, the following steps would typically be followed to estimate GHG emissions.

Step 1: Collect vehicle odometer data. The data may be available from vehicle registration or emissions inspection checks, and can be tied to the Vehicle Identification Number (VIN) to estimate annual mileage for different types of vehicles. This step can involve reconciling some complexities in the data, such as different registration and inspection dates for different vehicles.

Output: *Vehicle odometer data*

Step 2: Collect vehicle stock data. Ideally, the odometer data would be summarized by vehicle type to aid in a more accurate assessment of fuel consumption and GHG emissions. If the odometer data is not available by vehicle type, then data from vehicle registration programs or air pollution emissions models could be used to estimate vehicle type classes. Care should be taken if age-based emissions profiles are used since odometer data may not include a comprehensive inventory of older and newer cars.

Output: *Vehicle odometer data by vehicle type*

Step 3: Multiply the annual mileage per vehicle by the number of vehicles of each type. This calculation will result in estimates of the total VMT annually by vehicle type.

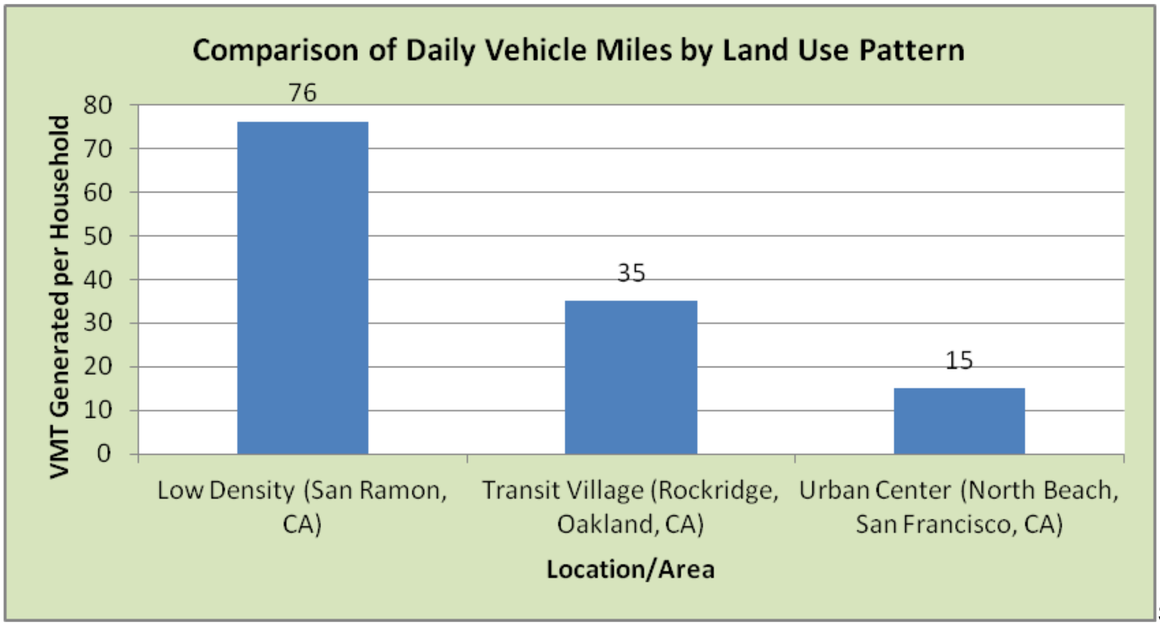
Output: *Total VMT annually by vehicle type*

Step 4: Apply Emissions Factors. Per mile emissions factors can be applied to estimate total GHG emissions. Emissions factors can be extracted from air quality analysis software such as MOVES and EMFAC. For more information on approaches, see Section 5.3.

Output: *Total GHG emissions*

In addition to odometer data serving as a check for other VMT estimates, it can also be used to compare similar households in different geographic locations to understand how variables such as proximity to urban centers or high quality transit may affect VMT generation. An example based on California data is shown below. Note, however, that these data are per household (and households tend to be larger in low density areas than in urban centers or transit villages) and they are for selected areas, not necessarily representative for all regions.

Figure 7. Daily Passenger VMT per Household by Selected Area Land Use Patterns



Source: Developed using data from Holtzclaw et al., "Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use – Studies in Chicago, Los Angeles, and San Francisco." *Transportation Planning and Technology*, 25:1 (2002).

Option 2: Use Household Travel Survey Data

As described above, there are a variety of household survey data sources. Data for the NHTS was last collected in 2009. The data for this widely used survey are located at http://nhts.ornl.gov/download.shtml. While the NHTS has good national coverage, its statistical validity drops below multi-county or MPO geographic levels. Therefore, other sources should be considered for smaller geographies.

Several states (e.g., Michigan, Ohio, New York, Utah, Massachusetts, Oregon, Idaho, and California) have developed their own statewide household travel surveys. Sometimes these surveys are collected at the same time as the NHTS since the states can take advantage of the national survey effort. Typically, statewide surveys have a sample size that is large enough to provide statistical reliability for all but the most sparsely populated counties. These surveys serve as the backbone data source for many travel modeling efforts. One disadvantage of statewide household travel surveys is that they are often not updated as frequently as other survey sources, and therefore, may not be as reliable in terms of estimating current VMT patterns or GHG emissions.

The most widely conducted travel surveys are at the MPO level. MPOs rely on household travel survey data as inputs to their travel models. MPO surveys tend to contain the most detail and can be used to provide city-wide or even sub-area specific VMT and GHG emissions data. As described earlier, trip underreporting is a significant issue for all travel surveys; however, given their smaller size and lower overall survey budgets, some MPO models have fewer error correction techniques. Practitioners should consult with the MPO prior to using the data to determine if there are any known errors or corrective measures. This website from the University of Minnesota provides links to many MPO travel surveys, although the list is far from complete: http://www.surveyarchive.org/archive.html.

Depending on the specific household travel survey, a number of different methods and techniques are available to analyze VMT and ultimately GHG emissions. For household level estimates, the following steps would be followed.

Step 1: Obtain Household Travel Data. Data can be obtained from surveys such as the NHTS, regional surveys, or other sources.

Output: *Household travel data*

Step 2: Expand Survey Sample to Universe. The next step is to expand the survey sample estimates to the entire population. For example, the NHTS includes estimates of the average VMT generated per driver by age (see table below). This information can be used to estimate VMT for a state or MPO, using the number of registered drivers by age to expand the survey data. This type of estimate will exclude some travel on the state or MPO network (e.g., pass through trips) but that may be acceptable if the focus of the inventory and any associated GHG reduction strategies is on the residents of the area.

Table 10. Average Annual VMT per Licensed Driver by Age, 2009

Driver's Age	VMT
16 to 19	6,244
20 to 34	13,709
35 to 54	15,117
55 to 64	12,528
65+	8,250

Source: FHWA, "Summary of Travel Trends: 2009 National Household Travel Survey," Prepared by A. Santos, et al, June 2011, FHWA-PL-11-022, Table 42, available at: http://nhts.ornl.gov/2009/pub/stt.pdf.

***Output:** VMT for state or MPO*

Step 3: Apply Emissions Factors. Per mile emissions factors can be applied to estimate total GHG emissions. For more information on approaches, see Section 5.3.

***Output:** Total GHG emissions for state or MPO*

Option 3: Use Land Use Data

A general approach using land use data would involve the four basic steps described below.

Step 1: Collect Land Use Data. Land use-based trip generation methods typically rely on an inventory of existing land uses associated with other planning efforts. In most cases, the inventories at a state or MPO level use residential data (i.e., housing units) only and accept the limitation that the method does not address commercial, visitor, and some employment trips.[33] Regional and local agencies are more likely to have complete land use inventories including both residential and non-residential land uses.

***Output:** Land use data*

Step 2: Estimate Vehicle Trips. The land use amounts are multiplied by vehicle trip rates (or person trip rates and then converted to vehicle trips) using trip generation rate sources such as the Institute of Transportation Engineers (ITE) informational report, *Trip Generation* or *NCHRP Report 365,* Transportation Research Board, 1998. Freight trips may be estimated using truck trip generation rates based on land use.

***Output:** Vehicle trips by land use type*

Step 3: Estimate VMT. Once trips are estimated, they are multiplied by average trip lengths, which can be obtained from a variety of sources such as the NHTS or *NCHRP Report 365*. The trips may also be disaggregated into common purposes such as home-based work (HBW), home-based other (HBO), and non-home-based (NHB) since trip lengths are often available by

[33] The lack of non-residential data for statewide or MPO levels may be appropriate to avoid double-counting VMT between residential and non-residential uses.

purpose. An important clarification to consider when estimating household generated VMT is whether to include NHB trips generated by residents. Many trip rate sources, such as the ITE report noted above, only include HBW and HBO trips because they only measure trips that crossed the driveway of the home. A full accounting of household generated VMT would track all the trips made by residents throughout the day. Approximately 25 percent of daily vehicle trips are NHB so excluding them could result in an underestimate of VMT and GHG emissions. VMT from freight trips may also be generated if data on average truck trip length are available.

Output: *VMT*

Step 4: Apply Emissions Factors. Per mile emissions factors can then be applied to estimate GHG emissions from the vehicle types for which VMT data have been estimated. These factors may or may not account for the effects of speeds on emissions. For more information about developing emissions factors see section 5.3.

Output: *GHG emissions*

Example

The table below contains an estimate of household generated VMT and GHGs for an average weekday using NHTS data.

Table 11. Weekday Household GHG Emissions Estimate Using NHTS VMT Data

State	2010 Households (1)	Average VMT Generated Per Household Per Weekday (2)	Total Weekday Household Generated VMT	CO_2 Equivalent Emissions Factor (for gasoline) (lbs per mile) (3)	CO_2 Equivalent Emissions per Weekday (metric tons)
Utah	831,563	90	74,840,670	24.116	818,669

Notes:

(1) Data from U.S. Census Bureau, available here: http://quickfacts.census.gov/qfd/states/49000.html

(2) Includes home-based work, home-based other, and non-home-based trips of household residents. Source: Fehr & Peers.

(3) Based on national average CO_2 equivalent emissions factor, available here: http://www.travelmatters.org/calculator/individual/methodology?sid=af3f9fa6663b3addbcc8503b47d0b06e#vmt

5.2. Estimating VMT Relying on HPMS Data and/or a Network-based Travel Model

Another way of developing estimates and forecasts of GHG emissions relies on VMT data derived from models. Two key sources of these model-based VMT forecasts are the Federal Highway Administration's HPMS and network-based travel forecasting models, both of which assign VMT to the roadway network (in contrast to methods described in Section 5.1, where VMT is estimated based on sources, such as vehicle population, households, or land uses). This section provides additional information about using HPMS data and network-based travel forecasting models, describes how to extract relevant information, and presents the strengths and weaknesses of these approaches.

Table 12. Selection Criteria for Estimating VMT with HPMS or Network-based Travel Models

Selection Criteria	HPMS or Network-based Travel Model	
	HPMS	Network Model
Analysis Type	Inventory or Forecast	Inventory or Forecast
Geographic Scope	State, regional, or county	State, regional, or county
Analysis Precision	Moderate for inventory Low for forecasts	Relatively high, but depends on sophistication of network model.
Data Needed	HPMS VMT Data, VMT by vehicle type	Network Model Output
Necessary Analytical Capabilities	Limited – HPMS data are readily available	Requires a travel demand model*
Level of Resources Required (i.e., staff/budget)	Depends on level of adjustments required	Depends on existing modeling capability*
Capable of Addressing Vehicle Technology/ Fuels Changes	Not directly addressed in travel modeling, but can be addressed through emissions modeling.**	Not directly addressed in travel modeling, but can be addressed through emissions modeling.
Capable of Addressing Changes in Travel Demand	Limited; requires additional analysis	Yes, designed to address transportation system investments but model sophistication varies in terms of ability to address land use factors, bicycle/pedestrian investments, etc.
Capable of Addressing Changes in Vehicle Speeds and Operations	Yes, to the extent that travel speeds are incorporated into the analysis.	Yes, accounts for congestion, but typically does not address system management strategies or eco-driving.

*Note: The level of effort required may not be significant for agencies with network model already well developed.
**Can be combined with other models and methods, such as MOVES, to incorporate changes in vehicle and fuel technology.

Description

Highway Performance Monitoring System (HPMS)

The HPMS is a program administered by the FHWA,[34] which requires that all state DOTs submit annual traffic count, highway inventory, revenue generation, and safety information as a condition of receiving Federal funding. Since it is impractical to count traffic or evaluate the pavement quality of every roadway segment in a state, models are used to translate a sample of data into the regional and statewide data required by FHWA. Related to GHG emissions estimation, the traffic count data are typically aggregated into VMT by vehicle class and roadway functional class at a variety of geographic levels.

Because all states collect HPMS data that must conform to FHWA requirements, these data are available for all states and metropolitan areas over 50,000 in population. FHWA reports VMT by Federal Aid Urbanized Area in *Highway Statistics*, which is the annual report that summarizes the HPMS data. Typically, Federal Aid Urbanized Area boundaries do not match with MPO boundaries although state HPMS programs often provide VMT by county.

By their nature, HPMS data are backward looking and can provide a good review of historic trends. FHWA's Publication *Highway Statistics* is available back to 1945 and the HPMS was established in 1978. HPMS reporting requirements include providing estimates of future VMT, which should be a 20-year forecast of annual average daily traffic (AADT). Since the data collected for HPMS are based on observed conditions, there are limitations to the forecasts, which may be developed from state procedures or MPOs or other sources. Other approaches could involve extrapolating trends by functional class, using regression to correlate changes in the population to VMT, or other types of statistical analyses. However, for all VMT-based methodologies, extrapolation of VMT and vehicle trends needs to account for demographic and economic changes. These (and other) factors would require analytical assumptions, which are subject to significant degrees of uncertainty and need to be thoroughly "vetted" and disclosed.

Another limitation of HPMS data is that it does not account for time of day variation in volumes and speeds. Moreover, since the data are associated with travel on the roadway network, this can create challenges if trying to assign emissions to trip generating sources within the state or region. For example, some states like California require VMT estimates and forecasts to account for trips that enter and exit MPO regions when analyzing GHG emissions, but exclude "through trips", those traveling through the MPO without a stop. This is different than conventional air pollution analysis that focuses on travel within a non-attainment or maintenance area, and HPMS does not provide information related to the origins or destinations of trips.

[34] The HPMS data are helpful in that the data reveal travel patterns over time, though accuracy depends heavily on the resources of each state. More information about HPMS data is available at: http://www.fhwa.dot.gov/policyinformation/hpms.cfm.

Network-Based Travel Forecasting Models

Network-based travel forecasting models are computer programs that are developed to estimate future travel patterns in a given area based on variables that influence both transportation supply and demand. Key structural and input variables for these models often include land use, socio-demographic characteristics, travel modes, transportation network, and travel costs. The models can be simpler or more complex, depending on the resources and needs of the region. For example, some larger MPOs have models that include separate components for forecasting truck travel or automobile ownership, or models designed to be responsive to changes in the pedestrian environment. Conversely, a region that is not contemplating transit over the planning horizon may leave out the mode choice step. A number of the largest MPOs are replacing their existing models with advanced tour- or activity-based models and some are testing advanced dynamic traffic assignment (DTA) to improve sensitivity to traffic operating conditions and provide more accurate forecasts of peak period conditions. As with all models, network models have various limitations, and it is important to consider these limitations.

> **Understanding the Sophistication of Travel Forecasting Models**
>
> Travel demand forecasting models are commonly used by MPOs, and several state DOTs also have statewide travel demand forecasting models. These tools vary in their sophistication, and the extent to which travel models account for different factors (e.g., land use, transit, bicycle and pedestrian activity) will affect the accuracy of VMT forecasts and their ability to address different types of strategies.
>
> While this Handbook is not designed as a resource on travel forecasting, it is important for those who wish to analyze GHG emissions to understand the strengths and limitations of their travel models. The following resources may be consulted for support.
>
> - *Travel Model Validation and Reasonableness Checking Manual*, FHWA/TMIP, 2010
> - *NCHRP Report 716, Travel Demand Forecasting: Parameters and Techniques*, TRB, 2012
> - *Metropolitan Travel Forecasting, Special Report 288*, TRB, 2007
> - *2010 California Regional Transportation Plan Guidelines,* CTC, 2010
>
> Other useful resources are available through the Travel Model Improvement Program (TMIP) – www.fhwa.dot.gov/planning/tmip/.

The most common network models are trip-based models where trip generation is usually a function of land use data. These models are often called three or four-step models after the number of key submodels (trip generation, trip distribution, mode choice, and traffic assignment) they include. Network-based travel models are fairly ubiquitous at the MPO level, which are urbanized areas (or portions of an urbanized area) with a population greater than 50,000. However, outside of MPOs, network-based travel models are less common. For example, many smaller communities do not have a network-based travel model and only a handful of states have a statewide model available.

In contrast to the HPMS data, network-based travel models are forward looking and generally produce a reasonably reliable forecast of future travel patterns. Therefore, these models can generally be relied on to forecast future GHG emissions (provided that they are well calibrated and validated, and provided that analysts can reliably predict future VMT by vehicle type and the GHG emissions characteristics of future vehicles). Unfortunately, while these types of models have been available since the 1960's they are not a good source of historic data. More often than not, when jurisdictions periodically update their models to remain current with the latest land use and transportation system changes, the prior version of the model is discarded. As time progresses, many jurisdictions cannot retrieve either input or output data from these older versions of the model. Thus, estimating historic VMT and GHG emissions can be difficult, which may be important, since several state GHG emissions reduction targets are based on 1990 GHG emissions levels (consistent with the Kyoto Protocol).[35]

A limitation of network-based models similar to that noted for HPMS data is that these models also have physical boundaries, which can make full accounting of VMT difficult for those trips that cross the boundaries. Further, some GHG mitigation strategies are targeted at VMT generators (i.e., land use development) so knowledge about both ends of a trip is often required to understand the effectiveness of the strategy. Quantifying VMT changes from mitigation strategies is subject to uncertainties. For GHG quantification, these uncertainties may be compounded by uncertainties in future vehicle technologies and fuels, and difficulty in distributing VMT among many different vehicles/fuel types/models/years expected in the future. GHG quantification by all models, including network-based VMT models, is also limited by the inability to accurately reflect non-recurring (for instance, incident-based) congestion and eco-driving behavior.

Strengths and Limitations

Of the tools described up to this point, network models have the advantage of being able to capture the GHG emissions related to population and employment growth as well as transportation network or system changes. Network models also allow for testing of both transportation demand and supply in an integrated model. The accuracy of network models is better than many of the other methods or tools discussed depending on the level of detail in the model. It is also important to consider that network models have been used for a long time, their modeling framework is well understood, and the inputs they require are generally available. The main limitation of these models is their complexity and cost. Smaller agencies may lack the staff expertise to develop a network model as such models require a considerable amount of resources to develop, calibrate, and validate. These models also require fairly expensive software and regular maintenance for land use and transportation databases to produce accurate results. As such, HPMS may be an effective alternative method because of data availability and limited effort necessary to obtain VMT data and then calculate GHG emissions. Key strengths and limitations of each method are summarized in the table below.

35 It may therefore be worthwhile for states to set GHG reduction targets/ policy in a way that future GHG reductions are tied to readily available starting points or model base years.

Table 13. Strengths and Limitations of Estimating VMT with HPMS and Network-based Travel Models

Method	Strengths	Limitations
HPMS	• Simplest method for estimating statewide VMT by roadway functional type • County, district, or regional VMT may also be directly available • Information on VMT by vehicle type is available • Reliable historic data available	• Given limited traffic count sample sizes, data quality may be an issue at small geographic scales or in rural areas • No explicit data on operating speeds or congestion, only speed limits on roadways are available • VMT forecasts rely on extrapolation that may not be sensitive to changes in land use, travel cost, or other important variables • Data is based on travel on a network and cannot isolate origins and destinations (which may be useful for some analyses) • GHG results are subject to uncertainty and inaccuracy in out years due to uncertainties in vehicle technologies and fuels, and distribution of VMT among different vehicle types and fuels
Network-based model	• Explicitly includes data on speed and traffic congestion (assuming model is calibrated to such factors) • Compared to HPMS, much more reliable forecasts for future conditions • Some ability to account for sources or contributors to VMT	• Data can be difficult to extract without properly trained staff or consultant assistance • Because network-models are custom tools, the VMT results may not be directly comparable between regions • Can be difficult to generate historic VMT estimates • Estimates or forecasts are based on fixed boundaries and may not capture the full length of trips entering or leaving the MPO or state boundary. • GHG results are subject to uncertainty and inaccuracy in out years due to uncertainties in vehicle technologies and fuels, and distribution of VMT among different vehicle types and fuels

Key Steps and Data Options

This section provides step-by-step instructions on how to extract the data needed to estimate GHG emissions from the two methods described above.

Step 1 – Estimate VMT

The first step in developing a GHG emissions estimate is the extraction of VMT data. Because the data format of the HPMS and network-based travel models are so different, there are two distinct methods from extracting the data from each data source.

Option 1: Use HPMS data

HPMS VMT data are fairly easy to extract. At the statewide level, the FHWA's *Highway Statistics* publication (http://www.fhwa.dot.gov/policyinformation/statistics.cfm) provides VMT data organized by the following:

- Federal functional classification
- Urban versus rural area designation
- AADT volume categories

The data from *Highway Statistics* are available as both webpage data and Microsoft Excel files, which make the data easy to post-process.

In addition to the FHWA data sources, all state DOTs also have HPMS data available; although the organization of this data varies considerably from state-to-state. For example, Ohio DOT summarizes HPMS-type VMT data by county organized by Federal functional classification (http://www.dot.state.oh.us/Divisions/Planning/TechServ/prod_services/Pages/DVMTRpt.aspx). On the other hand, the Alaska DOT organizes VMT data into three districts of the state, with distinctions made for urban and rural areas and Federal functional classification.

If conducting a base year estimate of GHG emissions, the HPMS data can be used directly. For future years, the basic steps involved in forecasting VMT in areas without a network model is to 'grow' or 'adjust' HPMS base year estimates based on mathematical relationships between VMT and commonly forecasted variables such as population and employment; or in more complex models, built environment variables (i.e., the Ds) such as land use density, land use diversity, regional accessibility, and distance to transit service. The main steps involved are dependent on the level of sophistication of the method or model. Some examples are listed below, which range from a very simple linear trend-line projection to more complex regression analyses that base VMT forecasts on a range of demographic and economic factors.

- Linear projection of VMT based on estimated growth factor;
- Linear projection of total VMT, based on regression analysis of historic VMT data, apportioned by functional roadway class;
- Linear projections of VMT by functional roadway class, based on historic VMT data, with adjustments to correct for changes in functional class categories;
- Linear projection of interstate VMT based on historic VMT data, and separate population-based forecast for non-interstate VMT;
- Analysis of anticipated VMT growth in each interstate corridor, and population-based forecast for non-interstate VMT; and
- Separate regression forecasts by functional roadway class, based on VMT, population, and employment, with growth factor employing a decay function.

More information on these methods and their use is available in the FHWA report: *Sample Methodologies for Regional Emissions Analysis in Small Urban and Rural Areas,* available at: http://www.fhwa.dot.gov/environment/air_quality/conformity/research/sample_methodologies/.[36]

Option 2: Use a network-based travel model

Obtaining VMT data from a network-based travel model is fairly straightforward for base year or future year conditions. Nearly every network-based model that is likely to be in common use will have the ability to output link-by-link average weekday traffic volumes. Some network-based models may only have a PM peak hour component, and in this case, only average PM peak hour weekday traffic volumes may be available. Many models may automatically generate a VMT report, which can be used to estimate VMT directly, however, as will become apparent later in this section, the disaggregate link volumes are more useful for ultimately estimating GHG emissions.

If annual GHG emissions estimates are desired, the average weekday or PM peak hour data will need to be factored up to generate annual link volumes or VMT. There are several methods to perform this factoring, but the most common is to develop an AADT factor, which will (as the name suggests) convert the average weekday traffic volume into an annual average daily traffic volume. Most state DOTs have a method to convert daily traffic data into annual average daily traffic data. Additionally, most MPOs have regular traffic data collection programs that can account for the weekend/weekday, PM peak hour/daily, and seasonal variations in traffic to develop a more localized AADT factor. Once AADT is known, it is straightforward to develop annual traffic volumes and VMT by multiplying traffic volumes by the length of road segments.

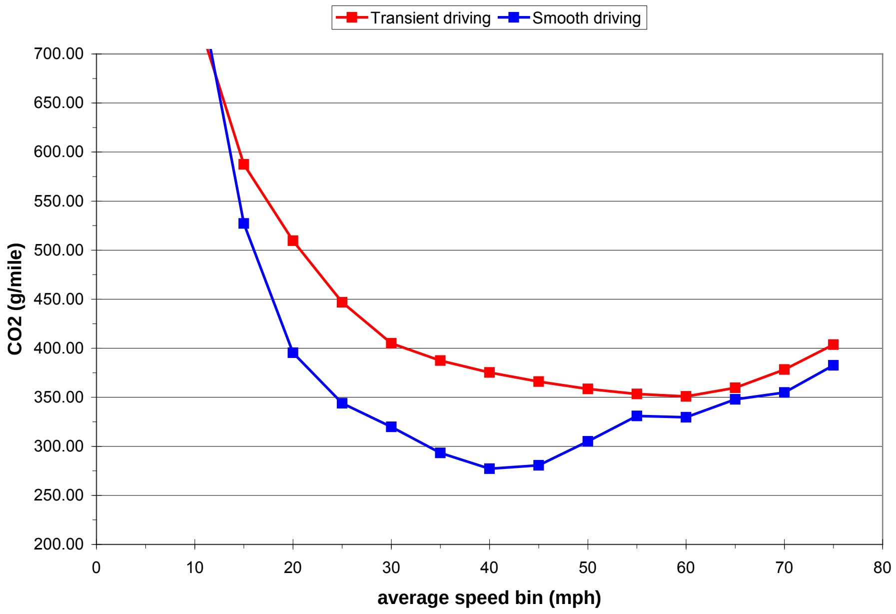
Output: *VMT*

Step 2: Estimate Speeds/Disaggregate VMT into Speed Bins (optional)

With the VMT data extracted, the next step in developing GHG emissions is to estimate the speed at which VMT was accumulated. While there are generic GHG emissions factors that do not explicitly consider speed, the figure below shows that GHG emissions rates for light-duty vehicles are highly variable based on speed – with nearly two times as much CO_2 per mile at low speeds as for mid-level speeds. Moreover, CO_2 emissions per mile are higher during transient driving (stop and start conditions) than during smooth driving at the same overall average speed.

[36] FHWA, "Sample Methodologies for Regional Emissions Analysis in Small Urban and Rural Areas," prepared by ICF International, October 2004.

Figure 8. CO_2 Emissions with respect to Speed, Light-duty Vehicles



Source: U.S. EPA, analysis using MOVES for all light-duty vehicles for 2010.

Given the importance of speed when calculating GHG emissions from VMT, the HPMS is at a disadvantage compared to network-based models since no future speed data is explicitly included as part of the HPMS. However, if only rough approximations are required, using functional class and geographic information from the HPMS can help to relate some speed information to the VMT data, based on reported speed limits.[37]

For example, the 2008 HPMS database showed the following information for the state of Arkansas:

Table 14. Arkansas 2008 Annual VMT (millions)

Functional Class	Rural	Urban
Interstate	4,510	3,890
Other Principal Arterial	4,577	904
Minor Arterial	3,178	3,348
Major Collector	4,756	2,863
Minor Collector	714	1,087
Local	1,980	1,347
Total	33,163	

Source: FHWA, HPMS 2008.

37 Note that if a more complex emissions factor program such as MOVES is used, HPMS speed data are not required since these programs have built-in default speed distribution data. However, even though defaults are included in the models, local data are recommended if they are available.

Given these data from the HPMS, a similar table of average speeds for each functional classification could be developed. An example table is below. These data could be developed based on speed limits, but ideally, these data would be developed from actual speed survey data from locations across the state.

Table 15. Arkansas Estimated Travel Speed by Functional Class

Functional Class	Rural VMT	Urban VMT
Interstate	70	60
Other Principal Arterial	65	45
Minor Arterial	50	35
Major Collector	40	30
Minor Collector	35	25
Local	35	25

Source: Sample table based on common speeds.

Alternatively, an analyst could use a sample of speed data across several roads in each functional class to develop an average speed for that functional class, and apply that across the entire functional class. In some cases, an analysis could also be based on formulas relating the volume to capacity (V/C) ratio and the free-flow speed to estimate speeds on individual road links. Grouping links with similar parameters and analyzing together, such as at a functional class basis, could simplify this analysis.

Extracting speed data from a network-based model is typically a simple process so long as the entire link database from the model run was extracted[38]. Within the output link database, information on traffic volumes, link length, "congested" link speed, and "free-flow" link speed are included. It is important to distinguish between congested link speed (which is the speed the model predicts on the link given the forecasted traffic congestion) and free-flow link speed, which is typically the speed limit or prevailing free-flow speed. Depending on the type of model, both congested and free-flow speed may be needed to accurately estimate GHG emissions. For example, many simple network-based travel models have a daily traffic model that will produce an estimate of congested speed. However, this congested speed is used as part of the traffic assignment portion of the model and is typically more representative of congested peak travel periods. Using congested travel speeds with a daily or annual VMT estimate would overstate potential GHG emissions. Therefore, if the congested speed represents conditions affecting 20 percent of the VMT and the remainder of the VMT occurs at or near free-flow speed, then the analysis should separately account for VMT data at the different speed levels. Most large MPO models have more explicit treatment of off-peak and peak travel times. Compiling the speed

[38] As described above, many network-based travel models can output model-wide or district-wide VMT totals. However, these VMT totals do not typically have any speed information associated with them.

data is typically done in a spreadsheet where the total VMT occurring in a given speed “bin” (a speed range) is totaled. The table below is an example of VMT data organized into 16 different speed bins.

Table 16. Example of Network-based Model VMT by Speed Bin Data

avgSpeedBinID	avgBinSpeed	avgSpeedBinDesc	avgSpeedFraction	VMT
1	2.5	speed < 2.5mph	0.002268	3,279,790
2	5	2.5mph <= speed < 7.5mph	0.010552	15,257,384
3	10	7.5mph <= speed < 12.5mph	0.017086	24,704,848
4	15	12.5mph <= speed < 17.5mph	0.038173	55,195,908
5	20	17.5mph <= speed <22.5mph	0.046069	66,612,590
6	25	22.5mph <= speed < 27.5mph	0.024576	35,534,917
7	30	27.5mph <= speed < 32.5mph	0.042075	60,838,530
8	35	32.5mph <= speed < 37.5mph	0.056443	81,612,600
9	40	37.5mph <= speed < 42.5mph	0.164311	237,583,396
10	45	42.5mph <= speed < 47.5mph	0.157075	227,120,589
11	50	47.5mph <= speed < 52.5mph	0.171162	247,489,494
12	55	52.5mph <= speed < 57.5mph	0.102830	148,685,722
13	60	57.5mph <= speed < 62.5mph	0.085127	123,088,581
14	65	62.5mph <= speed < 67.5mph	0.044135	63,816,294
15	70	67.5mph <= speed < 72.5mph	0.028628	41,394,434
16	75	72.5mph <= speed	0.009490	13,721,756

Source: Example values from MOVES2010, using the 2010 Lake County example from the MOVES demonstration training files, for HPMS vehicle type 20, source type 21,road type 3.

While it is fairly straightforward to extract speed information from a network-based travel model it is important to understand how reliable the model’s speed data are. For example, many models are not calibrated to match observed travel speeds. Therefore, before network-based travel model data are used, the practitioner should evaluate to make sure that the speeds make sense for roads of different functional classifications and for the model as a whole. In addition, the practitioner should perform some sensitivity tests to ensure that the model responds reasonably to changes in anticipated traffic flow. Guidance on these types of dynamic validation tests are provided in the following resource documents.

- *Travel Model Validation and Reasonableness Checking Manual*, Second Edition, 2010 (FHWA) http://tmiponline.org/Clearinghouse/Items/Travel_Model_Validation_and_Reasonableness_Checking_Manual_Second_Edition.aspx)

- *2010 California Regional Transportation Plan Guidelines*, 2010, (California Transportation Commission) http://www.dot.ca.gov/hq/tpp/offices/orip/rtp/index.html

If a model is not appropriately sensitive, increases in traffic volumes may not cause appropriate reductions in congested speeds, which would affect the GHG emissions because the VMT stratification across speed bins would not be correct. If the network-based model's speed estimates are questionable, then the same procedures outlined for the HPMS data may be applicable, including relying on the built-in speed distributions in air quality emissions modeling software. It is also possible to post-process the output speeds from travel models, using volume to capacity relationships, to generate more reasonable estimates of congested speeds.

Output: *VMT by speed bin*

Step 3: Estimate Vehicle Fleet Mix

GHG emissions vary widely based on the type of vehicle and type of fuel used. The table below provides some example emissions factors in grams of CO_2 equivalent (CO_2e) per mile for several types of vehicles:

Table 17. Example of Composite CO_2e Emissions by MOVES Vehicle Type

Year	County	Source Type ID	Source Type	CO2 Equivalent (g/mi)		
				Gasoline	Diesel	CNG
2010	Denver, CO	11	Motorcycle	397	n/a	n/a
		21	Passenger Car	395	431	n/a
		31	Passenger Truck	561	737	n/a
		32	Light Commercial Truck	556	731	n/a
		41	Intercity Bus	n/a	1,864	n/a
		42	Transit Bus	1,366	1,373	1,152
		43	School Bus	1,143	1,058	n/a
		51	Refuse Truck	1,725	1,799	n/a
		52	Single Unit Short-haul Truck	1,128	1,159	n/a
		53	Single Unit Long-haul Truck	1,052	1,104	n/a
		54	Motor Home	1,123	1,183	n/a
		61	Combination Short-haul Truck	2,062	2,076	n/a
		62	Combination Long-haul Truck	n/a	2,266	n/a

Source: Sample outputs predicted with MOVES2010b, for calendar year 2010 for Denver County, Colorado at the National scale. CO_2e emissions include running, start, and extended idle (as appropriate for each vehicle type) exhaust emissions of CO_2, N_2O, and CH_4, each pollutant normalized according to its Global Warming Potential (GWP).

Given this variability in emissions rates by vehicle class, it is important to determine the amount of VMT generated by different vehicle types. The FHWA's *Highway Statistics* publication provides national VMT by vehicle type, but not state-level detail. Travel information by vehicle type is more difficult to obtain than basic VMT data, and in many cases it may be necessary to contact a goods movement or freight division of the DOT to obtain the data. Often the data are split only into autos/light trucks and commercial trucks.[39] Below is an example data from Denver County, Colorado for 2010 travel by vehicle class.

Table 18. Example of VMT disaggregated by HPMS Vehicle Type

HPMSVTypeID	yearID	HPMSBaseYearVMT	HPMSVtypeName
10	2010	29,300,600	Motorcycles
20	2010	3,166,355,860	Passenger Cars
30	2010	2,138,573,800	Other 2 axle 4-tire vehicles
40	2010	8,120,505	Buses
50	2010	127,039,845	Single Unit Trucks
60	2010	173,942,134	Combination Trucks

Source: Sample outputs predicted with MOVES2010b, run for calendar year 2010 for Denver County, Colorado at the National scale.

Network-based travel models may also have limited information about vehicle type. In general, only the largest MPOs have a freight component to the travel model and there is often very little data by which to calibrate these freight models. If direct model output is used to estimate VMT by vehicle type, steps should be taken to ensure that the data are reasonable. Moreover, it should be noted that vehicle type groupings encompass a large variety of vehicles, with a wide range of variation in GHG emissions/mile. Issues such as vehicle age can be accounted for through the application of appropriate emissions factors or through use of an emissions model.

Given the limitations for both HPMS and network-based travel models when it comes to estimating VMT by vehicle type and the lack of finer-grained vehicle data related to vehicle age and other characteristics, it may be most advantageous to use a VMT distribution from emissions modeling software like MOVES or EMFAC. Note that the current version of MOVES does not have default VMT by vehicle type distributions, except at the national scale (it does produce estimates of VMT by vehicle type, which can then be converted to a distribution if needed). However, if MOBILE6 data are available, there is a documented procedure from the U.S. EPA to convert MOBILE6 files to MOVES format. Otherwise, vehicle type VMT (at the HPMS-class level) may be obtained from state agencies, HPMS reports, or other sources.

[39] As was the case with speed data, if a practitioner plans to use an air quality emissions modeling software like MOVES, these programs typically contain a built-in estimate of VMT by vehicle classification and additional detail may not be necessary.

However, even these approaches have limitations. In many cases the VMT by vehicle type distribution is based on vehicle registrations within a given area (state, county, region). While the registration distribution across different vehicle classifications is probably reasonable for light and medium duty vehicles, heavy duty trucks are often registered far from where they are operated. In addition, some fleet operators register many of their vehicles in one location even if they are not operated in that location. These factors can lead to difficulty in getting an accurate distribution of VMT by vehicle type, particularly for trucks.

> ***Output***: *VMT by vehicle type*

Step 4: Develop Information for Other Factors Influencing Emissions (optional)
VMT and vehicle emissions factors are the two most important pieces of information for developing GHG emissions from HMPS or network-based travel mode data. However there are other factors that could be influential for developing GHG emissions estimates. Many of these factors are not common, particularly across large geographies, but may be important. Examples include the carbon content of the fuel (e.g., based on whether there is a renewable biofuel blended with the standard fuel), penetration rate of hybrid electric or full electric vehicles, eco-driving programs, and steep grades or other unusual geography. Other common factors that influence criteria air pollutants such as meteorological data do not have a substantial impact on GHG emissions.

Most of the common emissions modeling tools have the ability to account for some of these factors explicitly. Other factors will have to be accounted for after the fact by either scaling emissions factors (e.g., speed management strategies) or scaling preliminary emissions totals. Any post-processed adjustments should be transparent and accompanied by substantial evidence that justifies the modifications. Given the variability of other factors that can influence GHG emissions, there is no standard protocol that can be recommended. Rather a reasonable estimate of the change in GHG emissions rates or total emissions must be made and applied accordingly.

> ***Output***: *Estimate of the change in GHG emissions rates or total emissions due to other influencing factors*

Step 5: Develop Emissions Factors and Estimate Emissions
Based on the VMT and fleet data developed using the procedures described above, GHG emissions can be calculated by applying an emissions factor. Or, MOVES can be run in Inventory Mode if all of the model-related inputs are available. For more information about developing emissions factors see Section 5.3.

> ***Output***: *GHG emissions*

Step 6: Conduct Additional Strategy Analysis (optional). To consider strategies that are not well accounted for in HPMS or travel model forecasts (e.g., travel demand management strategies, truck stop electrification), additional off-model analyses should be conducted. For more information about specific transportation strategy analysis methods, see Section 7.

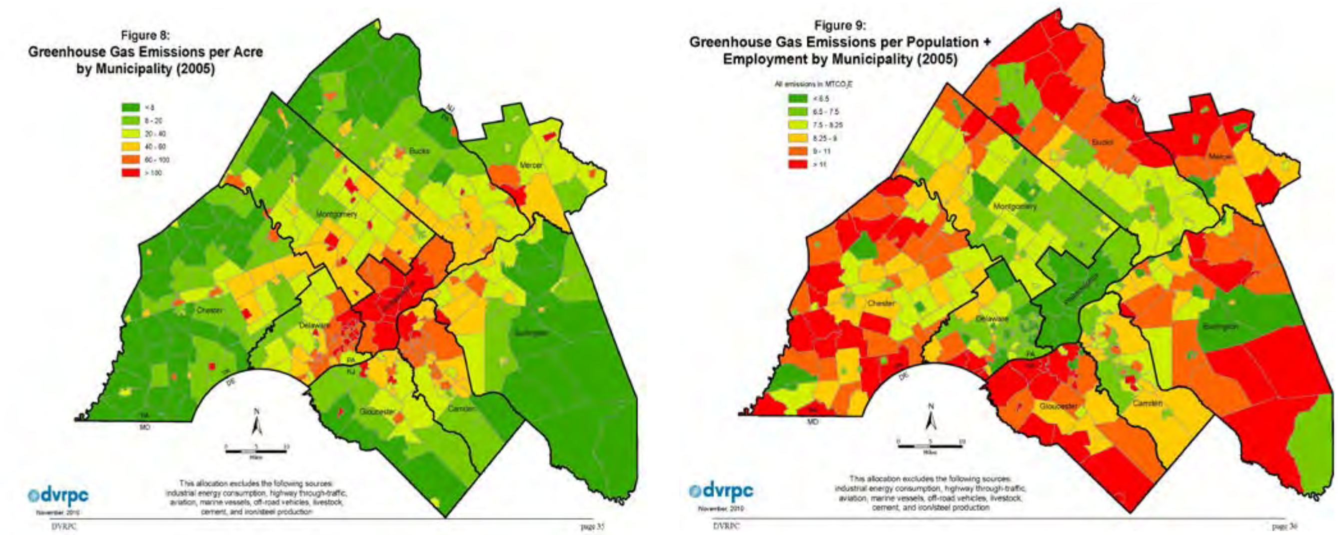
Examples

Delaware Valley Regional Planning Commission (DVRPC) GHG Inventory

One approach to developing a GHG inventory using a transportation demand model can be seen in the inventory developed by DVRPC. DVRPC developed a regional GHG emissions inventory that relies on travel demand model outputs to allocate GHG emissions to different traffic analysis zones.

HPMS data was used to determine a VMT total. Through traffic was estimated based on the travel demand model trip table that shows trips with origins and destinations outside the region. VMT from through traffic was subtracted from total VMT to focus the analysis on travel within the region. VMT was then apportioned to municipalities based on trip origins, destinations and trip length. Emissions were mapped per acre, per population and per employee.

Figure 9. DVRPC Maps Showing GHG Emissions by Geographic Area



Source: Delaware Valley Regional Planning Commission.

The map above to the left shows emissions per acre, which indicates that GHG emissions are higher in Philadelphia's urban core. If emissions for trips are allocated 50 percent to the trip origin and 50 percent to the trip destination, the map on the right shows that emissions are higher on a per population and per worker basis in the suburban and exurban areas around Philadelphia. The DVRPC inventory helps make the case for the role of smart growth in reducing the GHG emissions intensity of development in the region. DVRPC's inventory is available at: http://www.dvrpc.org/EnergyClimate/inventory.htm

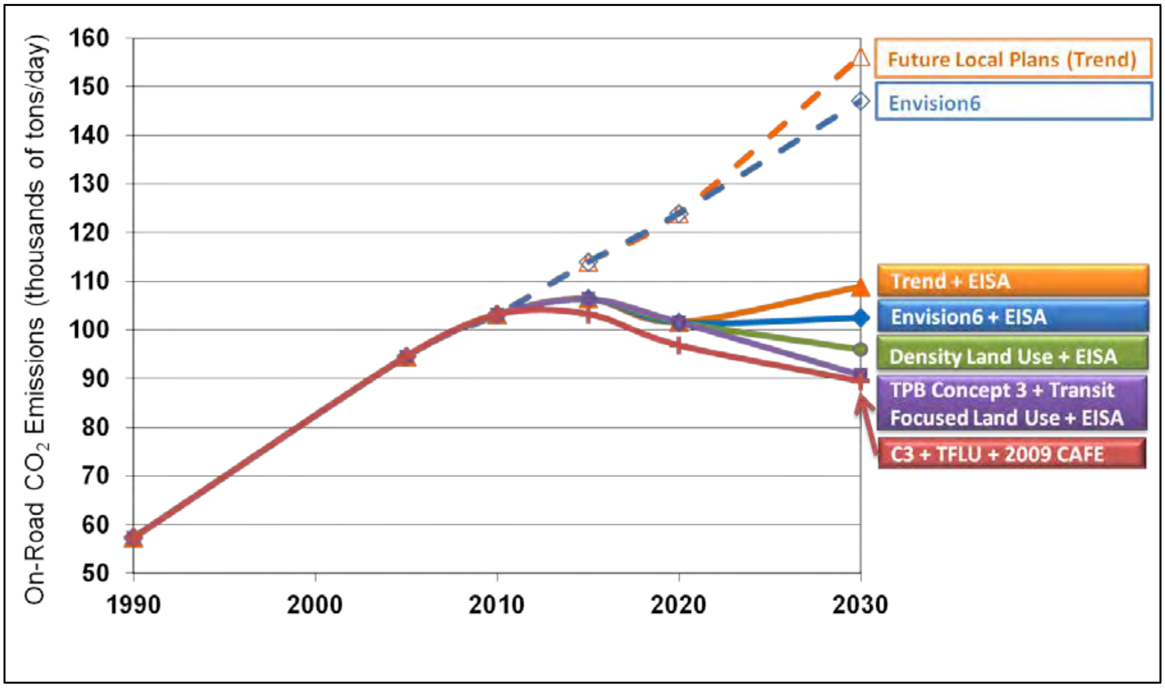
Capital District Transportation Committee (CDTC) GHG Forecast

CDTC, the MPO for the Albany metropolitan area, conducted an analysis of the GHG effects of its long-range transportation plan using guidelines from the New York State DOT, which include a set of lookup tables and adjustment factors to estimate fuel use per vehicle mile by average speed group. CDTC used its 3-step network-based travel forecasting model, and made an off-model adjustment that reduced VMT to account for land use, transit, and demand management policies. It then used a set of lookup tables of fuel economy by speed and adjustments to account for future fuel economy improvements and multiplied the VMT in each speed bin by the fuel consumption rate at each speed. Finally, CDTC converted its fuel consumption into CO_2 using a set of equations provided by the state.

Atlanta Regional Commission (ARC) GHG Forecast

As part of PLAN 2040 the long range plan for the Atlanta region, ARC undertook a detailed examination of alternative growth and development options to help policy and decision makers better understand the impact of growth patterns on the region. Analyzing differing growth scenarios helps policymakers and the public understand the benefits and impacts of alternative futures. As part of PLAN 2040 development, eight different land use scenarios were examined to test their effect on land conservation, mode share, congestion mitigation and access to jobs. By looking at these scenarios, insight was gained on the potential impacts that different land use patterns could have on transportation system performance and GHGs. ARC performed the scenario analysis using its 4-step travel demand model and MOBILE6 to model the emissions impacts of various land use scenarios describing different types of possible growth. Changes in land use and the transportation network were used as inputs in the travel demand model, which fed into the MOBILE6 calculations. The result allowed ARC to demonstrate the impact on GHGs of a variety of strategies, including Federal fuel efficiency standards, land use policies encouraging density, as well as the current regional plan, as shown below. ARC has since conducted additional analyses using MOVES.

Figure 10. ARC’s Emissions Forecast under Multiple Scenarios



Notes:

(1) Envision6 is ARC’s previous Regional Transportation Plan; it has now been replace by PLAN 2040.

(2) Density Land Use is a schema that increases regional density into key activity centers and curbs sprawl.

(3) EISA is the Energy Independence and Security Act CAFE standard

(4) TPB Concept 3 is the Transit Planning Board concept for regional transit buildout

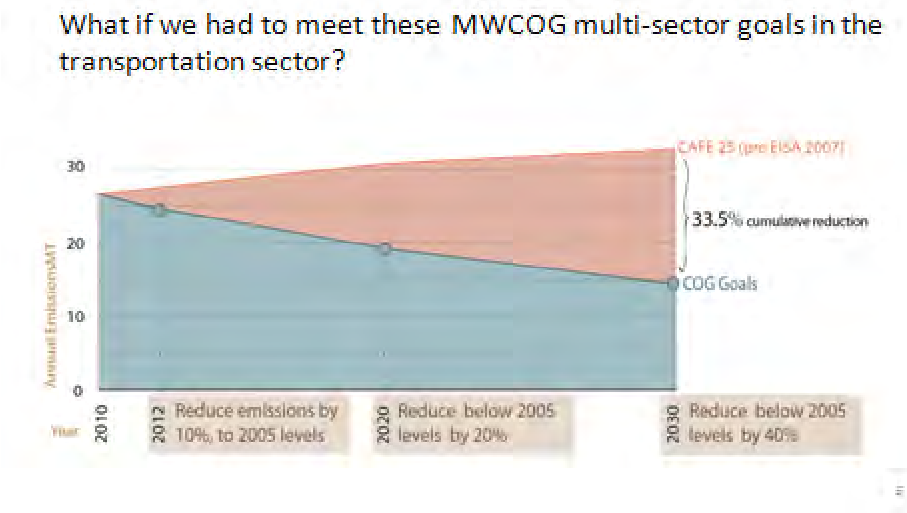
(5) Transit Focused Land Use focuses on nodes identified in CONCEPT3

Source: Atlanta Regional Commission. See http://www.atlantaregional.com/environment/air/climate-change

Metropolitan Washington Council of Governments (MWCOG) GHG Forecast

The National Capital Region Transportation Planning Board (TPB), the Federally designated MPO for the region, conducted a “what would it take” scenario study to determine how the MWCOG goals would be met in the transportation sector. TPB determined that cumulative emissions would need to be reduced by 33.5 percent from 2010 to 2030 to meet MWCOG’s goals.

Figure 11. MWCOG's "What Would it Take" Scenario Study



Source: "What Would it Take? Transportation and Climate Change in the National Capital Region: Final Results," Presentation to the Climate Energy, and Environment Policy Committee by Ronald Kirby, National Capital Region Transportation Planning Board, May 26, 2010. http://www.mwcog.org/uploads/committee-documents/aV5ZVl1c20100525135152.pdf

As part of this analysis, TPB conducted an inventory and forecast for years 2005, 2010, 2020, and 2030, and applied different scenarios to determine various ways of reducing emissions to meet the target. TPB used its travel demand model to forecast VMT using assumptions about projects and the network from its 2009 Constrained Long Range plan and its 2010-2015 Transportation Improvement Plan. TPB then applied CO_2 emissions factors generated by MOBILE6.2, and used software developed by a consultant to generate the CO_2 emissions totals (like ARC, TPB now uses MOVES rather than MOBILE6.2). Once the CO_2 emissions forecasts were generated, it was possible to apply anticipated CAFE standards and other possible emissions reduction measures using spreadsheet tools to better determine what it would take to meet the goals.

Maryland Department of Transportation, Climate Action Plan Analyses

Maryland DOT (MDOT) developed a 2006 baseline inventory, a 2020 baseline forecast, and a 2020 action scenario reflecting application of investments and strategies. The procedures were fairly intensive, and involved use of HPMS data and the MOVES model. The state does not have a statewide travel demand forecasting model, and several alternatives were available to determine forecast growth rates. MDOT elected to use forecasts based on historic trends of 1990-2006 HPMS VMT growth.

Annual GHG values were calculated based on 12 monthly runs of MOVES, each using traffic volumes, speeds, temperatures, and fuel values specific to an average day in each month to arrive at an annual total value. For the 2020 BAU scenario, the procedures for emissions analysis involved the following steps: 1) adjust traffic data to an average day in each month; 2) run MOVES for each of 12 months; 3) multiply VMT and emissions by the number of days in each month; and 4) aggregate to an annual total. Since MOVES includes the effects of post-2006 national vehicle programs (Model Year 2008-2011 CAFE standards, and Model Year 2012-2016 program), these technology programs were removed from the 2020 business as usual (BAU) scenario by revising the MOVES default database, and then these programs were credited for reductions in the 2020 action scenario.[40] Since the traffic data for roadway segments did not include congested speeds and hourly detail needed by MOVES, a post-processing software called PPSUITE was used to calculate these figures along with hourly congested speeds for each link, apply vehicle type fractions, aggregate VMT and vehicle hours traveled (VHT), and prepare the files in a format that could be input into MOVES. PPSUITE relies on data from the Maryland State Highway Administration's (SHA) Traffic Trends System Report Module to seasonally adjust AADT in order to estimate average daily traffic each month, and to disaggregate volumes to each hour of the day. MDOT used MOVES defaults for the miles per vehicle by source type.

For the 2020 action scenario, MDOT conducted analyses by modeling a range of strategies, including 2020 vehicle technology emissions reduction programs (including the CAFE standards 2008-2011 MY, the national program 2012-2016 MY, the Maryland Clean Car Program (2011MY), National Fuel Economy Standards (2017-2025 MY), and Proposed National 2014-2018 Medium and HDV Standards), by making adjustment to defaults in MOVES. MDOT also examined transportation fuels, including renewable fuels and a low carbon fuel standard, as well as implemented and adopted transportation plans and programs. In order to analyze the impacts of the committed and funded state, regional, and local transportation and land use plans, MPO VMT forecast data were used to adjust VMT growth rates by county, resulting in an estimate of a 1.4 percent annual rate of VMT growth between 2006 and 2020, compared to the HPMS historical baseline of 1.8 percent statewide. MDOT also separately analyzed a range of transportation emission reduction measures (TERMs) that have GHG benefits.

See documents related to the MDOT climate action plan at:
http://www.mdot.maryland.gov/Office%20of%20Planning%20and%20Capital%20Programming/Environmental_Planning.html

[40] To remove the benefits of the 2008-2011 CAFE standards and the 2012-2016 National Program, the database was revised so that all energy rates beyond 2007 were the same for each vehicle type, model year and fuel type.

5.3. Developing Emissions Factors & Emissions Inventories

This section describes how to estimate emissions either by developing and applying emissions factors from several common sources or using existing models.

Table 19. Selection Criteria for Approaches to Estimating Emissions Once Travel Activity Has Been Determined

Selection Criteria	Emissions Factors and Inventories				
	Simple Factor	Look-up Table Only Accounting for Fleet Characteristics	Look-up Table Accounting for Fleet Characteristics and Speeds	MOVES(1) Inventory	MOVES(1) Emission Rates
Analysis Type	Inventory or forecast	Inventory or forecast	Inventory or forecast	Inventory or forecast	Inventory or forecast
Geographic Scope	State or regional	State or regional	State or regional	Nation, state, region, county, or project	Nation, state, region, county, or project
Analysis Precision	Limited	Moderate	Moderate	High, with precision highest using local factors rather than defaults	High, with precision highest using local factors rather than defaults
Data Needed	VMT	VMT, fleet characteristics	VMT, speed bins, fleet characteristics	VMT and Population by vehicle type(2)	VMT and Population by vehicle type(2)
Necessary Analytical Capabilities	Limited – factors easily available from EPA/EIA sources	Moderate – needs disaggregation of VMT by vehicle type	Moderate – needs disaggregation of VMT by vehicle type and speed bin	Moderate – requires use and postprocessing of MOVES model inputs and outputs, although with use of National scale defaults, inputs are minimized.	High – requires use and postprocessing of MOVES model inputs and outputs, although with use of National scale defaults, inputs are minimized.
Level of Resources Required (i.e., staff/budget)	Limited – relatively easy	Limited – requires using additional factors	Moderate – requires additional analyses of speeds	Requires staff trained in the use of MOVES	Requires staff trained in the use of MOVES
Capable of Addressing Vehicle Technology/ Fuels Changes	No	Yes	Yes	Yes	Yes
Capable of Addressing Changes in Travel Demand	Yes, in aggregate; not by vehicle type	Yes(3)	Yes(3)	Yes(3)	Yes(3)
Capable of Addressing Changes in Vehicle Speeds and Operations	No	No	Yes	Yes	Yes

Notes:
(1) EMFAC can be applied in California instead of MOVES.
(2) MOVES may require significant input data if not relying on national default values. Increasing accuracy is achieved when more locally specific data are used. At a minimum, VMT by HPMS vehicle type is required for running emissions and population for other emission processes. Both have defaults available at the National scale but not at finer scales. More information is available from EPA.[41]
(3) If different VMT scenarios are considered then travel and land use changes may be addressed.

Description

There are several options for estimating emissions, once travel activity data (VMT) are estimated. These range from applying a simple composite emissions factor that reflects all on-road vehicles, to using tables of emissions factors for different vehicle types, or tables of emissions factors that account for vehicle speeds, to using the detailed emissions models, such as MOVES or EMFAC (in California). Generally, simpler approaches will lead to less accurate analytical results.

Simple CO_2 emission factors obtained from published sources can be multiplied with estimated VMT to produce an estimate of CO_2 emissions. Such factors are typically not sensitive to aspects like vehicle speed and fleet mix. For instance, the U.S. EPA has a simple GHG emissions factor of 460.2 grams of CO_2 equivalent per light duty vehicle mile traveled - http://www.epa.gov/cleanenergy/energy-resources/refs.html.

However, the accuracy of the CO_2 estimates can be improved if either the proportions of key vehicle types in the fleet or average speeds are known. To more accurately account for different emissions from the range of vehicle types in the fleet more accurately and efficiently, a look up table that provides simple emission factors by vehicle and fuel type may be used to calculate emissions from VMT data. These emission factors are also available from sources published by EPA.

MOVES is the preferred tool for estimating GHG emissions

For more information about EPA's MOVES model, including appropriate guidance documents, see:

- Resources on MOVES, including user manual: *http://www.epa.gov/otaq/models/moves/index.htm*
- Guidance: Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption *http://www.epa.gov/otaq/stateresources/ghgtravel.htm*

Currently, the best tool available to produce estimates of on-road transportation GHG (and other) emissions is EPA's MOVES model. In California, the EMFAC model may be used. The MOVES model estimates energy consumption and emissions, including atmospheric CO_2, CH_4, N_2O, and CO_2e. MOVES can estimate

[41] See EPA's GHG Guidance (Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption, EPA-420-D-12-001, January 2012).

emissions at the national, county (or custom, multi-county), or project scales and for annual or shorter periods of time.[42]

The model itself requires many inputs. Although defaults are available for most factors, locally specific inputs produce more accurate results. Inputs to MOVES include data on vehicle population, fuel type, and VMT. The model works by simulating actual vehicle drive cycles, including the effect of travel at different speeds and vehicle power loads. Although the current version of MOVES does not calculate emissions from off-road sources, a future version of the model will. EPA released a series of guidance documents for use of the MOVES model in 2010, updated, and released November 2012 guidance on use of the model for GHG analysis in 2012.[43]

Sensitivity to local driving conditions is valuable when examining transportation plans and policies, such as new highway capacity investments, congestion pricing, and other strategies that affect vehicle speeds and operating conditions. To capitalize on the additional capabilities of MOVES, though, a significant volume of input data may be required, along with significantly greater amount of user (and processing) time, as shown in Table 20.

[42] MOVES models emissions at the national, county, and project scales. Statewide estimates may be developed with national-level inputs and default downscaling, although EPA does not recommend this method. Instead, state-level estimates could be developed by aggregating counties of interest. See EPA's guidance on this topic at: http://www.epa.gov/otaq/stateresources/ghgtravel.htm.

[43] See EPA's web page at: http://www.epa.gov/otaq/stateresources/ghgtravel.htm for the latest version of this guidance.

Table 20. MOVES Data Inputs for GHG Analysis

Input	Default Data in MOVES?	Typical Data Source
Source (Vehicle) Type Population	Only for national default analyses (which can be used to analyze one or more states or counties) [44]	Local registration data – national defaults for heavy trucks and some other classes
Vehicle Type VMT	Only for national default analyses (which can be used to analyze one or more states or counties)	Travel model or HPMS
Month, Day, Hour VMT Fractions	Default data available, but local data preferred	MOVES, HPMS, count stations
Average Speed Distribution	Default data available, but local data preferred	Travel model
Road Type Distribution	Default data available, but local data preferred	Travel model
Age Distribution	Default data available through EPA's website, but local data preferred	Local registration data for light-duty and MOVES national data for heavy vehicles (if no better local source)
Ramp Fraction	Yes	Travel model
Meteorological Data	Yes, but local data preferred	MOVES or National Weather Service
Fuel Supply/ Formulation	Yes	MOVES or local data
I/M Program	Yes	MOVES or local data

The level of effort needed to use MOVES depends on the type of analysis and the existing capabilities of the organization. Using MOVES at the National scale (where the model relies mostly or entirely on national default input data) is relatively simple. Likewise, if an area is already using MOVES for transportation conformity analysis or for development of emissions inventories or forecasts for air quality planning purposes (i.e., state implementation plans), adding GHGs to the list of pollutants being modeled in the analysis involves almost no extra effort. On the other hand, if an area is starting from scratch with MOVES, and wishes to perform an analysis involving extensive use of local data, more effort will be required.

[44] As noted above, defaults may be used for national scale runs at the state or county level; however EPA cautions users about using the national scale for reasons of accuracy in the downscaling factors.

There are two calculation types in the MOVES model: to produce emissions inventories or emission rates. Each of these calculation types is described below.

Strengths and Limitations

Table 21. Strengths and Limitations of Approaches to Estimating Emissions, Once Travel Activity Data Estimated

Method	Strengths	Limitations
Simple Factor	• Easily applied • Readily available	• Does not capture effects of policies affecting vehicle types and operation • Lack of precision.
Look-up table only accounting for fleet characteristics	• Easily applied • Captures regional fleet characteristics (albeit, not by model and year)	• Does not capture effects of strategies that affect vehicle operation, such as congestion reduction strategies • Less precise than an analysis using MOVES
Look-up table accounting for fleet characteristics and speeds (vehicle operating characteristics)	• Easily applied • Captures regional fleet characteristics and operating conditions	• Less precise than an analysis using MOVES
MOVES in Inventory Mode	• The inventory mode in MOVES can reduce human error, because it eliminates the need for the user to conduct a separate post-processing analysis to apply emissions factors.	• Using MOVES in inventory mode requires running MOVES every time the travel demand model is modified or a new VMT scenario is prepared. This can be time consuming.
MOVES in Emissions Rate Mode	• May significantly reduce frequency of MOVES runs. Emissions rates calculated by MOVES are used along with outputs of the travel demand modeling process (speed, etc.) to determine emissions. Thus, a new MOVES run is not required for each transportation demand model run.	• Emission rates can be complex to apply, as separate rates are produced for running and non-running processes (starts and extended idle), all of which are needed for a complete GHG inventory. • Individual model runs can be very time consuming. These rates often then need to be recombined for the analysis. • MOVES runs can take longer in emission rate mode

Key Data Steps and Options

Using Appropriate Emissions Factors

Transportation agencies may be able to collect emissions factors or tables of factors for use in GHG analysis by working with their state air quality or environmental agency. These factors could be developed based on national defaults or reflect location-specific fleet information, and may be developed using MOVES. Regardless of how the emissions factors are developed, the analyst should be careful to apply the appropriate emissions factors. Specifically:

Make sure the emissions factor matches with the types of vehicles being examined. For instance, use a factor that reflects only light-duty vehicles if analyzing a travel demand management strategy that reduces commute trips, and use a factor that reflects all vehicles (including heavy-duty trucks) for a strategy like a traffic improvement that affects all vehicles. Even so, this is an extremely crude approach, in that a vehicle type encompasses a wide range of different models and model years with significant variations in GHG (as much as a factor of 4), and the variation would be enormous if all vehicle types are aggregated together.

Recognize that emissions factors may be produced for running emissions (per mile) and non-running emissions (per vehicle, to reflect emissions from engine starts and extended idling of heavy-duty trucks), or may be developed in a composite form (accounting for running and non-running emissions). Use a factor reflecting only running emissions to evaluate a strategy like ramp metering that affects only running emissions, and use appropriate factors reflecting total emissions to evaluate a strategy like ridesharing that reduces full trips.

Option 1: Use a simple emissions factor

The simplest way to estimate GHG emissions from VMT would be to apply a single emissions factor that is either not sensitive to fleet mix and speed or is blended to at least consider fleet mix and average speeds and/or loads. A web search will reveal many emissions factors for different vehicle types from a variety of sources.

For example, the U.S. EPA has several emissions factors directly published, including a default rate of 423 grams of CO_2 per VMT for a passenger car (http://www.epa.gov/otaq/climate/documents/420f11041.pdf).

Once an emissions factor is selected, calculating GHG emissions is simple:
VMT x Emissions Factor = CO_2 Emissions

To provide a slightly more refined answer, other GHG emissions (CH_4, N_2O, etc.) can be accounted for and the total reported in units of grams of CO_2 equivalent (CO_2e). The U.S. EPA document cited above provides guidance on this topic. As noted, CO_2 emissions constitute up 95 to 99 percent of the global warming potential emissions from a typical vehicle so assuming a conservative five percent of the global warming potential from light vehicle emissions come from other GHGs, the initial CO_2 calculation could be multiplied by (1/.95) = 1.053 to estimate the grams of CO_2e. While this approach is very simple to develop and apply, it does not account for several important factors such as the effects of variations in speed or non-running emissions processes, such as vehicle starting or idling. Additionally, if the fleet mix is fairly complex, this approach can be more cumbersome than the other approaches listed below that provide a better way of accounting for variations in the vehicle fleet. These approaches also cannot account for changes in fleet emissions due to changes in fuel economy rules and emission standards, so they would not be useful for projecting future GHG emissions.

Option 2: Use look-up table only accounting for fleet characteristics

This option is similar to the Option 1 but utilizes different emissions factors for different vehicle types. Common types include the following:

- Passenger cars (sometimes just called light duty vehicles)
- Light duty trucks (e.g., pickup trucks, minivans, sport utility vehicles)
- Heavy duty trucks (may be divided into various weight classes)
- Buses

Separate emissions factors may be developed for gasoline, diesel, or fuel types, and may be weighted to reflect the appropriate shares of the vehicle fleet. These factors would ideally be created using MOVES to reflect locally specific information but could be developed based on national data or by estimating vehicle fuel economy for each type of vehicle and multiplying by appropriate carbon coefficients.

Option 3: Use look-up table accounting for fleet characteristics and speeds (vehicle operating characteristics)

This option is similar to Option 2 but goes further and includes look-up tables that show different emissions factors for different speeds, which can be used in combination with VMT data that is broken out by speed bin. The key advantage of this approach over the simpler methods is that speed is an important factor that affects GHG emissions. Consequently, using different emissions factors at different speeds is necessary in order to show the emissions effects of changes in traffic congestion and other strategies that affect vehicle speeds.

Option 4: Apply MOVES in Inventory Mode

VMT estimates are a required input to the MOVES model, [45] which can then provide estimates of total quantity of emissions for a given location and time.

Step 1: Convert transportation model output (or other VMT estimates) into MOVES data input format. VMT by vehicle and road types as well as the temporal distribution is characterized in five components:

- HPMSVTypeYear – lists the base year VMT for a given year by HPMS vehicle type IDs.
- MonthVMTFraction – lists the monthly fraction of annual VMT by the 13 MOVES vehicle (“source use”) types.

[45] For all but the national scale, at which they are a suggested input. Note that the national scale can be used to estimate emissions at smaller geographic levels such as a state (or states) or a county (or counties).

- DayVMTFraction – lists the fraction of VMT for any months and day types (weekday/weekend) by MOVES source type, month, and road type.
- HourVMTFraction – lists the hourly VMT fractionation by source, road, and day types, as well as by hour.
- Roadtypedistribution – lists the fraction of VMT by each source type on each road type.

EPA provides several spreadsheet tools to develop these inputs for county or multi-county scale modeling.[46]

Users would also need to map the transportation demand forecast model links to the MOVES road types.

Step 2: Generate other MOVES data requirements. Other data that would need to be collected for the model (if not relying on defaults) would include:

- Link average speeds or speed bins by time period → 16 MOVES speed bins by hour of the day and road type or alternatively, simulated speed distributions
- Source type population (number of vehicles in the county or domain)
- Vehicle age (registration) distribution
- Fuel supply (market share of various fuels)
- Meteorological data (temperature and relative humidity)
- I&M program specifications (by county or domain)

MOVES Conversion Factors

MOVES requires annual VMT by vehicle type as an input. U.S. EPA provides a series of tools to convert inputs into the form needed by MOVES, including a spreadsheet tool that converts Annual Average Weekday Vehicles Miles Travelled (AADVMT) at the HPMS level into yearly VMT in MOVES' required input format, including by type of day, by month, and by MOVES source types. Default or user-supplied adjustment factors can be used.

Step 3: Import data into the MOVES database. Entry of non-default data would be handled by the MOVES' County Data Manager tool at the county scale or the Data Importer at the national scale, similar to the process followed by nonattainment or maintenance areas when conducting SIP or conformity analyses. Much of both this step and step 2 can be avoided by running MOVES at the National scale, relying on national defaults, as described in EPA's MOVES GHG analysis guidance, albeit with decreased accuracy.

Step 4: Run MOVES model and estimate emissions inventory. Once the data inputs are prepared, the model can be run. The model estimates GHG emissions according to a variety of classifications, including vehicle type/class, fuel type, model year, pollutant, and others, as well as by process (running, start, refueling, and extended idle).

[46] See http://www.epa.gov/oms/models/moves/tools.htm for a list and additional information on the available tools.

Option 5: Apply MOVES in Emissions Rate Mode

MOVES can also be used to estimate emissions rates: emissions per unit of activity. Use of MOVES in rates mode is generally more complex than using MOVES in inventory mode, but it may be more convenient for agencies that have already developed processes for using MOVES rates to generate estimates of emissions for other pollutants.

The basic activities included in MOVES are distance traveled and vehicle population. In the MOVES model, the variety of emissions processes (running exhaust, start exhaust, evaporative emissions, etc.) included are associated with one of these two types of activities for its reporting of emission rates. The resulting rates have units such as grams per mile (for running exhaust, for example) or grams per vehicle (for starting exhaust, for example). The emission rates produced by the MOVES model can be then applied to estimates of the associated activities to calculate total emissions. A typical instance would be coupling VMT estimates, such as from travel demand modeling, with running emission rates, produced with MOVES, to predict total running emissions. The same approach would be used to combine vehicle population estimates (the total number of vehicles) with the applicable emissions rates for start or extended idling to predict total emissions for these processes.

This analysis of emission rates, and subsequent calculations of total emissions, could be done using either post processors that may be specifically available for travel demand models or manual analyses using spreadsheet or database tools. More information on these technical and operational issues is available in the MOVES User Guide, and in the MOVES training materials found on EPA's website at: http://www.epa.gov/otaq/models/moves/trainingsessions.htm.

Step 1: Collect MOVES Inputs. This step involves all the components listed above in Option 4, Steps 1 – 3,

Step 2: Run MOVES and estimate emission rates. The MOVES model produces running emission rates by road type, emissions process, and speed bin. In addition, the user can select to have MOVES produce rates that are disaggregated further, depending on available activity data. For example, most users would have VMT by vehicle type, and therefore should request output of rates by vehicle type. It is less likely that users would have VMT by fuel type or model year, but those choices are also available. Similar emission rates are also estimated for non-running emissions processes, generally replacing variations in speed with variations in temperature or hour.

Step 3: Disaggregate vehicle activity as needed and match road types between the models. This step first involves disaggregating vehicle activity, if necessary, so that the appropriate amount of activity can be multiplied by the MOVES-predicted emission factors. The second step is to match road types between the travel demand model and the MOVES outputs. For example, a typical approach could be to determine a total emissions factor for methane from all heavy-duty vehicles on highway links with an average speed of 65 mph. Proper disaggregation and matching ensures the MOVES emission factors represent the activity on the road type or for each link on the network.

Step 4: Estimate GHG emissions. Properly matched emission rates are then multiplied by the applicable VMT estimate to produce total running emissions. Similarly, non-running emission rates are multiplied by the appropriate vehicle population. This calculation of GHG emissions may be performed manually or the emissions factors can be loaded into a post processor of a travel model.

Examples

The examples in sections 5.1 and 5.2 show how different agencies have applied emissions factors. A variety of states and MPOs have used MOVES to generate emission factors that are then used to post process the output of their travel demand model. For example, Hillsborough County MPO (Tampa) has used MOVES GHG emission rates by speed to calculate emissions for long range transportation plan scenarios. The analysis was implemented in a postprocessor. A regional inventory of GHG emissions from transportation was developed by MWCOG. GHG estimates from mobile sources were calculated using data and forecasts of VMT by vehicle type from the air quality conformity analysis and by applying MOVES in inventory mode.

6. Alternative GHG Estimation Approaches

This section reviews two other methodologies for estimating emissions: the first focuses on estimating freight emissions based on commodity flow data; the second is a statewide policy analysis tool developed by FHWA called the Energy and Emissions Reduction Policy Analysis Tool (EERPAT).

6.1. Commodity Flow Based Methods to Estimate Freight Truck Emissions

Table 22. Selection Criteria for Commodity-flow-based Methods

Selection Criteria	Commodity-flow Based Methods	
	Basic Approach (e.g., use commodity flow data)	Refined approach (e.g., estimate truck VMT)
Analysis Type	Inventory or Forecast	Inventory or Forecast
Geographic Scope	-State -Some regions	-State -Some regions
Analysis Precision	Limited – simple method relying on many assumptions	Moderate – depends on levels of refinement
Data Needed	Commodity flow estimates	Commodity flow estimates and truck survey data
Necessary Analytical Capabilities	Limited – only applying emissions factors	Requires some modeling skills
Level of Resources Required (i.e., staff/budget)	Limited – but depends on commodity flow data availability	Depends on existing capabilities – requires development of origin/destination truck trip table
Capable of Addressing Vehicle Technology/Fuels Changes	No	No
Capable of Addressing Changes in Travel Demand	Yes, to the extent accounted for in commodity flow data	Yes, to the extent accounted for in commodity flow data
Capable of Addressing Changes in Vehicle Speeds and Operations	No	No

Description

Emissions from freight truck transportation, as well as other freight modes, can be difficult to forecast, since they are heavily influenced by future economic conditions, affecting both, truck VMT and fleet turnover/technology. This is particularly true since U.S. economic conditions are difficult to forecast, especially over decades, as is needed for GHG analyses that often extend to 2050.

Moreover, freight truck emissions are often driven by factors that are external to a state or region. This is particularly true with pass-through traffic and internal-external trips (truck trips with one end outside of the state or region). Some states have developed statewide truck travel demand models. A small number of MPOs have developed travel demand forecasting models specific to freight trucks; many MPOs simply forecast truck traffic as a fraction of passenger vehicle VMT. While some travel demand models do estimate truck VMT, these estimates often do not adequately address some of the key factors that influence freight truck travel and emissions levels. The strengths and weaknesses of current approaches to modeling freight emissions are explained in greater detail in a 2010 National Cooperative Freight Research Program Report – "Representing Freight in Air Quality and Greenhouse Gas Models."[47]

Commodity flow data provides an approach to estimate current and future freight movement, and can be used as a basis for GHG emissions estimates. An advantage of commodity flow data is that it can be linked to underlying economic drivers, expressed in employment data by industry, so forecasts will reflect expected economic changes. Commodity flow data can also be useful for examining shifts between freight modes (e.g., truck vs. rail).

Some states that do not have truck models have used commodity flow data to directly estimate emissions from freight trucks using a simplified approach. The following section provides a methodology for using commodity flow data to estimate emissions.

Strengths and Limitations

Table 23. Strengths and Limitations of Commodity Flow Based Models

Strengths	Limitations
• Provide a simple means to estimate freight-related emissions, particularly where travel forecasting models for freight are lacking. • Commodity flow data and forecasts are linked to economic drivers.	• While some data is available, there is overall a lack of data about freight traffic within and between regions, particularly with regard to "empty miles." • These methods have limited ability to consider congestion effects on truck GHG, truck driver eco-driving programs, speed limits on trucks, logistics improvements that reduce truck GHG, and other variables.

[47] National Cooperative Freight Research Program Report 4, "Representing Freight in Air Quality and Greenhouse Gas Models," prepared by Browning, L. et al., 2010, http://onlinepubs.trb.org/onlinepubs/ncfrp/ncfrp_rpt_004.pdf, p. 8.

Key Steps and Data Options

Step 1: Gather or develop commodity flow data. These data are usually expressed as tons of freight transported between origin region and destination region, by mode and commodity type. Data sources include:

- The U.S. Census Commodity Flow Survey - reports historic commodity flows in five-year increments at the level of Bureau of Economic Analysis (BEA) regions. *For more information, see: http://www.census.gov/econ/cfs/*
- FHWA's Freight Analysis Framework reports historic commodity flows for 123 regions. The data includes forecasts to 2040 with eight different freight modes, including truck, rail water, air, multiple modes, pipeline, other and no domestic mode. *For more information, see: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/*
- Private vendors: Private vendors, such as IHS Global Insight, provide more detailed estimates. For example, IHS Global Insight's Transearch database can include forecasts.

  Output: *Tons of freight transported to, from, and within the state/region.*

Step 2: Calculate ton-miles by mode. Using commodity flow data and estimates of distance between origin and destination regions, calculate the ton-miles of commodity flow, by mode. No additional data sources required.

Step 3: Estimate emissions factors and calculate emissions. Simple ton-mile GHG emission factors can be obtained for freight modes. These factors are usually estimated based on national data. Multiplying the freight truck emission factor by the truck ton-miles produces a GHG estimate. The same approach can be applied for other freight modes.

Freight ton-mile emissions factors can be obtained from a variety of different sources. EPA's SmartWay Transport Partnership has estimated illustrative ton-mile emission factors for freight trucks.[48] EPA's Climate Leaders Program[49] has also estimated ton-mile emission factors for medium and heavy-duty trucks. The World Resources Institute and the World Business Council for Sustainable Development GHG Protocol Initiative provides factors for use in preparing corporate GHG inventories.

> ***Outputs:*** *GHG emissions factors per ton-mile for freight modes, GHG emissions for freight modes.*

Example: Massachusetts State Freight Plan analysis

Massachusetts DOT used a commodity flow approach for the Massachusetts State Freight Plan. Freight ton-miles were obtained from the Global Insight Transearch database to estimate

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[48] http://www.epa.gov/smartway/documents/partnership/shipper/partnership/420b12005.pdf.

[49] http://www.epa.gov/climateleadership/documents/resources/commute_travel_product.pdf.

freight ton-miles transported by truck in the state. Ton-mile emissions factors from EPA were then used to calculate emissions. Global Insight provided forecasts of freight traffic through 2035, allowing the state to develop a baseline forecast for emissions analysis. See http://www.massdot.state.ma.us/planning/FreightPlan.aspx.

A more complex application of commodity flow data involves converting ton-mile data into truck trips, to estimate truck VMT. This approach has been used by some state DOTs for statewide freight analysis, as well as by a few MPOs to analyze external truck trips (those with one trip end within the metro area). In this approach, estimates of truck average payload by commodity type are used to convert commodity flow data to truck trips. Average payload factors have been estimated by researchers using the Census' Vehicle Inventory and Use Survey (VIUS) and other sources, and are available from FHWA. FHWA has recently updated VIUS estimates of average payloads for trucks by commodity.[50] Additional truck trips may need to be estimated to account for empty truck trips. Once the state or MPO has an origin/destination (O/D) table of truck trips, the trips can be assigned to the roadway network as part of the travel modeling process. Truck VMT and emissions can then be estimated using the approaches discussed in Section 5 above.

[50] FHWA, Office of Freight Management and Operations. "Estimation of 2007 VIUS Variable." October 15, 2009.

6.2. Energy and Emissions Reduction Policy Analysis Tool (EERPAT)

Table 24. Selection Criteria for EERPAT

Selection Criteria	EERPAT
Analysis Type	Scenario/strategy analysis
Geographic Scope	State
Analysis Precision	Screening level analysis – not suitable for project or detailed plan-level analysis
Data Needed	Extensive demographic, land use, strategy-related data required as inputs.
Necessary Analytical Capabilities	Tool is readily available but requires understanding of data inputs
Level of Resources Required (i.e., staff/budget)	May be significant depending on data collection required
Capable of Addressing Vehicle Technology/Fuels Changes	Yes
Capable of Addressing Changes in Travel Demand	Yes.
Capable of Addressing Changes in Vehicle Speeds and Operations	Limited to some congestion impacts

Description

The Energy and Emissions Reduction Policy Analysis Tool (EERPAT), which is based on Oregon's GreenSTEP Model, is designed specifically for GHG analysis. The EERPAT is a statewide policy analysis tool for providing rapid analysis of many scenarios that combine effects of various policy and transportation system changes, including those that are often difficult to analyze using traditional transportation system analysis tools.[51] EERPAT is sensitive to a large number of factors such as land use, transportation demand, vehicle technology, fuels, price and other inputs. The model is an open source tool and is designed to be adapted and used by other states.

51 Available online at: http://www.planning.dot.gov/FHWA_tool/default.asp.

Strengths and Limitations

Table 25. Strengths and Limitations of EERPAT

Strengths	Limitations
• EERPAT provides policy sensitivity for different GHG mitigation measures, including carbon taxes, technology solutions, transit, and demand management. • It can evaluate future changes in land use and it is sensitive to external changes in the price of fuel, as well as other pricing strategies. • EERPAT can incorporate changes in tailpipe emissions associated with changes in technology such as increased use of electric vehicles or plug-in hybrids. • The model can be used to assess the overlapping effects of bundles of GHG mitigation strategies.	• VMT estimates are attributed to the regions where the households are located instead of where the travel occurs. The model does not include trips originating outside of the state. • There are a large number of model inputs and some may be difficult to obtain. For example: o Battery range of electric vehicles, o Percentage of workers paying for parking o Percentage of employers with strong employer-based programs and percentage of households subject to strong TDM programs.

Key Steps and Data Options

Step 1: Collect demographic data to generate synthetic households. The model allows the user to generate a set of synthetic households for each forecast year that represents the likely household composition for each county, given the county-level forecast of persons by age. Each household is described in terms of the number of persons in each of six age categories residing in the household. A total household income is assigned to each household, given the ages of persons in the household and the average per capita income of the region where the household resides. Sources for this type of data include:

- U.S. Census
- State economic growth forecasts

EERPAT model inputs are shown below.

Table 26. EERPAT Model Inputs

Input Data and Assumptions	Description
Demographics	County population projection by age cohort State average per capita income growth Statewide population projection
Land Use	Urban growth boundary expansion rates Growth proportions in metropolitan, other urban and rural areas Urban mixed use assumptions
Transportation Characteristics	Rate of transit revenue mile growth Rate of freeway & arterial lane mile growth
Mitigation Strategies	Households affected by travel demand management, vehicle operations and maintenance strategies Car sharing deployment assumptions TDM travel reduction assumptions
Vehicle Fleet	Light weight vehicle ownership and use assumptions Vehicle type percentages Average fleet MPG by type and model year Electric Vehicle (EV) & Plug-in Hybrid Electric Vehicle (PHEV) travel range, market penetration Vehicle use optimization
Cost	Travel, parking, carbon, VMT, etc.
Fuel	Fuel type, carbon lifecycle, emissions per Kilowatt of electricity
Other	Incident reduction assumptions, truck deadhead percentage

Step 2: Collect input data to apply land use and transportation system characteristics. EERPAT includes models to estimate density and land use characteristics at a Census tract level based on more aggregate policy assumptions about metropolitan and other urban area characteristics. Each household is assigned to a metropolitan, other urban, or rural development type in the county where it is located based on policy assumptions about the proportions of population growth that will occur in each type. The number of lane miles of freeways and arterials is computed for each metropolitan area based on base-year inventories and policy inputs as to how rapidly lane miles are added relative to the addition of metropolitan population. In addition, growth in transit revenue miles is also input, including the revenue mile split between electrified rail and buses.

Step 3: Collect data on mitigation strategy assumptions, vehicle fleets, costs, and other inputs. The model assigns each household as being a participant or not in a number of travel demand management programs (e.g. employee commute options programs, individualized marketing) and/or to vehicle operations and maintenance programs (e.g. eco-driving, low rolling resistance tires) based on policy assumptions about the degree of deployment of those programs and household characteristics. Input assumptions about the market penetration of plug-in hybrid electric vehicles (PHEVs) and probability models are used to determine future shares of PHEVs and EVs based on input assumptions about the range of these vehicles. Total variable costs are determined for vehicle travel based on fuel economy, electric power consumption and policy variables (carbon taxes, parking fees, etc). Data sources for these inputs include:

- Statewide travel models
- Studies and estimates related to mitigation strategies and future fleets

Step 4: Calculate fuel consumption and estimate GHG emissions. The model estimates vehicle usage and vehicle fuel economy based on the travel behavior of the synthetic households. Each household is assigned the number of vehicles it is likely to own based on the number of persons of driving age in the household, the income of the household, the supply of transit and freeways and whether the household is located in an urban or mix-use area. This behavior is sensitive to a range of factors, including the price of fuel, the range of electric vehicles, the cost of parking, the impacts of congestion on fuel economy, the availability of other modes, etc. The model incorporates the overlapping effects of multiple policy strategies and considers how household budgets would respond to transportation costs.

Output: *GHG emissions based on travel behavior and vehicle technologies.*

Example: Oregon GHG scenario analyses

The model was developed first in Oregon as the GreenSTEP Model. GreenSTEP is currently being used to test various scenarios for the Oregon Statewide Transportation Strategy (STS) for reducing transportation sector greenhouse gas emissions. In the first round of modeling, a total of 144 scenarios were modeled. Policies were organized into six general categories:

- Urban (urban growth, mixed-use, transit, parking, bicycles)
- Pricing (fuel and carbon taxes, VMT tax, PAYD insurance)
- Marketing (travel demand, management, eco driving)
- Roads (capacity, incident management)
- Fleet (vehicle age, vehicle type, car sharing)
- Technology (fuel economy standards, electric vehicles, etc.)

Based on the GreenSTEP model, EERPAT was developed for application to other states. Its use was piloted by FHWA in Florida and documentation for the model is available on the FHWA website at: http://www.planning.dot.gov/FHWA_tool/.

7. Specific Transportation Strategy Analysis Methods

A range of tools and approaches can be used to analyze the effects of transportation GHG reduction strategies that cannot be directly accounted for in standard travel forecasting methods. These "off-model" analyses often use simple spreadsheet calculations or sketch planning methods. A wide range of tools are available, and samples of these analyses are described in more detail below. Note that some of the methodologies described below may not always be applicable to a regional or state-level analysis, but could be used to generate data for these analyses.

7.1. Transportation demand management strategies

Several spreadsheet-based calculators are available to estimate the impact of TDM strategies (i.e., reducing VMT, including transit improvements, ridesharing programs, and bicycle and pedestrian improvements). These calculators use a variety of empirical information from case studies and statistical analyses of price elasticities and travel time elasticities to predict the impact of TDM measures on either a site-specific basis or a region-wide basis. Most of the calculators focus on commute reduction measures that can be implemented by or through employers.

Table 27. Sample TDM Analysis Tools and Approaches

Tool/Approach	Brief Description
COMMUTER	Designed to analyze the impacts of transportation control measures such as transit employer-based transportation demand management programs and transit improvements, on VMT, criteria pollutant emissions, and CO_2. *For more information see: http://www.epa.gov/otaq/stateresources/policy/pag_transp.htm#cp*
TRIMMS	Developed by the University of South Florida. It is conceptually similar to the COMMUTER model, and can provide travel activity estimates. It was recently updated to include some emissions derived from MOVES.[52] *For more information see: http://www.nctr.usf.edu/clearinghouse/software.htm*
BAAQMD tool	Spreadsheet based tool intended to evaluate the impact of strategies at employer sites and local public strategies based on the California Air Pollution Controls Officers Association (CAPCOA) research (http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf). Results have been validated with case studies in the San Francisco Bay Area.

[52] At this time, emissions included in TRIMMS are exclusively for the year 2011 and do not include all MOVES pollutant processes.

Example Method for Assessing TDM Policies: Travel Efficiency Assessment Method (TEAM)

Developed for U.S. EPA, TEAM uses Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) with outputs from regional travel demand models and other relevant data (e.g., transit fares) to assess the potential VMT reduction for TDM and other "travel efficiency" strategies in larger geographic areas. Emissions factors from MOVES are then applied to the travel activity results from TRIMMS. Key steps in this approach include:

Step 1: Identify strategies of interest

Step 2: Select the sketch-planning tool (may be TRIMMS or some other tool)

Step 3: Collect the data

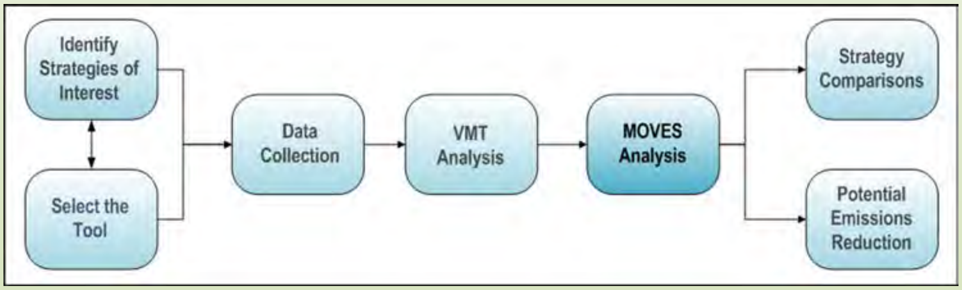
Step 4: Complete the VMT analysis

Step 5: Conduct the MOVES analysis to generate emission factors

Step 6: Compare strategies

The flow chart below lays out these steps.

Figure 12. Key Steps in the TEAM Approach



Source: U.S. Environmental Protection Agency, "Analyzing Emission Reductions from Travel Efficiency Strategies: The TEAM Approach." Developed by ICF International, September 29, 2011. http://www.epa.gov/otaq/stateresources/ghgtravel.htm

A more detailed assessment of many of these tools' capabilities, inputs, and outputs is available in a recent report from U.S. EPA.[53]

Strengths and Limitations

Key strengths and limitations of tools used to estimate the impacts of TDM strategies are noted in the table below.

[53] U.S. EPA, "Potential Changes in Emissions Due to Improvements in Travel Efficiency – Final Report," prepared by ICF International, March 2011. http://www.epa.gov/otaq/stateresources/policy/420r11003.pdf.

Table 28. Strengths and Limitations of Tools Used to Estimate Impacts of TDM Strategies

Strengths	Limitations
• Can use outputs from existing travel demand models. • Default data and existing modeling tools are available. • Allows quick comparison of results for different scenarios that use the same input or baseline data • Elasticity values, which are important for determining impacts, can be altered by the user if data are available, or defaults can be used.	• Using default data will reduce regional sensitivities. • Lack of familiarity with MOVES may be a limitation to using this methodology. • Due to data limitations, assumptions may need to be used. • Local travel time and price elasticity values are typically difficult to obtain, so national defaults are often used. • The effects of TDM strategies on network speeds and congestion are not captured in sketch planning tools like TRIMMS.

Example: Metropolitan Washington Council of Governments (MWCOG)

Metropolitan Washington Council of Governments' (MWCOG) Commuter Connections Program implements several Transportation Emission Reduction Measures (TERMs) to assist the region in meeting conformity requirements. The TERMS included are: Maryland and Virginia Telework, Guaranteed Ride Home, Employer Outreach, Mass Marketing, and Integrated Rideshare-Software Upgrades Project. The COMMUTER model is used as part of the analysis of the Employer Outreach TERM. The impacts of employer outreach are estimated by first inputting employer baseline ("before") mode shares and commuter assistance program strategies into the model. The model then estimates the "after" mode split and the average vehicle ridership when the program is in place. The COMMUTER model uses time and cost coefficients that are based on coefficients that are used in the region's transportation modeling. Adjustments may be made to these coefficients due to new data collected from a Household Travel Survey.[54] See http://www.mwcog.org/uploads/pub-documents/o15eWFw20120201151437.pdf.

[54] National Capital Regional Transportation Planning Board, Metropolitan Washington Council of Governments, "Commuter Connections Transportation Demand Management Evaluation Project – Transportation Emission Reduction Measures (TERMS): Revised Evaluation Framework 2008-2011," prepared by LDA Consulting. May 18, 2010.

7.2. Land use strategies

Off-model techniques are particularly useful for analysis of land use strategies because travel demand models typically do not capture the impact of small scale land use changes, including land use mixing, pedestrian accessibility and friendliness, and increased density, on travel patterns. There is an extensive body of research on the impact of such factors, known as the “4 Ds” (density, diversity, design, and destinations). Off-model techniques must typically be applied to account for them.

A number of tools exist to conduct off-model analyses of land use strategies. Some, such as INDEX and PLACE3S, can interface with travel demand model outputs. Other tools typically estimate changes in VMT based on relationships between factors such as population density, land use mix, and urban design. See below for a sample of transportation and land use analysis tools and approaches.

Table 29. Sample Transportation and Land Use Analysis Tools and Approaches

Tool/Approach	Brief Description
INDEX	Robust sketch planning model. Can interface with travel demand model and contains 4D adjustments to account for smart growth developments.
PLACE3S	Robust sketch planning model. Can interface with travel demand model and contains 4D adjustments to account for smart growth developments.
URBEMIS	User friendly model originally developed by the California Air Resources Board to assist local agencies with estimating emissions impacts of land use projects. Allows user to estimate potential vehicle travel and emission reduction benefits of site-based strategies, such as pedestrian/bicycle facilities, transit, on-site services, telecommuting, and alternative work schedules. Not ideal for large-scale, mixed-used, or smart growth plans
Sustainable Communities Model	Regional model can be configured for sub-area and project-level analyses. Uses California factors only. Requires extensive data from user, including trip generation, VMT, and fuel. Calculates effects from a variety of GHG mitigation techniques to determine the most cost-effective option. Allows communities to optimize planning and design decisions that result in the greatest environmental benefit for the least cost.
MetroQuest	Uses GIS-based sketch planning that offers immediate 40-year future scenario planning with the purpose of informing non-technical users about the trade-offs and costs of planning decisions in relation to GHG output. Uses data generated from analysis by regional travel forecasting models.
CommunityViz	GIS–based decision support software for planners and resource managers. It is an ArcGIS® extension that adds interactive analysis tools and a decision–making framework to the ArcGIS platform. Scenario 360 helps you view, analyze and understand land-use alternatives and impacts.

Examples

Cape Cod, Massachusetts Pilot Project

The Interagency Transportation, Land Use, and Climate Change Pilot Project conducted in Cape Cod, Massachusetts integrated climate change mitigation and adaptation measures into a transportation and land use planning strategy. Transportation and land use scenarios were evaluated using CommunityViz, and tested against performance indicators such as VMT and GHGs. The Volpe Center then worked with the National Park Service (NPS), the Cape Cod Commission, and the Commonwealth of Massachusetts to determine how to incorporate elements of a refined scenario into the region's planning efforts and long-range plans.[55]

Blueprint Sacramento

Sacramento's regional vision planning process used integrated land use, transportation modeling and extensive community involvement. The process developed a "blueprint" for how the region will grow and develop over the 50-year horizon. A number of different modeling tools were used to simulate the impact of different land use strategies on the demand for transportation and the creation of GHG emissions, among other impacts.

The primary technical component of the Blueprint development process was the I-PLACE3s platform, a public domain software package designed to integrate community participation, urban planning and design, and quantitative analysis. The Blueprint used a version of the software that could operate over the Internet, providing real-time feedback during public workshops. The software allowed users to apply a range of zoning designations to each land parcel in a given area. There are options to vary inputs such as building density and the number of available parking spaces. I-PLACE3s was able to calculate changes in each scenario and then display the results in tables and charts for easy comparison. By running the software over the Internet, the system did not require sophisticated equipment - it was possible to use laptops donated by local businesses.

The Sacramento Area Council of Governments (SACOG) utilized two additional tools to supplement the I-PLACE3s model. The first was MEPLAN, a land use and economic forecasting model that allocated growth to the region's transportation analysis zones, including variables for development policies, development costs, and rents. Outputs from MEPLAN were disaggregated to the parcel level and used to populate the I-PLACE3s database. The second tool was the regional travel demand model, SACMET, which used the impact assessment output from I-PLACE3s. SACMET was enhanced with data from household travel surveys to adjust vehicle trips and vehicle miles traveled based on land use density, mix of uses, and distance measures at the zonal level. SACMET and MEPLAN have since been replaced by new generation models that better capture the relationships between land use and transportation,

[55] Research and Innovative Technology Administration, Volpe National Transportation Systems Center, "Interagency Transportation, Land Use, and Climate Change Pilot Project." http://www.volpe.dot.gov/coi/ppoa/publiclands/projects /interagencypilotproject.html.

economic systems, and demographic changes. The integrated framework allows for better understanding of infrastructure investments and policy options.

SACOG found that use of such a comprehensive data-driven approach to be very effective. Once the system was built, it could be adjusted relatively simply by changing assumptions and other policy variables. The technical approach and transparency facilitated development of multiple scenarios, and helped to build public support, as participants could better understand the source of future decisions.

For more information, see:
http://www.fhwa.dot.gov/planning/processes/land_use/case_studies/sacramento_ca/index.cfm.

7.3. Transportation system management and eco-driving strategies

Transportation System Management (TSM) strategies include measures such as traffic surveillance, work zone management, electronic toll collection, traffic incident management, road weather management, emergency management, and traveler information services. TSM strategies also include measures such as ramp metering and signal timing that reduce recurring delay, as well as other types of intelligent transportation system (ITS) technologies that reduce non-recurring delay due to incidents, weather conditions, work zones, and special events. TSM strategies typically reduce emissions by reducing idling and delay, and allowing for smoother traffic flow. Eco-driving involves public education efforts to encourage drivers to operate their vehicles more smoothly, with fewer rapid starts and stops, as well as other practices, such as keeping tires fully inflated. The benefits of these strategies are not captured in most regional travel models, and therefore, off-model analyses are often conducted for these strategies.

Tools to analyze TSM strategies can be characterized as follows:

- **Sketch planning tools** produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements, and are generally used in relation to regional (or statewide) planning. These approaches are typically the simplest and least costly of the traffic analysis techniques, but are usually limited in scope, analytical robustness, and presentation capabilities. Two examples are: the **ITS Deployment Analysis System (IDAS)** and **Screening for ITS (SCRITS)**.
- **Deterministic tools** typically implement the procedures of the Highway Capacity Manual (HCM) to quickly predict capacity, density, speed, delay, and queuing on a variety of roadway types. They are good for analyzing the performance of isolated or small-scale transportation facilities, but limited in their ability to analyze network or system effects. Two examples of deterministic models are Traffix and Highway Capacity Software (HCS).
- **Traffic simulation tools** perform detailed representations of traffic flow in real-world locations. These tools require a large amount of detailed input data, including detailed roadway geometric, signal timing, and trip generation/distribution data, and extensive validation and quality control. Because of their data and computer processing

requirements, simulation tools are generally not appropriate for use at a regional scale.[56] Simulation tools can be combined with travel demand models to examine freeway performance in individual corridors. Simulation tools include macroscopic simulation models such as **FREQ, PASSER,** and **TRANSYT-7F**, which simulate traffic flow taking into consideration cumulative traffic stream characteristics (speed, flow, density); microscopic simulation models, such as **CORSIM/TSIS, Paramics, and VISSIM,** which model individual vehicle movements; and mesoscopic simulation models, such as **SYNASMART-P and TRANSIMS**, which combine the properties of both macroscopic and microscopic models.[57] Newer methods of "dynamic traffic assignment" (DTA) combine the ability to re-route traffic through the network with less-rigorous models for synthesizing the effects of congestion. Examples, such as **CUBE Avenue, Dynameq** and **TransModeler,** are somewhat less demanding in terms of data and analyst time, allowing for analysis of larger sub-regional transportation networks.

Example: Implementing Integrated Corridor Management (ICM) strategies on the U.S. 75 corridor in Dallas, Texas

The Integrated Corridor Management (ICM) initiative demonstrated the benefits of integrating ITS technologies on U.S. 75, a major corridor in Dallas, Texas. By integrating ITS assets and implementing ITS strategies regionally, ICM improves mobility, safety and reduces fuel consumption.

The analysis, modeling and simulation of Integrated Corridor Management (ICM) strategies on U.S. 75 combined a macroscopic trip table manipulation for determining trip patterns; a mesoscopic analysis for assessing the impact of driver behavior in reaction to ICM strategies; and a mesoscopic traffic simulation model (DIRECT) for reflecting the effects of signal timing. The analysis used 2007 as the model base year, and focused on morning peak periods.

The analysis assessed mobility, reliability and variability, and emissions and fuel consumption. Mobility measures included travel time, delay (defined as the total observed travel time less the travel time under noncongested conditions), and throughput (defined as the number of vehicles and persons per hour by direction). Reliability and variability were calculated from multiple simulated runs under all scenarios. Emissions and fuel consumption were determined by calculating and matching emission rates to reference values in EMFAC, the California Air Resources Board's emission factors model. The values were monetized by applying costs per ton of pollutants released and the purchase price of fuel.

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[56] FHWA, "Traffic Analysis Toolbox, Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools," July 2004.

[57] Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream, with simulation taking place on a section-by-section basis rather than by tracking individual vehicles. Microscopic simulation models, in contrast, simulate the movement of individual vehicles based on car-following and lane-changing theories. Mesoscopic simulation models combine the properties of both microscopic and macroscopic simulation models; as such, they provide less fidelity than microsimulation tools but are superior to the typical planning analysis techniques. For more information on these types of tools, see FHWA's Traffic Analysis Tools Program at: http://ops.fhwa.dot.gov/trafficanalysistools/index.htm.

The study evaluated comparative travel time information (pre-trip and en-route traveler information); incident signal retiming plans for arterials; incident signal retiming plans for frontage roads (frontage roads run parallel to U.S. 75); light-rail transit (LRT) smart parking system; Red Line capacity increase (Red Line is a LRT); LRT station parking expansion (private parking); and, LRT station parking expansion (valet parking).

Benefits were savings in travel time, increased travel time reliability, reduced fuel consumption, and reduced emissions. Expected annual savings included 740,000 person-hours of travel, and a reduction of fuel consumption by 981,000 gallons of fuel. For more information, see: http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/313049832D53A59885257926006FCF0C?OpenDocument&Query=Home.

7.4. Freight strategies

Freight strategies within the purview of DOTs and MPOs include idle reduction programs and policies; truck driver eco-driving programs; logistics improvements (e.g., use of ITS tools to reduce truck clearance times at international borders and weigh stations); freight bottleneck removal; overall congestion relief; incentives for retrofit of older diesel engines; and mode shift strategies. The U.S. EPA SmartWay Transport Partnership offers information to analyze the benefits of some of these strategies. For example, the SmartWay web site (www.epa.gov/smartway) includes several calculators and models that provide fuel consumption rates of idling trucks and of idle reduction solutions; guidance for states that want to incorporate idle reduction projects in their air quality plans; current and prior idle reduction projects funded by SmartWay and others, and the environmental and related benefits of these projects; and other key tools and information on the effectiveness and benefits of reducing idling from trucks and locomotives. EPA also has created the SmartWay Transport Partnership **Freight Logistics Environmental and Energy Tracking Performance Model (FLEET)**, which can also be found on EPA's website at http://www.epa.gov/climatechange/wycd/tools_transportation.html.

Sketch analyses can also be applied to freight strategies. These are typically spreadsheet calculations that use assumptions about the effectiveness and penetration rate of strategies. Examples of such analyses can be found in *Moving Cooler*.[58] Consideration of freight emission reduction strategies will need to take into account future changes in fuel economy of freight trucks, such as the joint DOT and EPA fuel efficiency and GHG emission program for medium- and heavy-duty vehicles.[59] States and MPOs can also analyze strategies to support technology and fuel changes, such as through providing alternative fuel infrastructure.

Example: Southern California Association of Governments (SCAG)

The Southern California Association of Governments' (SCAG) "Regional Goods Movement Plan" supports state and local goals to reduce GHG emissions. SCAG has done extensive analysis of the air quality and GHG emissions impacts of a number of different freight strategies. The strategies considered focus primarily on truck and locomotive emissions, since SCAG is actively engaged in planning improvements to highway and railroad systems.

For example, SCAG's regional "Clean Truck Corridor Strategy" involves the creation of a bi-directional corridor that would be restricted to truck traffic and have limited ingress/egress points. This freight corridor would streamline the flow of freight trucks moving to and from the Ports of Los Angeles and Long Beach. By creating a dedicated truck lane, the freight corridor would be a catalyst for the use of zero-and/or near-emission truck technologies. Incentives would be provided for zero or near-zero emission trucks and clean truck infrastructure (including wayside power).

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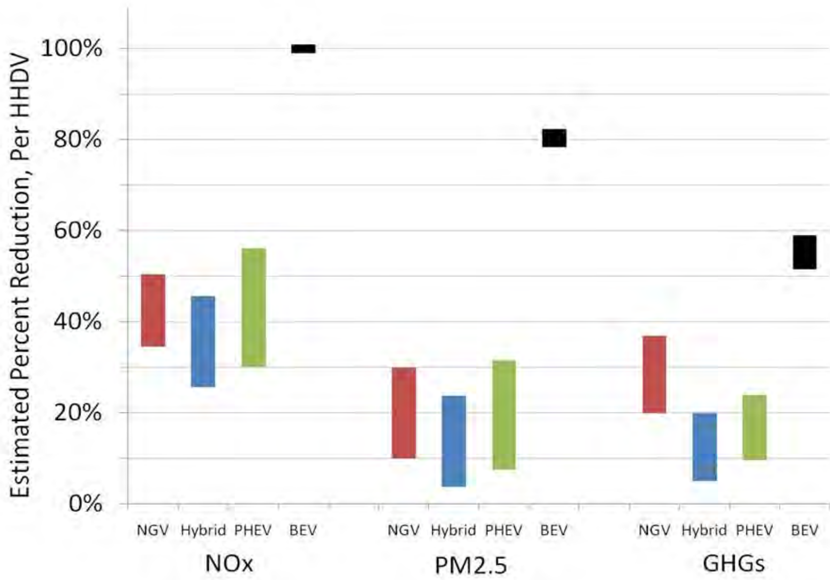
58 Cambridge Systematics, "Moving Cooler: an analysis of transportation strategies for reducing greenhouse gas emissions," Urban Land Institute, October 2009.

59 "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and heavy-Duty Engines and Vehicles," *Federal Register 76:179,* September 15, 2011, p. 57106.

SCAG's analysis included four categories of advanced truck technologies: advanced natural gas vehicles, hybrid-electric vehicles, plug-in hybrid electric vehicles, and battery electric vehicles. For each category, SCAG described the current state of technology, expected developments over the next 10-20 years, and barriers to advancement. SCAG estimated the expected emissions benefit, incremental vehicle cost, and timeframe for commercial availability for each technology and truck weight class. SCAG developed hypothetical scenarios for deployment of these emission reduction technologies in 2023 and 2035, including region-wide emissions benefits and costs. The figure below shows emissions reductions for advanced technology HHDVs (the heaviest class of heavy duty vehicles) in 2035.

Figure 13. 2035 Emission Reduction for Advanced Technology HDVs



Source: Southern California Association of Governments, "Environmental Mitigation Strategies, Task 10.2 Report," prepared by ICF International, September 2011.

Other strategies analyzed by SCAG included an enhanced truck inspection and maintenance program, conditional use permits for warehouses, increased enforcement of ant-idling regulations, expansion of on-dock rail, expansion of near-dock rail, grade separation of rail intersections, an off-peak delivery program, and improved transportation system management. SCAG used forecasts for truck traffic and estimates of vehicle emissions based on the EMFAC model and other sources to estimate the CO_2 emissions impacts. SCAG also considered strategies to reduce emissions from locomotives. They quantified the benefits and costs of several strategies to reduce locomotive emissions, including the accelerated deployment of Tier 4 locomotives, railroad main line electrification, and strategies focused on switching locomotives.

For more information, see:
http://rtpscs.scag.ca.gov/Documents/2012/final/SR/2012fRTP_GoodsMovement.pdf.

8. Additional Considerations in GHG Analysis: Lifecycle Analysis and GHG Emissions from Transportation Construction & Maintenance

This section discusses two areas of emissions analysis: lifecycle analysis and emissions from transportation infrastructure construction and maintenance. While these may be important considerations for transportation agencies and there are some available methodologies and tools, these approaches are still emerging in practice. Neither lifecycle emissions nor construction and maintenance emissions have comprehensive, agreed-upon methodologies that are widely accepted for use in transportation planning.

8.1. Lifecycle GHG Analysis

Table 30. Selection Criteria for Lifecycle Emissions Analysis Methods

Selection Criteria	Lifecycle Assessments	
	Alt Fuels, using GREET Model	Electric Transit Emissions
Analysis Type	Inventory or forecast	Inventory or forecast
Geographic Scope	-State -Regional -Possible at local level	-State -Regional -Possible at local level
Analysis Precision	Incorporation of lifecycle information supplements on-road emissions information	Incorporation of lifecycle information supplements on-road emissions information
Data Needed	Fuel mix, inventory results	Ridership, passenger load
Necessary Analytical Capabilities	Moderate – uses direct emissions inventory results, but requires familiarity with modeling	Limited– relatively simple calculation approach
Level of Resources Required (i.e., staff/budget)	Limited if inventory already prepared	Limited – relatively simple calculation approach
Capable of Addressing Vehicle Technology/Fuels Changes	Yes	Yes
Capable of Addressing Changes in Travel Demand	Accounted for within the direct fuel consumption estimates	Accounted for within the direct fuel consumption estimates
Capable of Addressing Changes in Vehicle Speeds and Operations	Accounted for within the direct fuel consumption estimates	No

Description

A fundamental difference between GHG emissions and criteria pollutant emissions is that the environmental impact of GHG emissions (climate change) does not depend on the location or timing (e.g., diurnal profile) of the emissions. Because of this, it can be important in some circumstances to consider emissions that are caused by transportation plans and projects but do not come directly from the vehicle tailpipe. The field of lifecycle assessment (LCA, also known as lifecycle analysis) is concerned with understanding the full environmental impacts associated with all the stages of a project or product life. In its complete form, LCA can cover raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Transportation agencies could potentially use LCA to examine the full lifecycle of GHG emissions associated with all transportation activities. However, its application is typically limited to analyses involving alternative vehicle fuels and electric transit service, since these strategies reduce or eliminate tailpipe emissions but may not yield corresponding reductions in total GHG emissions from a lifecycle perspective.

This section presents two methods: one for analyzing alternative vehicle fuels and one for analyzing electric transit service. Note that these two methods are not substitutes for one another, but rather both examples of types of LCA applied to emissions from different activities. At the present time, LCA is an emerging field of analysis, and analysis methodologies have not been standardized.

Strengths and Limitations

Table 31. Strengths and Limitations of Lifecycle Emissions Analysis Methods

Analysis/Method	Strengths	Limitations
Alternative Fuels, using GREET	• Use of defaults allows for users to easily estimate reductions associated with each alternative fuel. • Incorporates environmental impacts associated with producing and distributing biofuels – known as “upstream” emissions.	• A lifecycle approach to emissions analysis may be unfamiliar to transportation decision makers and difficult to communicate to stakeholders. • Emissions analyses cannot be compared to prior analyses that did not use a lifecycle approach. • In some cases, GREET relies on national default values that may differ substantially from local conditions.
Electric Transit Service	• Methodology is straightforward and easy to apply using accessible data sources.	• Does not account for emissions associated with electric passenger vehicles. • Electricity use by a transit agency may span state or regional boundaries – with varying carbon intensities associated with the electricity sources.

Key Steps and Data Options

Option 1: Alternative Transportation Fuels

For agencies that have conducted LCA analysis, the preferred approach for analyzing lifecycle emissions associated with alternative fuels is Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model, which simulates the use of fuels in passenger cars and two classes of light duty trucks.

Step 1: Determine the carbon intensity of the fuel pathway. The GREET model, which is available for download for practitioners, provides default estimates for over 100 different fuel pathways. Users can select the vehicle and fuel(s) of interest using the tool and can specify the fuel source if known. A sample table of results from the GREET model appears below.

Table 32. Lifecycle GHG Impacts of Sample Alternative Fuels

Fuel	Feedstock	WTP	PTW	WTW
		gCO$_2$e/mi		
Gasoline	U.S. Average	93	358	451
Ethanol (E85)	Corn	19	352	371
	Switchgrass	-233	352	119
CNG	NA NG: U.S. Average	119	272	391
LNG	NA NG: U.S. Average	118	273	391
Hydrogen	Central NG SMR	238	0	238
	Electrolysis, Renewables	3	0	3
Electricity	U.S. Mix	333	0	333
	California Mix	172	0	172
Diesel	U.S. Average	79	308	386
FTD	non-NA from NG	170	297	467
Biodiesel (B20)	Soybean	21	308	329
Renewable Diesel	Soybean	-207	298	92

Source: GREET.

Output: *Lifecycle impacts of each fuel by grams of CO_2 per mile (gCO$_2$e/mi) as:*

- *"well to pump (WTP)," – emissions to extract, produce, and transport the fuel*
- *"pump to wheel (PTW)," – tailpipe emissions; and*
- *"well to wheel (WTW)." – the sum of WTP and PTW.*

Common Tool: The GREET Model

State DOT and MPO practitioners can download the GREET results mini-tool (available at: http://greet.es.anl.gov/results). The mini-tool is a simple MS Excel™-based tool that users can use to compare the lifecycle emissions attributable to conventional and alternative fuels. Steps to use the mini-tool are as follows:

1. **Select functional unit for comparative purposes**. In most cases, state DOT and MPO practitioners would choose per mile ("per mi").
2. ***Optional:* Select vehicle type.** The GREET model has default assumptions for vehicles using gasoline. If the user is interested in comparing the use of alternative fuels to more fuel efficient vehicles, then select HEV (Hybrid Electric Vehicle) or one of the PHEV (Plug-in Hybrid Electric Vehicle) options. Otherwise, all comparisons will be in reference to a typical gasoline vehicle.
3. **Select the alternative fuel to compare against gasoline**. Options include Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Ethanol, Diesel, Fischer-Tropsch Diesel (FTD), Biodiesel, Renewable Diesel, Pyrolysis Gasoline, Pyrolysis Diesel, Gaseous Hydrogen, and Electricity.
4. ***Optional:* Select feedstock or source of alternative fuels.** Unless the user is confident of the sources of the fuel, the user should select the first option as a feedstock for each alternative fuel. For instance, in the case of CNG, this would be "North America Natural Gas: U.S. Average"; for Ethanol it would be "Corn."

The results are shown on a results sheet in Excel, with the fuels listed as columns and the breakdown of energy inputs in rows. The total grams of carbon dioxide equivalents per mile (gCO2e/mi) are shown as well-to-pump (WTP), pump-to-wheels (PTW), and well-to-wheels (WTW; sum of WTP and PTW). PTW is effectively the same as tailpipe emissions.

More information about the GREET model can be found here: http://www.transportation.anl.gov/modeling_simulation/GREET/index.html

Step 2 (if needed): Recalculate Baseline Emissions on WTW Basis. If the existing baseline emissions estimate includes only tailpipe (PTW) emissions, then to properly calculate a lifecycle GHG impact of alternative fuels, the user would need to re-calculate the baseline GHG emissions for WTW, rather than just the tailpipe or PTW emissions.

For example, if the current emissions estimate was calculated as: *VMT x PTW_Gasoline*, this will need to be re-calculated as: *VMT x WTW_Gasoline,* which allows for the user to estimate reductions associated with an alternative fuel.

> ***Output:*** *Transportation emissions on a WTW basis.*

Step 3: Calculate percentage change in emissions per fuel. Using the GREET results, the user can calculate the percentage change in emissions associated with an alternative fuel. That percentage change can be applied to the GHG emissions estimates for the fraction of the VMT that would be using the alternative fuel.

Output: *Reduction in CO_2e associated with alternative fuels.*

Option 2: Electric Transit Service Emissions

Public transit service powered by electricity is considered an indirect source of GHG emissions. Electric transit includes most heavy rail, light rail, and trolley bus systems, as well as some commuter rail systems. The American Public Transportation Association (APTA) has developed recommendations for quantifying GHG emissions from transit for the purposes of a GHG inventory.[60] A similar approach can be used for forecasting emissions.

Note that this approach would not be valid for forecasting lifecycle GHG for new or expanded electric transit infrastructure and vehicles, since that would require LCA analysis for the construction/manufacture of the infrastructure/vehicles, which would likely be significant.

Step 1: Estimate current and/or historic electricity used for transit propulsion. Data for this can generally be obtained from the following source:

- National Transit Database Table 17 (Energy Consumption)

  Output: *Agency electricity use in kilowatt hours (kWh) by mode*

Step 2 (for forecasts): Calculate ratio of electricity use per passenger mile or vehicle revenue mile. This can be done by using the known electricity use in kWh per mode from Step 1 and dividing it by passenger miles or vehicle revenue miles associated with electric transit service. Data for this is available through:

- National Transit Database Table 19 (Transit Operating Statistics: Service Supplied and Consumed).

  Output: *Kilowatt hours per passenger mile or kilowatt hours per revenue mile.*

Step 3 (for forecasts): Estimate future transit electricity use. Use a forecast of passenger miles or vehicle revenue miles to estimate future electricity use. Using a constant ratio of electricity use per passenger mile assumes no improvement in vehicle load factors. Using a constant ratio of electricity use per vehicle revenue mile assumes no improvement in vehicle fuel efficiency. A more sophisticated approach will account for changes in both of these factors.

Reporting Alternative Fuel Benefits
Unless the DOT or MPO baseline GHG emissions are calculated on a WTW basis, report a percent reduction attributable to alternative fuels on a WTW basis, rather than an absolute (tons) GHG emission reduction. Reporting benefits in this way will help the user avoid the potential of under- or over-estimating the GHG benefits of incorporating alternative fuels based on varying WTP and PTW parameters.

[60] American Public Transportation Association, Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit, APTA CC-RP-001-09, 2009.

Output: *Estimate of kWh used by transit service.*

Step 4: Estimate GHG emissions. GHG emissions can be estimated using electricity generation emission factors expressed in grams CO_2-equivalent per kilowatt hour. Emissions factors for electricity should reflect the source of the electricity and can be obtained from the following sources:

- Generator-specific emissions factors, if agency purchases electricity from a specific source; or
- Region-specific emissions factors from U.S. EPA's eGRID database.[61]

Output: *GHG emissions (current or forecast) from electric transit.*

Example: Los Angeles County MTA Sustainability Report

An example of an agency that estimates GHG emissions from electricity-based transit service operations is the Los Angeles County Metropolitan Transportation Authority (LACMTA). The agency calculates annual GHG emissions from the agency's heavy rail, light rail, and bus systems in an annual Sustainability Report. Because LACMTA purchases electricity from three different utilities, the electricity generation emission factors are estimated specific for each provider, rather than using a regional average. See: http://www.metro.net/projects/Metro-Environmental/sustainability-reports/

[61] See: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

8.2. Planning-level Analysis of Emissions from Construction and Maintenance of Transportation Infrastructure

Table 33. Selection Criteria for Construction and Maintenance Emissions Analysis Methods

Selection Criteria	Construction & Maintenance Emissions
Analysis Type	Inventory or forecast
Geographic Scope	-State -Regional -Possible at local level
Analysis Precision	Varies based on level of sophistication of analysis and number of factors that are considered.
Data Needed	Type and length of activity; engineering data
Necessary Analytical Capabilities	Varies based on level of sophistication of analysis and number of factors that are considered.
Level of Resources Required (i.e., staff/budget)	Varies based on level of sophistication of analysis and number of factors that are considered.
Capable of Addressing Vehicle Technology/Fuels Changes	N/A – Methods are focused on equipment and materials, not on-road vehicles
Capable of Addressing Changes in Travel Demand	N/A – Methods are focused on equipment and materials, not on-road vehicles
Capable of Addressing Changes in Vehicle Speeds and Operations	N/A– Methods are focused on equipment and materials, not on-road vehicles

Description

Construction and maintenance of transportation infrastructure is a sizable and often overlooked source of GHG emissions and energy consumption in the transportation sector. Construction of infrastructure consumes significant amounts of energy, mostly in the production of materials needed in the construction process. Once new infrastructure is in place, additional energy must be expended over time to maintain it. Transportation plans and projects that reduce GHG emissions by a marginal amount may actually result in a net increase in GHG emissions if the emissions associated with constructing and maintaining new infrastructure are taken into account.[62]

New York State DOT (NYSDOT) has developed a lookup-table procedure for estimating construction and maintenance energy consumption and emissions at the planning level, which is used by all of the New York MPOs to report GHG emissions pursuant to requirements in the state energy plan. Detailed information on specific equipment, technologies, and materials to be used in construction and maintenance typically are not available at a planning stage, so simplified assumptions are made. This analysis provides an estimate of the total magnitude of emissions associated with construction and maintenance and may provide a basis for considering alternative construction and maintenance techniques to reduce these emissions. NYSDOT has also developed a tool known as MOVES-Roadway and Rail Energy and Greenhouse Gas Analysis Extension (MOVES-RREGGAE) that combines construction and maintenance emissions information with operational emissions rates from MOVES. These procedures are available upon request from NYSDOT.

Because the information on construction and maintenance emissions used by New York is somewhat dated (MOVES-RREGGAE also relies on an older version of MOVES), FHWA has a research contract underway to develop up-to-date emissions information and a spreadsheet tool to facilitate estimating these emissions at the planning level. This tool would allow MPO or state DOT users to enter information about the lane miles and roadway/project type of planned construction, and estimate emissions from that level of construction. It will also allow users to estimate maintenance emissions from current and future roadway networks, estimate changes in operational emissions from both work zone delay and improved pavement smoothness, and evaluate the emissions benefits of alternative construction techniques. The tool is expected to be available in 2013.

Strengths and Limitations

Table 34. Strengths and Limitations of Construction and Maintenance Emissions Analysis Methods

Analysis/Method	Strengths	Limitations
Construction and Maintenance of Transportation Infrastructure	• NYSDOT methodology is straightforward and easy to apply using accessible data sources.	• Information used in the analysis is somewhat dated (but is in the process of being updated).

[62] This Handbook focuses on methods used for GHG analyses in statewide and metropolitan transportation planning. Detailed information on specific equipment, technologies, and materials to be used in construction and maintenance typically are not available at a planning stage, so simplified assumptions are made. This section does not address project-level analysis tools.

Example: Greater Buffalo Niagara Regional Transportation Council (GBNRTC) Energy and GHG Analysis

GBNRTC completed an energy and GHG analysis of its 2030 Long Range Transportation Plan. In addition to estimating the changes in "direct" (motor vehicle) operational energy consumption and GHG emissions associated with the plan, GBNRTC also estimated the "indirect" energy and emissions associated with transportation infrastructure construction. The "indirect" analysis includes energy use and emissions from construction equipment, transportation of materials, and those embodied in materials. Using information on the lane miles and project type associated with the new projects in the plan (track miles for rail transit projects), GBNRTC used NYSDOT procedures to estimate the "indirect" energy, and then convert energy consumption to CO_2 emissions. See http://www.gbnrtc.org/index.php/resources/publications/reports/.

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Publication No.: FHWA-HEP-13-026