Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects

Requested by:

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EXECUTIVE SUMMARY

Given the increasing scientific understanding of the threat of global climate change, many states and local governments are now placing increased attention on ways to reduce greenhouse gas (GHG) emissions, and the linkages between transportation planning and energy consumption. Lack of regulatory requirements, however, has meant that state departments of transportation (DOTs), metropolitan planning organizations (MPOs), and other transportation agencies have limited experience analyzing the GHG emissions impacts of transportation plans and projects and may not be familiar with available techniques for analysis. Moreover, some transportation agencies are concerned that the available techniques are not sufficient to conduct the types of transportation plan, project, and strategy analysis that are needed to address GHG emissions. The purpose of this report is to help transportation practitioners understand the strengths, limitations, and applicability of available GHG analysis techniques for transportation, and identify gaps in existing methodologies.

The mechanics of calculating the GHG emissions impacts of transportation projects and programs are conceptually quite simple. Carbon dioxide (CO_2) is by far the most significant GHG emitted by transportation sources, and CO_2 is emitted in direct proportion to fuel consumption, with some variation by type of fuel. As a result, estimating the GHG implications of transportation projects primarily involves estimating the amount of fuel – gasoline, diesel, and other fuels – used by motor vehicles and other transportation sources.

Although conceptually simple, this calculation in practice is quite complex, since vehicle fuel consumption depends on a variety of factors, including the mix of vehicle type, model year, and fuel type; vehicle operating characteristics, such as speeds and accelerations; and vehicle maintenance, tire pressure, and other factors. Moreover, some of these relationships (such as the implication of vehicle operating characteristics on fuel consumption) are complicated.

This report identifies a total of 17 tools or methods that can be used to analyze the GHG implications of transportation projects. Existing tools are categorized into three groups:

1) ***Transportation GHG calculation tools*** – These tools require the user to provide transportation activity levels (e.g., VMT or fuel consumption) and vehicle fleet inputs (e.g., vehicle fleet mix, age) in order to calculate GHG emissions. They vary in terms of their sophistication, and ability to address a range of different types of inputs and types of analysis. The most commonly used of these tools include the following: EPA's MOBILE6 model, State Inventory Tool (SIT), and Motor Vehicle Emissions Simulator (MOVES), and the U.S. Department of Energy's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model.

2) ***Transportation/emissions strategy analysis tools*** – These tools are designed to estimate travel and emissions impacts of specific types of transportation strategies, based on inputs about transportation programs or strategies (e.g., type of strategy, other parameters of specific strategies). Most of the analytical strength of these tools is in the estimation of travel impacts; the CO_2 calculation procedures are generally very simple, and often do not account for complex implications of vehicle operating characteristics on emissions. These tools include EPA's Commuter Model and the Federal Highway Administration's (FHWA) Intelligent Transportation Systems Deployment Analysis System (IDAS).

3) ***Energy/economic forecasting tools –*** These tools are designed to forecast energy consumption, typically based on economic factors such as economic growth and fuel prices. They include the U.S. Energy Information Administration's National Energy Modeling System (NEMS) and several other

tools developed by the U.S. Department of Energy for national and international analysis of energy demand.

Of all of these tools, the one with both the most detailed GHG emission calculation procedures and applicability for a broad range of transportation analyses is EPA's **MO**tor **V**ehicle **E**mission **S**imulator (MOVES), which analyzes CO_2, N_2O, and CH_4 from motor vehicles. Released in draft in January 2005, the MOVES model contains much more complex relationships between travel activity and GHG emissions than the MOBILE6 model, and can be used to analyze the implications of changes in vehicle operating characteristics on GHG emissions. It was designed for macroscale, mesoscale, and microscale analyses, and was developed in order to address gaps in other emissions models. It also relies on inputs from the transportation planning process, such as VMT and speeds, rather than inputs of fuel consumption Consequently, MOVES is recommended as a preferred modeling approach, to be used in coordination with appropriate input data or defaults.

Several other tools, however, can be used for specific purposes. EPA's State Inventory Tool can be used for developing a statewide GHG inventory. EPA's Commuter Model and FHWA's IDAS Model are valuable for analyzing the impacts of specific transportation strategies. Sketch planning methods, using simple spreadsheet calculations, can also be applied and may be most useful for individual strategy analyses.

No formal models or tools have been developed to easily analyze the implications of certain types of transportation projects and policies, such as non-road and multimodal transportation strategies. Further research on transportation GHG methodologies should focus on three areas: 1) developing practical approaches to assess the impacts of strategies that affect consumer vehicle purchase decisions and other programs and policies that affect vehicle fleet characteristics; 2) developing tools or approaches to more easily analyze the impacts of multi-modal transportation strategies; and 3) developing simple methods to analyze the direct impacts of transportation infrastructure construction and maintenance (i.e., emissions from construction equipment, snow removal equipment, etc.) on GHG emissions. Moreover, transportation agencies need additional guidance and training on how to conduct GHG analyses using tools such as EPA's MOVES model.

1 INTRODUCTION

1.1 BACKGROUND

Many state and local governments are implementing policies that are placing more attention on greenhouse gas (GHG) emissions and the linkages between transportation planning and energy planning. As of January 2006, forty-two states and Puerto Rico have developed GHG inventories and 29 of them have developed detailed Climate Change Action Plans. Seven states have actually set numerical GHG emission reduction targets and at least four have considered transportation measures in the portfolio of options that will be used to achieve those targets.[1] California has adopted regulations to reduce GHG emissions from new vehicles by 22 percent by the 2012 model year and 30 percent by the 2016 model year. New York State has developed a State Energy Plan, which recommends that metropolitan planning organizations include estimates of energy use and GHG emissions in their transportation plans. As these and other states aim to address global climate change, transportation agencies will need to take a more active role in developing inventories of transportation-related GHG emissions and evaluating GHG reduction strategies.

Although transportation is a major component of all state GHG inventories, state departments of transportation (DOTs) have provided limited input toward the development of these inventories. In states that have developed GHG inventories, this work has been led primarily by state environmental agencies relying on inventory techniques and guidance provided by the U.S. Environmental Protection Agency (EPA). Consequently, state DOTs have had little direct experience analyzing GHG emissions and are not very familiar with the tools available for GHG analysis.

Several methods are available to analyze the GHG impacts of the transportation sector and transportation investments. These tools and techniques have different capabilities and reflect different levels of data input. In addition, many of the GHG analysis tools have notable limitations when it comes to analyzing the GHG implications of transportation projects and plans. For instance, EPA's MOBILE6 model, the accepted motor vehicle emissions model for analyzing criteria pollutant emissions in transportation conformity analyses and State Implementation Plans (SIPs), is not sensitive to important factors like vehicle speeds in calculating carbon dioxide (CO_2) emissions. Moreover, many GHG analysis tools and techniques rely on transportation fuel consumption data as a data input, yet transportation agencies typically do not have good data or tools to forecast fuel consumption.

Given the recent release of some of these tools as well as lack of requirements for GHG analysis, many state DOTs and other transportation agencies are not familiar with the range of tools available for GHG analyses. They also need to understand the quality and applicability of these tools for analyzing transportation projects and programs in order to understand which tools and procedures are effective to use.

1.2 STUDY PURPOSE

The purpose of this report is to provide practical information to help transportation practitioners better understand the available greenhouse gas analysis techniques for transportation analysis. The objectives are threefold:

1. To identify methods that are available to accurately estimate GHG emissions from transportation activities, projects, and programs;

[1] As of January 2006, the seven states that had set numerical GHG emissions targets were Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, Rhode Island, and Vermont.

2. To evaluate these methods in terms of their strengths and limitations, and applicability for different types of transportation analysis; and
3. To identify gaps in existing tools, and develop recommendations for new methods or improvements to existing methods to fill these gaps.

1.3 REPORT ORGANIZATION

This report is designed to help transportation practitioners understand the analysis methods that are most appropriate for different types of transportation GHG analyses. It contains the following sections:

Section 1: Introduction
This section describes the motivation and purpose of this report.

Section 2: Fundamental Issues in Conducting Transportation GHG Analyses
This section provides a description of the basic mechanics of estimating GHG emissions from transportation sources, and highlights some fundamental issues to consider in conducting GHG analyses for transportation projects and programs.

Section 3: Available GHG Analysis Techniques
This section identifies, describes, and assesses 17 GHG analysis tools and techniques. It highlights the applicability and value of the tools.

Section 4: Recommended Methodologies for Transportation GHG Analysis
This section identifies recommended methodologies to use for different types of transportation GHG analyses. This section is designed to help guide the user to the most appropriate tools and techniques, based on the purpose of the analysis (e.g., state GHG inventory development, state GHG inventory projections, regional or local transportation plan/program analysis, project-level/corridor/strategy analysis).

Section 5: Gaps in Methodologies and Research Recommendations
This section identifies gaps in existing methodologies, and includes research recommendations to fill these gaps.

Appendix A: Summary of Methodologies
This section includes a "fact sheet"-style description of each GHG analysis tool, with information on the developer, purpose, modes addressed, gases analyzed, methodologies used, date released, and availability.

Appendix B: Assessment of Methodologies
This section assesses of applicability, strengths, and limitations of each GHG analysis tool.

2 FUNDAMENTAL ISSUES IN CONDUCTING TRANSPORTATION GHG ANALYSES

Prior to selecting a GHG analysis technique, it is important to have a basic understanding of the fundamental relationships between transportation and GHG emissions, and the mechanisms by which transportation sources emit these gases. This section highlights issues to consider in analyzing the GHG implications of transportation plans, projects, or activities.

2.1 THE IMPORTANCE OF CARBON DIOXIDE AND FACTORS AFFECTING EMISSIONS

Transportation sources emit several different gases that contribute to global warming, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs). Carbon dioxide is by far the most prevalent GHG emitted by transportation sources. According to the U.S. GHG Inventory, nationally over 95 percent of transportation GHG emissions were in the form of CO_2 in 2004, when measured in terms of global warming potential (CO_2 equivalent emissions).[2] The remainder of transportation GHG emissions were in the form of N_2O, 2.2 percent; CH_4, 0.1 percent; and HFCs, 2.3 percent.

Given the importance of CO_2, it is usually appropriate and acceptable for transportation GHG analyses to focus solely on this gas, particularly if resources are limited and if the analysis is designed to provide a general indication of GHG impacts.

Mechanics of Calculating CO_2 Emissions

Calculating the CO_2 emissions associated with transportation is conceptually quite simple. CO_2 is emitted in direct proportion to fuel consumption, with some variation by type of fuel. As a result, estimating the GHG implications of transportation projects primarily involves estimating the amount of fuel – gasoline, diesel, jet fuel, and other fuels – used by motor vehicles and other transportation sources.

The amount of CO_2 produced is a product of the amount of fuel combusted, the carbon content of the fuel, and the fraction of carbon that is oxidized when the fuel is combusted. A simple formula for the calculation of CO_2 for each fuel is as follows:

$$CO_2 \text{ emitted} = \text{Fuel Combusted x Carbon Content Coefficient x Fraction Oxidized x } (44/12)$$

Fuel combustion (in gallons for liquid fuels or cubic feet for natural gas) is converted into units of energy (Btus). The carbon content of fuel varies by type of fuel, and is usually expressed in terms of units of carbon per Btu. The fraction of the carbon oxidized is a lesser consideration since it has traditionally been assumed to be 99 percent for all fossil fuel combustion.[3] The factor 44/12 is the weight of CO_2 in relation to the amount of carbon in the fuel, assuming all carbon burned eventually oxidizes to form CO_2.[4]

[2] GHG emissions are typically reported in terms of CO_2 equivalent (CO_2 Eq.) to provide a common unit of measure. Other GHGs are converted into CO_2 equivalent on the basis of their global warming potential (GWP), which is defined as the cumulative radiative forcing effects of a gas over a specified time horizon in comparison to CO_2. Radiative forcing is the change in balance between radiation entering the Earth's atmosphere and radiation being emitted back into space.

[3] Recent analyses conducted for the U.S. EPA suggest that the oxidation fraction for light-duty gasoline vehicles is virtually 100 percent, and EPA recently has recommended use of the 100 percent fraction for transportation for its international reporting.

[4] Some carbon in fossil fuels is emitted in the form of carbon monoxide (CO), which swiftly decays into CO_2, and volatile organic compounds, which also decay into CO_2.

Consequently, the key analysis that needs to be conducted to estimate CO_2 is to determine the amount of fuel consumed by fuel type (e.g., motor gasoline, diesel, jet fuel, compressed natural gas, etc.).

Complexities Associated with Estimating Transportation Fuel Consumption

Although conceptually simple, this calculation in practice is quite complex since transportation agencies do not typically collect data to track vehicle fuel consumption by fuel type. In a limited number of cases, fuel data are available and can be used directly in calculating CO_2. For instance, for GHG inventory development, state fuel tax records are often used to estimate motor vehicle fuel consumption and CO_2. The availability of direct measures of fuel consumption, however, is generally limited for transportation agencies, and fuel consumption estimates may not be available at all for project-level, corridor, or regional analysis.

Transportation modeling generally focuses on estimating vehicle miles of travel (VMT) for motor vehicles, or person miles traveled (PMT) for transit and non-road modes. Given the primary use of VMT as a metric for transportation activity, the other key factor necessary to estimate vehicle fuel consumption is vehicle fuel economy (miles per gallon). Many factors influence vehicle fuel economy, including:

- the mix of travel by vehicle type and model year;
- vehicle operating characteristics, such as speeds and accelerations; and
- other factors, like vehicle maintenance, tire pressure, and air conditioner use.

The relationships between these factors and fuel economy are not simple. For instance, the implications of vehicle operating speeds on fuel consumption are not linear and depend on vehicle type and size. Consequently, an approach that assumes an average fuel economy by vehicle category will not accurately account for the effects of transportation projects that address vehicle speeds and traffic flow. The effects of vehicle operating speeds on fuel economy also vary based on the model year and age of the vehicle; for instance, studies of vehicle fuel economy taken during the 1990s show less of a drop off in vehicle fuel economy above 55 miles per hour than similar studies of vehicles during the 1970s and 1980s, due to vehicle design changes affecting aerodynamics, engine operating efficiency, etc.[5] As a result, an approach that assumes a standard formula for the level of fuel consumed per mile at a certain vehicle speed will not accurately account for the effects of changes in vehicle designs over time.

2.2 FACTORS AFFECTING EMISSIONS OF NON-CO_2 GHGS

Nitrous Oxide and Methane

Like CO_2, N_2O and CH_4 are released during fossil fuel consumption, but in much smaller quantities. Their emissions rates, however, are not directly proportional to fuel consumption. N_2O and CH_4 emissions rates per mile are affected by vehicle emissions control technologies. The newest motor vehicle emission control technologies produce significantly less N_2O and CH_4 than early emission control technologies (for instance, for a gasoline powered automobile, a vehicle with low emission vehicle (LEV) technology produces only about one-third the N_2O emissions of a vehicle with Tier 1 emission controls).[6] As a result, emission factors for on-road vehicles are usually presented in per-mile units, and analyses of these pollutants require information on VMT <u>and</u> the distribution of miles by vehicle type (e.g., automobile, light-duty truck, heavy-duty truck), fuel type (e.g., gasoline, diesel), and technology type (e.g., Tier 0, Tier 1, LEV). Knowing the emissions control technology used by vehicles is very important for generating accurate results. As simple formula for the calculation of N_2O or CH_4 emissions for each individual vehicle/fuel/technology type is:

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[5] See Davis, S. and S. Diegel, *Transportation Energy Data Book: Edition 24.* Oak Ridge National Laboratory (ORNL-6973), December 2004, pp. 4-26 to 4-27, citing studies conducted by FHWA in 1973, 1984, and 1997.

[6] According to U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003,* N_2O and CH_4 from on-road sources declined by over 20 percent between 2000 and 2003 while VMT rose.

$$\text{Emissions} = \text{VMT}_{(\text{Vehicle, Fuel, Technology Type})} \times \text{Emission Factor}_{(\text{Vehicle, Fuel, Technology Type})}$$

For non-road modes, N_2O and CH_4 are generally assumed to be proportional to fuel consumption, making the calculation relatively simple. However, with the introduction of emission control technologies to non-road sources, such as retrofits of diesel transportation construction equipment, more detailed analysis by control technology type may be needed to accurately address the impacts of these technologies on N_2O and CH_4.

HFCs and Other Gases

HFCs are synthetic chemicals that are used in vehicle air conditioning and refrigeration systems as alternatives to ozone-depleting substances being phased out under the Montreal Protocol. Leakage of HFCs during equipment operation, servicing, and disposal also contributes to GHGs, and so the level of HFCs released depend on factors such as air conditioning use and amount of refrigerated transport.

Finally, the transportation sector also contributes to emissions of several other compounds that are believed to have an indirect effect on global warming. These include ozone, carbon monoxide (CO) and aerosols. Scientists have not yet been able to quantify their impact with reasonable certainty; thus, these compounds are not included in reporting GHG emissions.[7]

2.3 ROLE OF DIFFERENT MODES OF TRANSPORTATION

On-road vehicles are the largest contributor to GHG emissions from transportation sources. In 2004, about 81 percent of U.S. transportation GHG emissions came from fossil fuel combustion by on-road vehicles, which include passenger cars, sport utility vehicles (SUVs), vans, trucks, motorcycles, and buses. Non-road sources produced about 16 percent of all transportation GHGs, with the majority coming from aircraft, followed by boats and ships, rail and pipelines. Two percent of GHG emissions came from releases of HFCs from vehicle air conditioning and refrigerated transport, while one percent came from lubricants, such as oil used in motor vehicle engine combustion.

Transportation agencies are most likely to be concerned with on-road sources, given the proportion of emissions relative to other sources and the role of State DOTs, MPOs, and other agencies in transportation planning for on-road sources. For some analyses, however, it may be important to address other modes of transportation (for instance, analysis of developing a light-rail line, a ferry system, or a major airport expansion) or all transportation sources (in the case of developing a statewide GHG inventory).

The calculation procedures for estimating CO_2 from on-road and non-road sources are conceptually the same, since CO_2 is released in direct proportion to fuel consumption, with differences in the amount of emissions by fuel type. The carbon content of a specific fuel (e.g., diesel) is the same regardless of what mode consumes it (e.g., trucks, locomotives, ships). However, the tools available to analyze emissions from non-road sources differ from those that can be used for exclusively assessing on-road emissions. Moreover, state and local transportation agencies often have limited data on fuel consumption by non-road modes.

[7] Ozone traps heat in the atmosphere and prevents a breakdown of CH_4, but its lifetime in the atmosphere varies from weeks to months, making it difficult to estimate the net radiative forcing effects. CO indirectly affects global warming by reacting with atmospheric constituents that would otherwise destroy CH_4 and ozone. Aerosols are small airborne participles or liquid droplets that have both direct and indirect effects on global warming. The most prominent aerosols are sulfates and black carbon, or soot. Sulfate aerosols also have some cooling effect by reflecting light back into space.

A summary of the fuel types commonly used by various modes is provided below.

Fuel Types Commonly Used by Different Transportation Modes

	Light-duty vehicles	Heavy-duty vehicles	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
Motor gasoline	√	√	√			√	√
Diesel (Distillate)	√	√	√	√		√	√
Jet fuel					√		
Aviation gasoline					√		
Residual fuel						√	
Electricity				√			
Other fuels*	√	√	√				

*Other fuels include: compressed natural gas (CNG), liquefied petroleum gasoline (LPG), and other alternative fuels.

2.4 THE VALUE OF CONDUCTING LIFECYCLE EMISSIONS ANALYSES

Although most GHG analyses focus on energy that is used to directly power transportation sources (vehicles, vessels, aircraft, etc.), there are other activities related to transportation that can be considered in GHG analyses.

Upstream and Downstream Activities

In addition to emissions produced directly through vehicle use, transportation activities require an array of additional "upstream" processes, such as the manufacture of vehicles and extraction and refining of crude oil. There also are "downstream" processes, such as vehicle and oil disposal, which require energy consumption and may release other GHGs.

A full lifecycle analysis of transportation takes into account direct activities, as well as upstream and downstream activities related to fuels and vehicles. Specifically, a full lifecycle analysis includes:

- the full fuel cycle, including upstream emissions (sometimes called "well-to-pump" analysis) associated with drilling, exploration and production, crude oil transport, refining, fuel transport, storage, and product retail, as well as downstream disposal or recycling of oil products.
- the full vehicle lifecycle, including vehicle manufacturing (raw material extraction, processing, and transport; manufacture of finished materials; assembly of parts and vehicles; and distribution to retail locations), maintenance, and disposal.

When developing a GHG inventory, GHG emissions from these processes are largely accounted for in the industrial or commercial sectors rather than the transportation sector.[8] Consequently, theses emissions are not usually considered within traditional transportation analyses.

A lifecycle assessment is important, however, in evaluating transportation policies that affect vehicle fuels and technology types. For alternative fuel vehicle strategies (e.g., purchases of alternative fuel buses, incentives for consumer use of alternative fuel vehicles), the benefits of strategies on a lifecycle GHG basis may be very different than when only examining direct vehicle emissions. For instance, for certain types of fuels, vehicle GHG emissions are lower than conventional fuels but are offset by higher

[8] Emissions from upstream activities that involve transportation, such as crude oil transport, are included as part of the transportation sector in GHG inventories, and should not be double-counted. However, in developing a state GHG inventory, many of these upstream activities occur outside of state boundaries, and so would not typically be included in state GHG inventory estimates, although the emissions are associated with transportation fuel consumption within the state.

upstream emissions. As a result, lifecycle analysis is often conducted when examining vehicle fuels/technology combination.

Lifecycle analysis may also be beneficial for broadly demonstrating the full implications of transportation activities, particularly when considering strategies that may reduce vehicle ownership. Based on data from the GREET and LEM models (described in Section 3), upstream (fuel cycle and vehicle cycle) GHG emissions are 18 to 43 percent of direct GHG emissions, varying by vehicle and fuel type.[9]

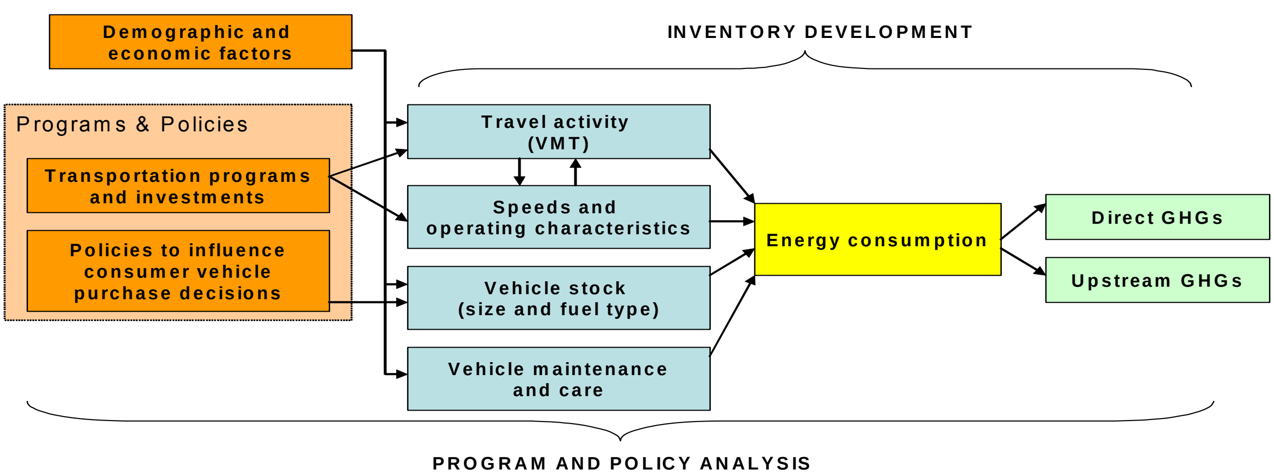
Infrastructure Construction/Maintenance

In addition to vehicle and fuel cycle related emissions, lifecycle transportation GHG analyses also sometimes consider infrastructure construction and maintenance, such as road building, repaving, snow removal, and other activities necessary to maintain transportation systems. These emissions are not typically included in estimates for the transportation sector since they involve non-transportation mobile sources (such as construction equipment, mowers, snow removal trucks, and aircraft ground support equipment).

Transportation agencies may be interested in GHG emissions associated with these activities, however, as the emissions are a result of their direct actions, unlike most transportation sector emissions which are indirectly affected by transportation investments and depend upon consumer vehicle purchase and use decisions. State DOTs or MPOs may wish to examine ways to reduce GHG emissions from their own processes as part of an environmental management system or other commitments to reduce emissions. The GHGs emitted directly as a result of transportation infrastructure construction and maintenance will generally be very small in comparison to the amount of GHGs emitted due to transportation activity by motor vehicles, aircraft, rail, and other sources.

2.5 STRATEGIES TO REDUCE TRANSPORTATION GHG EMISSIONS, AND TYPES OF GHG ANALYSES

Understanding the factors that affect GHG emissions is important for developing strategies to reduce GHG emissions and for understanding approaches for quantifying the GHG impacts of transportation. The following diagram is a schematic that identifies these factors and types of analysis.



[9] U.S. Environmental Protection Agency, *Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003*. Draft. Appendix B.

Transportation GHGs are emitted largely as a result of energy combustion, with different levels of emissions associated with different fuels. Energy consumption, in turn, is a function of vehicle travel activity and vehicle fuel economy, which is determined based on vehicle stock (including vehicle type, size, and fuel type), speeds and other operating characteristics of vehicles (including idling), and levels of vehicle maintenance and care. Demographic and economic factors play a key role in influencing vehicle travel activity and vehicle purchase and use decisions. Levels of vehicle travel, in turn, can affect vehicle speeds and operating conditions, due to congestion.

Transportation and energy/environmental programs, policies, and investments will affect the factors that together produce and influence GHG emissions, including:

- Travel activity – For instance, transportation agencies often implement transportation demand management (TDM) programs and investments designed to encourage shifts from single occupancy vehicles to ridesharing, transit, bicycling and walking, or avoiding vehicle trips entirely; development of new highway capacity, in contrast, may induce additional vehicle travel.
- Speeds and vehicle operating characteristics – Speed limits, the degree of infrastructure maintenance, and the supply of capacity also will affect vehicle operations. Moreover, transportation agencies also often directly implement programs designed to improve travel conditions (such as implementation of traffic flow improvements or intelligent transportation systems), to reduce vehicle idling (such as through idling restrictions, truck stop electrification, and incentives to purchase auxiliary power units), encourage reduced traffic delay (such as by encouraging alternative work schedules to shift drivers to off-peak periods and managing traffic work zones).
- Vehicle maintenance and care – Policies often are designed in part to encourage travelers to maintain their vehicles (such as inspection and maintenance programs or public education programs).
- Changes in vehicle stock - Finally, strategies can also be implemented to encourage or mandate consumers, freight shippers, or fleets to purchase more fuel efficient vehicles or alternative fuel (less carbon-intensive) vehicles. These strategies, which include implementation of vehicle fuel efficiency standards, feebates, and tax credits for purchasing fuel efficient or low emissions vehicles, are typically not under the control of state or local transportation agencies; rather, they are more often established by policymakers and implemented by environmental agencies.

When examining the impacts of transportation policies, investments, or programs on GHG emissions, the methodology should involve two steps: 1) determining the impacts on vehicle travel, fuel economy, or fuel type used; and 2) then calculating the GHG impact based on the change in these factors. The first step can often be addressed through use of a travel demand forecasting model or sketch planning methods that are traditionally used by transportation agencies in order to analyze the implications of their programs on VMT and criteria pollutant emissions. If the purpose of the analysis, however, is to develop a transportation GHG emissions inventory, then data need to be collected on transportation fuel consumption and/or vehicle travel for use in calculating GHG emissions.

3 AVAILABLE TRANSPORTATION GHG ANALYSIS TOOLS

A range of tools are available that can be used to analyze GHG emissions from the transportation sector. These tools, however, vary significantly in their capabilities and ease of use for transportation GHG analysis. Most of them were not designed primarily for transportation GHG analysis, and as a result, the methodologies and procedures employed are not always easy to use for transportation GHG analyses and do not always account for the full range of factors that influence GHG emissions.

3.1 TYPES OF TOOLS AND THEIR USES

This report identifies a total of 17 tools or methods that can be used to analyze the GHG implications of transportation projects. Existing tools are grouped into three categories, based on their primary function:

- Transportation GHG calculation tools;
- Transportation strategy analysis tools; and
- Energy-focused forecasting tools.

Specific tools and their potential uses are described below. See *Appendix A* for a more detailed description of each tool.

Transportation GHG Calculation Tools

These tools are designed to develop emissions estimates based on user-provided inputs, such as vehicle miles traveled (VMT) and/or fuel consumption (or to develop emission factors that can be combined with VMT estimates to develop emissions estimates). Some tools are designed with VMT as a primary input, while others are designed with fuel consumption as the primary input. They vary in terms of the transportation sources they address, level of sophistication, and ability to address a range of different types of inputs and analyses. The primary limitation of these types of tools is that the user may either not have access to solid data inputs or may not understand the assumptions inherent in the default data. Many of these tools were developed by the U.S. Environmental Protection Agency (EPA), and several have common methodologies or build upon each other.

These tools, their potential uses, and key characteristics, are described briefly below. They are divided into three sub-groups.

Multi-sector Inventory Tools – These tools are designed to develop GHG inventories or projections for all economic sectors, including transportation:

State Inventory Tool (SIT) – Developed by the U.S. EPA, the SIT is designed to develop a comprehensive GHG inventory (CO_2, CH_4, N_2O, and HFCs) at the state level, using a combination of state-specific inputs and default data. It requires inputs of transportation fuel consumption and VMT.

State Inventory Projection Tool (SIPT) – Developed for the U.S. EPA, the State Inventory Projection Tool builds on inventory estimates from the SIT by allowing users to forecast GHG emissions through 2020. Projections are based in part on projected fuel consumption reported by the U.S. Energy Information Administration.

Direct GHG Emission Calculation Tools – These tools focus solely on transportation sources, and are designed to develop emission factors or emission estimates for gases emitted during vehicle use:

MOBILE6 Model – This is the EPA-approved model that generates on-road motor vehicle emission factors for use in transportation analysis at the state, region, or project level. In addition to criteria pollutants, the model generates CO_2 emission factors, which can be combined with

VMT data to estimate CO_2 emissions. The CO_2 emission factors only account for vehicle type and model year; the emission factors do not account for impacts of vehicle operating conditions (e.g., travel speeds) on CO_2 and expected changes in future vehicle fuel economy.

NONROAD Model – This EPA-approved emissions model is used to develop estimates of criteria pollutant and CO_2 emissions estimates for non-road sources, such as recreational vehicles, agricultural equipment, construction equipment, lawn and garden equipment, recreational boats, airport ground support equipment, railroad maintenance equipment and others. NONROAD does not address commercial marine vessels, locomotives, or aircraft.

National Mobile Inventory Model (NMIM) - EPA developed NMIM to integrate the input data requirements, model runtimes, and post-processing requirements for MOBILE6 and NONROAD models into a single package.

EMFAC - The California Air Resources Board (CARB) developed EMFAC as the California version of MOBILE6. Using emission factors and vehicle activity inputs, EMFAC develops emission estimates for on-road vehicles to be used in developing emission inventories, projections, and other project level analyses. The CO_2 emission rates vary by vehicle speed.

Climate Leadership in Parks (CLIP) Tool - Prepared for EPA, the CLIP Tool allows for GHG and criteria pollutant emissions estimation at the local level for all highway and non-highway transportation and mobile sources (including off-road sources such as construction equipment). Although default vehicle characteristics are geared toward travel situations at national parks, CLIP allows users to enter additional data to reflect local conditions.

Draft New York State DOT Guidance on Transportation GHG Analysis – New York State Department of Transportation (NYSDOT) developed a series of draft guidance documents to assist in calculating the fuel consumption and the GHG impacts of transportation projects for project alternatives analysis and for metropolitan planning organizations' (MPO) Transportation Improvement Programs (TIPs) and long-range transportation plans. The methods accounts for the impacts of vehicle speeds on fuel consumption, relying on procedures summarized in Caltrans' "Energy and Transportation Systems" manual (from 1983).

Life-cycle GHG Emission Calculation Tools

Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) Model - Developed by the Argonne National Laboratory (sponsored by U.S. DOE), GREET is designed to fully evaluate the energy and emission impacts of advanced vehicle technologies and new transportation fuels (considering the fuel cycle from wells to wheels and the vehicle cycle through material recovery to vehicle disposal).

Lifecycle Emissions Model (LEM) - Developed by Mark Delucchi at the University of California, Davis, LEM estimates energy use, criteria pollutant emissions, and CO_2-equivalent greenhouse-gas emissions from transportation and energy sources.

Motor Vehicle Emissions Simulator (MOVES) – Being developed in stages by the U.S. EPA, MOVES is eventually intended to replace MOBILE6, NONROAD, and NMIM. The existing version of MOVES estimates energy consumption (for use in calculating CO_2), N_2O, and CH_4 from on-road vehicles from 1999 to 2050, and accounts for the impacts of vehicle speeds, age, and stock on emissions. It also includes estimates of direct and upstream emissions, based on the GREET model. MOVES can be used to develop regional, statewide, and national GHG emissions estimates, and can be used to generate emissions factors for project-level analyses.

Transportation/Emissions Strategy Analysis Tools

These tools are designed to estimate the travel and emissions impacts of specific types of transportation strategies, based on inputs about the transportation programs or strategies (e.g., type of strategy, other parameters of specific strategies). Most of the analytical strength of these tools is in the estimation of travel impacts; the user does not need to calculate a change in VMT or speeds, since the model performs that analysis. The CO_2 calculation procedures are generally very simple, and often do not account for complex implications of vehicle operating characteristics on emissions. These tools include:

COMMUTER Model – Developed by the U.S. EPA, the COMMUTER Model is designed to analyze the impacts of transportation control measures (TCMs), such as transit employer-based transportation demand management programs and transit improvements, on VMT, criteria pollutant emissions, and CO_2. The CO_2 calculations are simple, and based on default emission factors from MOBILE6.

Intelligent Transportation Systems Deployment Analysis System (IDAS) - The Federal Highway Administration (FHWA) developed IDAS as a sketch planning tool to estimate the impacts, benefits, and costs resulting from the deployment of ITS components; it estimates emissions of CO_2 and criteria pollutants.

Energy/Economic Forecasting Analysis Tools

These tools are designed to forecast energy consumption, typically based on economic factors such as economic growth and fuel prices. Most of these tools are designed for national-level analysis, and can not be readily used for metropolitan area or project-level analyses. Although these tools have strengths in terms of examining the implications of economic factors on transportation energy consumption, they typically are not geared toward analyzing the impacts of transportation investments and rely on data inputs that are not typically used in the transportation planning process. These tools include:

National Energy Modeling System (NEMS) - Developed by the Energy Information Administration (EIA) within the U.S. Department of Energy (DOE), NEMS represents the behavior of energy markets and their interactions with the U.S. economy to develop annual projections and evaluate national energy policies. A transportation demand module (TRAN) within the model forecasts the consumption of transportation sector fuels, which can be used to calculate CO_2.

VISION – Developed by the Argonne National Laboratory (sponsored by U.S. DOE), VISION is an excel-based model that provides estimates of the potential energy use, oil use, and carbon emission impacts to 2050 of advanced light- and heavy-duty highway vehicle technologies and alternative fuels.

World Energy Protection System (WEPS) Transportation Energy Model (TEM) – Developed by U.S. DOE, as a component of WEPS (a world energy consumption model), the Transportation Energy Model (TEM) generates forecasts of transportation sector energy use by transport mode at a national and multi-national region level. The WEPS accounting framework incorporates assumptions about the future energy intensity of economic activity (ratios of total energy consumption divided by gross domestic product [GDP]), and about the rate of incremental energy requirements met by different energy sources. Projections produced by WEPS are published in the annual report, *International Energy Outlook.*

Systems for the Analysis of Global Energy Markets (SAGE) – Developed by the U.S. DOE to replace WEPS, SAGE develops projections of energy consumption to meet energy demand, estimated on the basis of each region's existing energy use patterns, the existing stock of energy-using equipment, and the characteristics of available new technologies, as well as new sources of primary energy supply.

3.2 ASSESSMENT OF TOOLS

As shown above, there are a wide range of tools that can be used to analyze GHG emissions impacts of transportation. Most of the tools, however, have significant limitations for conducting the types of analyses that are needed by transportation agencies. Specifically:

- Most of the energy analysis tools (i.e., NEMS, VISION, WEPS/TEM, and SAGE) are designed for use at the national level, and are not appropriate for regional transportation analysis or project-level analysis. Moreover, energy forecasts in these models rely largely on demographic and economic factors, such as population, economic activity, and fuel prices, to predict transportation fuel consumption, and are not geared toward analyzing the impacts of transportation investments or strategies on fuel consumption. As a result, projections of fuel consumption may not reflect assumptions and plans related to transportation investments or reflect expected future travel conditions.
- State-level inventory procedures, such as those applied in the SIT, rely on inputs of motor vehicle fuel consumption, which can be taken from state fuel tax records; however, fuel purchases may not match with actual levels of fuel consumption. For instance, fuel sales may not equal fuel consumption at a state or local level if gas prices tend to higher in one jurisdiction than in a neighboring one. Boundary issues also are important for modes like aircraft, railroads, and freight ships, which may purchase fuel in one location but travel over many geographic boundaries.
- The transportation strategy analysis tools that estimate CO_2 (i.e., COMMUTER Model, IDAS), as well as the most commonly used transportation emission analysis model – MOBILE6 – use simple CO_2 emission factors based on vehicle type or analysis year but do not account for the effects of vehicle operating characteristics – which are affected by transportation plans, programs, and certain types of projects – on fuel consumption and CO_2.

Appendix B contains an assessment of each of the seventeen tools, including a summary of strengths and limitations, and ratings across four criteria: data input availability, ease of application, technical robustness, and policy sensitivity.

Of all the tools examined, EPA's MOVES provides the most functionality and applicability for conducting different types of transportation GHG analyses. EPA's MOVES model was *designed for transportation emissions analysis* and overcomes most of the limitations of these other tools when it comes to GHG analysis. Based on input from stakeholders, MOVES was envisioned and designed so that it could be used for a range of purposes including:

- National inventory development for EPA reports and regulations;
- Inventory development for regulatory requirements (e.g., SIPs, conformity);
- Policy evaluation (e.g., technologies, fuels, travel incentives);
- Hot spot and project level analysis; and
- Model validation and uncertainty analysis.

Inputs to MOVES include factors like VMT and vehicle fleet mix, which come out of the transportation planning process and are generally available to transportation practitioners. The tool also accounts for the effects of transportation investments and policies, including changes in levels of vehicle travel, mix of vehicles (classification and fuel type), activity patterns (e.g., VMT mix by road type and time of day), and operating speeds. The tool includes a great deal of default data that simplifies analysis at different levels of geography (e.g., nation, state, county) and time spans. The model includes several advances over

MOBILE6 to make it easier to use. For instance, it includes a new graphical user interface (GUI), and the model defines vehicle use types on the basis of HPMS vehicle classifications (as opposed to EPA's weight-based emission classifications used in MOBILE6) to avoid the need for transportation practitioners to map their HPMS data to EPA categories. It is designed for macroscale, mesoscale, and microscale analyses, and to be used in coordination with other models (e.g., travel models, dispersion models).

MOVES is being developed in several releases, and will be expanded over time to enable analyses of non-road transportation sources. In terms of GHG analysis, a key limitation to the current version (MOVES2004) is that it does not directly output CO_2 emissions, only energy consumption. Consequently, the user must post-process the results to develop CO_2 estimates. However, this is a fairly simple calculation, and the MOVES2006 version currently under development will directly calculate CO_2. In addition, the current version of the tool is designed primarily for GHG inventory development and certain types of strategy analysis. While the tool can be used for project-level analyses, documentation on how to use the tool to estimate emissions factors for simple project level analyses is lacking and the complexity of the tool makes it cumbersome for very simple analyses. However, the GUI was designed to make analyses user-friendly, it can be used to generate emissions factors based on user-supplied inputs, and the model is designed specifically for analyses of certain types of transportation strategies.

Although MOVES provides the strongest and most up-to-date methods for analyzing the GHG impacts of on-road vehicles, the tool does not address every potential GHG analysis component (for instance, the current version of the tool does not address non-road modes). As a result, other approaches are needed for certain types of analyses. These are discussed in Section 4.

4 RECOMMENDED METHODOLOGIES FOR GHG ANALYSIS

As noted in Section 3, EPA's MOVES model provide a robust methodology for analyzing the GHG impacts of on-road transportation sources, and was designed to be used for many of the different types of analyses that may need to be undertaken by transportation agencies. However, other tools provide some different functionalities, and in many cases, more than one methodology will be appropriate. The selection of a tool or methodology should consider the following issues:

1. What modes will be addressed? Different tools may be needed if examining non-road modes in addition to on-road modes. For instance, the current version of MOVES does not address non-road modes.
2. What gases must be addressed? In many cases, it will be sufficient to only examine CO_2, but in some cases, it may be necessary to address other GHGs.
3. What level of detail is needed? For many kinds of transportation analysis, a simple sketch planning approach may be appropriate. For instance, when examining transportation projects or strategies that only affect VMT, not travel speeds or vehicle stock, it may not be necessary to use a more complex analysis tool that accounts for all of these factors.
4. What data are available? Data availability will also influence what types of methodologies can be used and what types of assumptions must be developed. For instance, if limited data are available on vehicle characteristics, assumptions will need to be made about the types of vehicles using a facility or the types of vehicle trips that are reduced as a result of a strategy.

This section recommends methodologies that are most suitable for the following different types of analyses:

- State-level transportation GHG inventory development;
- State-level transportation GHG inventory projections;
- Regional or local transportation plan or program analysis; and
- Transportation project or strategy analysis.

4.1 STATE-LEVEL TRANSPORTATION GHG INVENTORY DEVELOPMENT

Analysis Purpose

The purpose of this type of analysis is to develop estimates of total transportation-related GHG emissions within a state for a historical period or base year.

Key Questions and Considerations

In order to develop a GHG inventory for a state, data on transportation fuel consumption and/or vehicle travel need to be collected to be used in the emissions calculation. Issues that need to be considered include:

- What modes will be addressed? The analysis can consider on-road motor vehicles or all transportation modes. If all transportation modes are to be included in the inventory, the analyst must determine data available to estimate fuel consumption or travel activity levels for each mode within the state, and these data are often not readily available.
- Do state-level energy estimates mesh with estimates from transportation data sources? Fuel sales estimates may not equal actual fuel consumption by transportation sources within the state.
- How to address boundary issues? If the state contains an airport, port, or major intermodal facilities that are used for goods movement to other states or personal travel by residents of other states, this raises questions about how to assign the emissions.

Recommended Analysis Methodologies

Two approaches are recommended to develop an inventory of GHG emissions, depending on the purpose and level of detail required in the inventory:

EPA's State Inventory Tool - for a basic inventory of all transportation GHGs

The SIT is a good option for developing a state-level GHG inventory and historical estimates of GHGs from transportation, given availability of default data and the simplicity of the tool. This approach can be considered a "top-down" GHG inventory methodology, since it relies upon state-level data on motor vehicle fuel consumption in calculating CO_2 (the most important GHG) from motor vehicles. Based on its structure, this 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.

- *Strengths:*
  - The SIT takes into account all transportation modes, is very easy to use, and has flexible data requirements.
  - The model was developed specifically for state-level emissions inventory development, and the internal methodology is consistent with that of the national GHG inventory. It follows EPA's State GHG Inventory Development guidelines. Outputs are calculated directly using default data derived from these national values or customized to reflect user-provided state-level data.
  - It calculates all GHGs from transportation sources (CO_2, N_2O, CH_4, HFCs).
- *Limitations:*
  - The model relies on fuel consumption data as an input to calculate CO_2 emissions, but State DOTs may not have access to data on fuel consumption for each mode (particularly for rail, aircraft and ships), state fuel sales data may not accurately reflect fuel

consumption within the state (e.g., due to interstate freight movements), and default values may not be as accurate as locally-developed data.
    - The tool does not provide a breakdown of CO_2 emissions by vehicle type (e.g., autos, light-duty trucks, heavy-duty trucks, buses), which limits the usefulness of the results for conducting more detailed analyses. The analyst will need to post-process the results to determine GHG emissions by vehicle type, smaller geographic areas (e.g., county, metro area), road type, or other characteristics of interest.
    - The procedures for calculating N_2O and CH_4 require the user to input data on VMT, but the procedures for calculating CO_2 are based on inputs of vehicle fuel consumption (typically drawn from state fuel tax records). As a result, there is a potential disconnect between the figures being used for the CO_2 calculation and the N_2O and CH_4 calculation.

EPA's MOVES - for more detailed inventory for on-road sources

MOVES can be used to develop a more detailed GHG inventory for on-road sources, including breakdowns of emissions by vehicle type, roadway type, and other factors. This may be considered a "bottom-up" methodology since, unlike the SIT, the calculation of CO_2 from motor vehicles is based on data on VMT and speed, operating characteristics, and fleet characteristics of vehicles.

- *Strengths:*
    - MOVES uses VMT data as an input, rather than fuel consumption, and VMT data are more readily available to transportation agencies.
    - MOVES includes a great level of detail, characterizing vehicles into bins defined by fuel type, engine type, model year group, and regulatory class.
    - It accounts for activity patterns based on roadway type and speed, and includes default data on vehicle travel at the county level. As a result, it can quickly produce detailed inventories for a state broken down by county, road type, vehicle type, and reflect user-specified data.
- *Limitations:*
    - Given the level of detail in the model, it offers the potential for more accurate determinations of GHG emissions, but this requires more significant inputs of data. The development of such input data could be time consuming, especially during the transition from MOBILE6 to MOVES.
    - The results may need to be reconciled with state fuel data, depending on how inventories have been developed historically and on the purpose of the inventory.
    - The current version of MOVES does not address non-road sources.

Combination

These two approaches may be combined to develop the most accurate inventory: use the State Inventory Tool approach to develop GHG estimates for all modes and for all gases. Then, outputs from MOVES can be used to apportion the CO_2 from motor vehicles to individual vehicle types and other sub areas, such as by county, if desired.

4.2 STATE-LEVEL TRANSPORTATION GHG INVENTORY PROJECTIONS

Analysis Purpose

The purpose of this type of analysis is to develop forecasts of future GHG emissions levels as a baseline or for policy/investment analysis.

Key Questions and Considerations

In developing projections of GHGs at a state-level, key issues are:

- Is the approach sensitive to transportation investment and policy considerations that the user may want to examine? Traditional energy forecasting models rely largely on economic forecasts, such as economic growth and fuel prices, to predict vehicle fuel economy and VMT, and are not geared toward analyzing the effects of transportation investments or policy changes on aggregate vehicle fuel consumption. In most cases, it will be useful to use a forecasting approach that takes into account existing forecasts of VMT that have been developed by the state DOT or MPOs within the state.
- What types of forecast data are available? For instance, does the state have an energy forecasting model or other assessment of projected energy use that can be used in estimating future GHGs? Does the state have existing forecasts of statewide VMT for light-duty and heavy-duty vehicles, and information on travel activity patterns in order to develop projections for modes such as transit, aviation, and rail? The GHG forecasting approach should be able to account for these travel activity projections.

Recommended Analysis Tools

Three different approaches, described below, are recommended as useful for developing statewide projections. The selection of a method will depend on the use of the projections and existing data availability.

EPA's State Inventory Projection Tool – for simple baseline projections based on historical trends

This tool forecasts state-level GHG emissions through 2020, and is a good option for developing simple projections of transportation GHG emissions based on historical data.

- *Strengths:* The tool is easy to use, and can be used to develop GHG projections for CO_2, N_2O, and CH_4 for all modes with relatively limited input data.

- *Limitations:* The projection methodology relies largely on linear trends, and does not account for factors such as population and employment growth, freight travel activity growth, state-level vehicle mix changes, alternative fuel/technology uptake, and land use patterns. The tool is also not designed to predict the impacts of transportation policies and investments (e.g., airport expansion, new highway facilities) on statewide transportation emissions. Consequently, the tool cannot be used to examine alternative transportation plans or statewide policies.

EPA's MOVES – for forecasts that account for detailed transportation factors and different on-road transportation scenarios

MOVES is a strong option for analyzing state-level GHG emissions for on-road sources, taking into account factors such as VMT and vehicle operating conditions.

- *Strengths:*
  - MOVES can be used to develop more accurate forecasts of on-road vehicle GHG emissions, since it relies upon inputs, such as projections of VMT and vehicle speeds, which may come out of the statewide transportation planning process.
  - Since the tool is sensitive to factors such as VMT and vehicle operating conditions, it can be used to conduct policy analyses, to examine the implications of alternative investment programs, or for sensitivity analyses (e.g., to examine effects of changes in vehicle fleet conditions, vehicle operating conditions, etc.) assuming the user is able to provide inputs on VMT, vehicle operating characteristics, and vehicle fleet characteristics.

- *Limitations:* Given the level of detail in the model, it offers the potential for more accurate determinations of GHG emissions, but this requires more significant inputs of data. The development of such input data could be time consuming, especially during the transition from MOBILE6 to MOVES.

Spreadsheet Analysis/Post Processing of VISION – for forecasts that account for impacts of fuel prices on VMT and vehicle technologies

VISION is a spreadsheet tool designed for quick analyses of the impacts of changes in vehicle technology shares, fuel prices, and VMT growth on carbon emissions at the national level. The tool can be adapted to analyze these types of effects at a state level, or post-processed to generate percentage changes in emissions, which are then applied to a baseline state forecast.

- *Strengths:* VISION is designed for analysis of the implications of alternative policies that affect fuel prices, VMT growth rates, and vehicle technology shares, and is more readily geared toward these types of policy analyses than the SIPT or MOVES. It accounts for the effects of fuel price on VMT.

- *Limitations:* VISION is designed for use at the national level, rather than the state level.

4.3 REGIONAL OR LOCAL TRANSPORTATION PLAN / PROGRAM ANALYSIS

Analysis Purpose

The purpose of this type of analysis is to analyze the implications of transportation plans and programs on regional (i.e., metropolitan area) or local (i.e., county or municipality) GHG emissions. For instance, this might include an analysis of a metropolitan planning organization's long range transportation plan (LRTP) or transportation improvement program (TIP) or a local government's transportation program, and might involve a build/no build analysis, or comparison of alternative plans/programs.

Key Questions and Considerations

- Are metropolitan/local area data (e.g., VMT by road type, vehicle fleet mix, average speeds) available for developing accurate estimates? Typically, estimates of future travel patterns and conditions will come out of a regional travel demand forecasting model. Future vehicle fleet characteristics, however, may be influenced by broader national or international policies and trends, such as vehicle fuel economy standards and fuel prices; as a result, long-term analyses (20 years or more) should consider expected changes in vehicle characteristics.
- How will all of the different types of transportation investments, e.g., operations (ITS) projects, transportation demand management (TDM)—many of which cannot be analyzed using a traditional four-step travel demand forecasting model—be addressed? Some specific types of programs should be examined off-model and can be used to adjust figures coming out of the travel demand forecasting model.

Recommended Analysis Tools

EPA's MOVES

MOVES is designed to analyze county-level or regional GHG emissions from on-road sources, taking into account factors such as VMT and vehicle operating conditions that come out of the travel demand forecasting process. The user must conduct an analysis, using a four-step travel demand model or other methods, to analyze the implications on VMT and vehicle operating characteristics of a regional or local transportation plan. These inputs are then run through MOVES to generate emissions results.

- *Strengths:*
  - Since the tool is sensitive to factors such as VMT and vehicle operating conditions, it can be used to conduct policy analyses, to examine the implications of alternative investment programs, or for sensitivity analyses (e.g., to examine effects of changes in vehicle fleet conditions, vehicle operating conditions, etc.) assuming the user is able to provide inputs on VMT, vehicle operating characteristics, and vehicle fleet characteristics. It can more accurately assess the implications of regional programs and investments that affect traffic congestion and speeds.
  - MOVES uses similar inputs to the MOBILE6 model, which is currently the EPA-accepted model for regional analysis of criteria pollutant emissions for transportation conformity purposes. As a result, many of the data inputs necessary for the analysis should be readily available to transportation agencies. The model also provided default values for vehicle age distributions, technology types, and other factors.

- *Limitations:*
  - The model uses inputs of VMT and vehicle characteristics that come out of the travel demand forecasting process, as well as other factors like vehicle fleet mix that may be

available or estimated from other sources. However, there may be a need for off-model analyses of specific types of programs and strategies, such as transportation demand management (TDM) programs.
  - The current version of MOVES also does not address non-road sources like rail and ferries.

Spreadsheet Calculation Approach

Off-model spreadsheet calculations can be used to analyze the GHG emissions effects of elements of a transportation plan not directly addressed in MOVES. For instance:

- A regional analysis of GHG emissions associated with rail, aircraft, and ships or boats could be conducted using spreadsheet calculations relying on a methodology similar to that used in EPA's *State Inventory Tool*. The user would need to input data that could be used to calculate fuel consumption and consequently CO_2 emissions from each mode. The challenges associated with a regional analyses of non-road modes is similar to the challenges faced in a statewide analysis: potentially limited data on fuel consumption and activities by these modes, limited data for developing projections, and boundary issues that make it difficult to assign emissions to the region.
- A spreadsheet calculation approach similar to that developed by the *New York State Department of Transportation* could be developed to analyze the implications of transportation construction, maintenance, and support activities as part of a regional plan. This approach would require the user to estimate levels of activity and/or fuel consumption, and can rely upon EPA's *NONROAD model* for appropriate GHG emission factors for estimating emissions from construction and maintenance equipment.

4.4 TRANSPORTATION STRATEGY / PROJECT ANALYSIS

Analysis Purpose

The purpose of this type of analysis is to analyze the implications of specific transportation projects or strategies on GHG emissions. For instance, this might include an analysis of a transit investment, a highway project, an Intelligent Transportation System (ITS) program, a regional transportation demand management program, or alternative fuel vehicle purchases.

Key Questions and Considerations:

- What modes of transportation are affected? Although most transportation strategies focus on one mode (such as reducing on-road vehicle travel or improving the efficiency of rail operations), some strategies may affect multiple modes (such as development of a commuter rail service, which will result in an increase in rail activity and a decrease in on-road VMT). The types and range of modes affected will influence the methodological approach and tools that can be used.
- What types of transportation system impacts will the strategy have? Since transportation GHG emissions are affected by the level of transportation activity, operating conditions, and type of mode/vehicle/fuel used, the analyst must first determine the implications of the strategy or project on these characteristics. The approach for analyzing a project designed solely to reduce VMT can be much simpler than a strategy that affects VMT, vehicle operating characteristics, and vehicle stock simultaneously.
- How far into the future will the analysis consider? For projects and plans that affect travel activities, typically estimates of future travel patterns and conditions will come out of a regional travel demand forecasting model. Future vehicle fleet characteristics, however, may be influenced by broader national or international policies and trends, such as vehicle fuel economy standards and fuel prices; as a result, long-term analyses (20 years or more) should consider these expected changes in vehicle characteristics.

Recommended Analysis Tools

As noted in Section 2, transportation strategy/project analysis requires two steps:

1) Analyze the impacts of the strategy/project on the transportation system, i.e., impacts on vehicle travel by vehicle type, changes in vehicle stock (fuel economy or fuel type), impacts on vehicle speeds and operating characteristics; and
2) Calculate the GHG impacts based on the change in these factors.

In most cases, the first step will be handled using a travel demand forecasting model or a sketch planning approach that relies upon assumptions (e.g., price elasticities; estimates of participation in a voluntary program; estimates of travel, operating, and/or vehicle implications based on past project experience, surveys, program specifications, or other approaches). The second step is then handled by using a transportation GHG calculation tool, such as MOVES, which is our recommended tool for on-road GHG emissions analysis. If the strategy has multiple effects, such as a major transportation investment or traffic flow improvement that affects VMT and vehicle speeds, then the outputs of an analysis can be run directly through MOVES to calculate emissions with and without the project. In other cases, where the effects of a strategy are limited in nature, such as reduced VMT from a bicycle path, it can be most efficient to simply develop GHG emission factors using MOVES, MOBILE6, or another tool (or even use a national average for light-duty vehicles), and apply this to the reduction in VMT.

Some methodologies, such as EPA's COMMUTER model (for transportation demand management programs) and FHWA's IDAS (for ITS projects) have built in a simple GHG calculation procedure, and can be used to calculate the travel and CO_2 implications of a project or strategy in one step. Although the CO_2 emission factors have limitations, they may be adequate for simple strategy analyses, particularly since the uncertainty in the travel estimates (i.e., the estimated reduction in VMT) is likely much larger than the uncertainty in the CO_2 emission rates.

The tremendous variety of different transportation projects/strategies means that different considerations must be taken into account and different approaches may be applicable for different types of strategies/projects. Analysis approaches are identified below for those that affect:

- the amount of on-road vehicle travel;
- on-road vehicle operating characteristics;
- use of alternative fuels and advanced technology vehicles; and
- use of non-road sources.

Methods also are identified to examine the emissions impacts of project construction, maintenance, and support. It should be noted that some strategies (e.g., development of a new light rail line) involve more than one effect (e.g., an increase in transit rail service and a decrease in VMT) and multiple approaches may be combined.

1. Strategies/Projects that Affect On-Road Sources

A. Strategies/Projects that Affect the Amount of Vehicle Travel

For strategies/projects that primarily affect the number of vehicle miles traveled (but do not have a measurable effect on overall traffic flow or vehicle speeds), such as park-and-ride lots, bicycle facilities, and most transit improvements, the primary procedure for analyzing the GHG impact is to estimate the reduction in VMT and calculate the reduction in fuel consumption based by multiplying by average vehicle fuel economy. In some cases, a program will increase VMT for certain vehicle types (e.g., new bus services) and so it is important to recognize both the VMT decrease and increase by certain vehicles. Approaches that can be used include:

- **COMMUTER Model –** EPA's COMMUTER model can be used to estimate both the VMT and CO_2 impacts of demand management strategies. Although the tool uses a very simple CO_2 calculation procedure, the overall uncertainty in the CO_2 emission factors is relatively low in comparison to the uncertainty in the travel activity estimates (i.e., VMT reductions). As a result, the tool is appropriate for basic strategy analysis.
  - *Strengths:* The COMMUTER model automatically estimates the vehicle trip, VMT, and emissions reductions associated with TDM programs, based on inputs provided by the user. All calculations are handled in the tool.
  - *Limitations:* The CO_2 calculation is very simple in the current version of the model and does not take into account detailed information on the mix of vehicles affected or operating characteristics of vehicle trips reduced. It does not reflect changes in vehicle fuel economy in the future. It also will not calculate emissions of N_2O or CH_4.

- **Spreadsheet Calculation, based on Travel Analysis and MOVES –** MOVES can be used to analyze the impacts of VMT reduction strategies by inputting the amount of VMT reduced and characteristics of the vehicles in terms of vehicle type, road type, and operating characteristics, or by using MOVES to generate an emissions factor for use in the analysis. Under this approach, the analyst first uses a tool such as the COMMUTER model, a 4-step transportation model, or sketch planning approach to estimate impacts on

VMT (positive or negative), and to determine the types of vehicles that will be affected (e.g., light-duty vehicles, buses). The VMT impacts are then multiplied by appropriate GHG emission factors or estimates of fuel economy, based on the assumed mix of vehicles reduced, road types, average speeds, etc. A simple spreadsheet tool can be developed, which includes look-up tables for emission factors/fuel economy values for different types of vehicles on different types of roadways for different years and different operating characteristics.

- *Strengths:* MOVES provides more detailed and accurate fuel consumption and emissions estimates than the COMMUTER model, since it uses a much more sophisticated process.
- *Limitations:* MOVES is currently geared more toward emissions inventory development than to calculating the emissions effects of individual projects. The user would need to make sure to change the default values to ensure that the emissions results reflect a reduction in the appropriate vehicle types (e.g., only light-duty vehicles), road types (e.g., arterials and local roads for bicycle projects), and vehicle operating characteristics, since the default values will not be accurate for individual types of projects.

B. Strategies/Projects that Affect Vehicle Operating Characteristics

For strategies/projects that affect vehicle operating characteristics, such as traffic signalization improvements and ITS projects, it is necessary to use a GHG technique that accounts for the effects of operating characteristics (speeds, idling, and congestion levels) on fuel consumption and GHG emissions.

- **IDAS** - IDAS can be used to estimate the changes in operating characteristics for ITS programs, impacts on fuel consumption, and effects on CO_2.
  - *Strengths:* IDAS automatically estimates the fuel consumption and emissions reductions associated with ITS programs, based on inputs provided by the user. All calculations are handled in the tool.
  - *Weaknesses:* The CO_2 calculation is very simple and does not take into account detailed information on the mix of vehicles by technology type, age, and other factors. The CO_2 calculation also does not effectively account for the impacts of speed changes in CO_2 emissions.

- **Analysis of Travel Impacts and Use of MOVES –** MOVES can be used to calculate the emissions effects of changes in vehicle operating conditions. The user provides information about VMT and drive cycle operating characteristics (e.g., speeds by road classification) with and without the program in order to analyze implications. The user needs to provide these inputs based on traffic analyses for a project, results of a four-step travel demand model, or other data on travel implications. Different VMT levels can be input to the MOVES model in each scenario, since VMT can also vary by road type or in total levels due to diversions of traffic or induced travel.
  - *Strengths:* MOVES is well suited for analyzing the implications of transportation projects or programs that affect vehicle operating characteristics (speeds, idling, and congestion levels) since it accounts for all of these factors in calculating energy consumption and emissions.
  - *Limitations:* The user must analyze the travel impacts of the strategy separately from MOVES. For certain types of strategies, such as idling reduction, it would be easiest to use MOVES to generate an idle emissions factor, and then apply this in a spreadsheet analysis, rather MOVES to estimate the emissions impact directly.

C. Strategies/Projects that Involve Switching to Alternative Fuels/Advanced Technologies

Some strategies focus on increasing the use of alternative fuels or advanced technology vehicles. These strategies include incentives for individual consumer vehicle purchases, requirements for alternative fuel vehicle purchases, and public purchases of alternative fuel vehicles (e.g., CNG buses). For these strategies, the primary procedure is to estimate the change in the number or share of vehicles by technology/fuel type, the average VMT for each of these vehicles, and apply an emission factor that reflects the level of GHG emissions per mile.

- **Analysis of Vehicle Impacts and Use of MOVES** – MOVES includes a strategy analysis sheet that enables the user to alter the share of vehicles in different vehicle technology/fuel type categories. For example, the tool can be used to estimate the GHG impacts associated with different penetration rates or sales fractions by vehicle model for a range of advanced technologies. The user must input the share of vehicles by each technology/fuel type category.
    - *Strengths:* The strategy analysis sheet allows for quick analyses of the impacts of different adoption rates for advanced technology vehicles. MOVES addresses not only direct vehicle emissions but also broader lifecycle emissions, which are important when examining alternative fuels. The procedures rely upon emission factors from GREET, and so eliminate separate calculation or running of GREET for lifecycle effects.
    - *Limitations:* MOVES does not forecast the impacts of incentives or other policies on consumer vehicle choice; these impacts must be examined off-model, based on research literature or analysis of results from a tool like *NEMS*. Often, for transportation agencies, the most difficult part of the analysis is determining the change in consumer vehicle purchase and use in response to a strategy.

- **Spreadsheet Analysis using Emission Factors from MOVES**– Rather than using MOVES directly, a spreadsheet analysis can be effective for analyzing more limited strategies such as the purchase of alternative fuel buses. The spreadsheet would require the user to estimate the number of vehicles purchased, the average VMT for each of these vehicles, and then apply an emission factor in GHG emissions per mile, which could be drawn directly from *MOVES, GREET*, or *VISION* (based on GREET) or *LEM*.

2. Strategies/Projects that Affect Non-Road Sources

Strategies and projects that involve non-road transportation modes require different tools than those for on-road modes. There currently are no formal tools that are designed specifically to focus on the GHG impacts of airport, rail, or maritime strategies and projects. Instead, spreadsheet calculation approaches can be utilized for these types of analyses. A general approach is to calculate the change (increase or decrease) in fuel consumption for each mode, and calculate CO_2, as well as N_2O and CH_4, based on the carbon content of the fuel and established emission factors. The calculation is straightforward, and can rely upon procedures used in the national GHG inventory and *SIT*. The key challenge is accurately estimating the change in fuel consumption, which would most likely need to be estimated based on the change in travel activity (e.g., number of new ferry trips, average miles per trip, and average fuel consumption per mile). As part of the evaluation, it will also be important to calculate the change in motor vehicle GHG emissions if the non-road project is designed to reduce on-road traffic (for example, implementation of a new ferry service to reduce vehicle travel).

3. Impacts of Project Construction, Maintenance, and/or Support

For any transportation project analysis, it may be useful not only to examine the GHG impacts of the project as it operates, but also the emissions associated with project construction, maintenance, and/or on-going support. The *New York State DOT's GHG guidance methodology* is the only identified tool that provides a standardized methodology for conducting such an evaluation. The method's primary weakness is that it is based on assumptions of fuel consumption from construction equipment that were developed by Caltrans in the early 1980s, and so are more than 20 years old. The fuel consumption rates used may not be applicable to current construction equipment and processes.

A revised approach would be to conduct a spreadsheet analysis that requires calculating the amount and type of construction equipment used, and then using data from the NONROAD model (which was most recently updated in 2004) to calculate fuel consumption and emissions. A spreadsheet tool could be developed to simplify and standardize this process.

5 GAPS IN METHODOLOGIES AND RECOMMENDATIONS FOR FURTHER RESEARCH

Given the limitations of existing GHG methods and the on-going development of MOVES, it is our recommendation that MOVES be used for GHG analyses where appropriate, and that additional efforts focus on developing guidance material on using MOVES for different types of GHG analyses. In addition, simplified GHG emissions analysis tools, such as spreadsheets, are needed for analyses not handled in the current version of MOVES (such non-road transportation projects and analyses of highway construction and maintenance activities). Other analysis tools (e.g., VISION, COMMUTER model, or four-step travel models) may also be needed to assess the implications of transportation projects and policies on factors such as VMT and vehicle mix that are inputs to MOVES.

This section of the report discusses three major gaps in methodologies that should be considered a priority in future research related to transportation GHG emissions. These include:

1) Methods to develop estimates of changes in vehicle stock and fleet mix, particularly in regard to strategies that affect consumer vehicle purchase decisions;

2) Methodologies or tools to analyze the GHG effects of transportation strategies that involve multiple modes; and

3) Methodologies or tools to analyze the direct impacts of transportation system construction, maintenance, and operations on GHG emissions.

The discussion below provides recommendations for addressing each of these gaps, including an estimate of the expected level of effort and resources required for each.

5.1 METHODS TO ADDRESS VEHICLE STOCK IMPACTS

Existing Gap: As discussed earlier, EPA’s recently released MOVES model provides a robust methodology for calculating the effects of transportation plans and projects on on-road vehicles’ GHG emissions. MOVES, however, requires the user to input estimates of vehicle travel activity (e.g., VMT), vehicle operating characteristics (e.g., speeds), and vehicle stock (e.g., mix of vehicle types), or use model-provided defaults. While a variety of established methods are available to analyze the vehicle travel and operating effects of traditional transportation investments (e.g., travel demand forecasting models, tools like EPA’s Commuter Model, FHWA’s IDAS model, sketch planning methods), analysis approaches typically are not designed to address the effects of strategies on consumer vehicle purchase decisions, and in turn, on the on-road vehicle fleet. As a result, transportation agencies cannot readily analyze strategies focused on improving vehicle fuel economy through vehicle fleet changes, such as fuel economy mandates, feebates, or fuel taxes. Strategies that affect vehicle stock also can have indirect effects on VMT (for instance, greater fuel economy results in lower per-mile fuel costs, which can encourage increased vehicle travel; this effect is known as the “rebound effect”), yet these indirect effects are not accounted for in typical transportation demand forecasting models. Appropriate guidance and/or tools are needed to conduct analyses of transportation strategies that affect vehicle stock and fleet mix, including information to help develop inputs that could be used in tools such as MOVES.

Recommendation: To fill this gap, an analysis tool could be developed to analyze the implications of state-level or multi-state-level fuel economy improvement strategies on vehicle fleet mix, average fuel economy, and VMT. The tool would function as a simplified version of the transportation component of the NEMS model but geared toward state-level analysis. The tool could build off of DOE's VISION model, which is a spreadsheet tool that allows analysis of the implications of changes in fuel prices (or fuel taxes) on vehicle travel. However, it would also need to account for the implications of strategies like fuel economy mandates, feebates, and other incentives for consumers or manufacturers on vehicle purchase decisions (In VISION, like MOVES, the user must input shares of vehicles by technology/fuel type; the tool is not designed to calculate changes based on policies). Alternatively, a resource document could be developed to help analysts understand the expected impacts of programs like feebates on vehicle fleet fuel economy, based on the existing literature.

Resource Requirements: It would be fairly resource intensive to create a tool that can address the full range of incentives and programs to influence vehicle purchase and manufacture decisions, in part due to limited empirical data on these programs. As a result, a relatively simple tool is estimated to require about $150,000. The first step in this research effort would be to conduct a review of research recently completed, on-going, and planned research by the U.S. Department of Energy and other governmental and non-governmental agencies. Based on the results of that review, a detailed scope of work identifying milestones should be developed.

Timeframe: 12 months for research review, draft development, initial user testing, and refinement.

5.2 METHODS TO ADDRESS MULTI-MODAL TRANSPORTATION STRATEGIES

Existing Gap: EPA's MOVES model currently focuses on emissions from on-road vehicles, although there are plans to eventually expand it to address all transportation modes. Many of the other most useful tools for transportation agencies also focus on emissions from on-road vehicles (e.g., EPA's Commuter Model, FHWA's IDAS model). However, transportation strategies that involve non-road modes of transportation are common; for instance, ferry services and commuter rail services that are designed to reduce motor vehicle trips, and strategies to shift freight shipments from truck to rail. There is a need for a simple tool that can be used by transportation agencies to assess the effects of transportation services and strategies that affect non-road sources.

Recommendation: In order to fill this gap, it would be useful to develop a spreadsheet tool that can be used to calculate the GHG effects of implementing a transportation strategy or program that involves non-road components. The tool would provide emission factors for non-road transportation sources, including ships, boats, and ferries of different sizes, types, and fuel; various types of rail (e.g., commuter rail, intercity passenger rail, freight rail); and aircraft. The tool would enable the user to input information about the type of service or strategy being tested in a manner that is simple for the user, such as number of ferries, estimated number of trips per day and trip lengths, and number of days of operation per year. The tool would utilize information about estimated fuel consumption, drawn from existing studies on fuel use for different types of non-road vehicles, and GHG emission factors drawn from the official U.S. GHG Inventory for each fuel type.

The tool should be relatively simple and not attempt to recreate the full workings of the planned MOVES model (which is expected to include non-road uses). The most important component of the streamlined tool being proposed here would be to calculate the GHG emissions from the non-road transportation source. It is expected that in most cases, the user will have some estimate (from a project-level study, etc.) of the change in on-road vehicle activity associated with the non-road strategy (for instance, the user would have an estimate of the number of reduced vehicle miles traveled associated with implementing a commuter rail line). Although the user may want to use a more detailed analysis tool, such as MOVES, for the on-road emissions, the tool should be designed to provide a simple estimate of the change in on-road GHG emissions if the user provides basic inputs such as estimated reduction in VMT in order to calculate the net change in transportation emissions. This would enable transportation staff to analyze the implications of a non-road/mode-shift strategy on net GHG emissions.

Resource Requirements: Tool should be simple, recognizing that EPA will be investing resources in developing an updated version of MOVES that includes non-road sources. For an interim spreadsheet tool, approximately $70,000 seems adequate.

Timeframe: 6 months for development, initial user testing, and refinement.

5.3 METHODS TO ADDRESS TRANSPORTATION CONSTRUCTION/MAINTENANCE ACTIVITIES

Existing Gap: Most transportation sector emissions cannot be directly altered by transportation agencies but depend on consumer decisions about vehicle purchases and travel choices, and external factors like land use patterns, population, and economic growth. Transportation agencies, however, directly emit some GHGs through construction, maintenance, and operation of transportation infrastructure and vehicles, and may seek opportunities to reduce these emissions. Unfortunately, there are no established tools or guidance procedures on how to analyze the impacts of transportation system construction, maintenance, and operations on GHG emissions, aside from the New York State DOT guidance documents. While the NYSDOT guidance is useful, it is not as user-friendly as would be desired for a typical user at a State or local transportation agency to analyze the implications of their transportation programs. Moreover, the method is based on assumptions of fuel consumption from construction equipment that were developed by Caltrans in the early 1980s, and so are more than 20 years old. The fuel consumption rates used may not be applicable to current construction equipment and processes. There are opportunities for transportation agencies to reduce their direct GHG emissions output through equipment technologies, fuels, and levels of activity, and so developing an applicable method or tool for analyzing these emissions would be helpful to transportation agencies.

Recommendation: Develop a relatively simple spreadsheet tool that allows the user to enter information about the use of equipment for transportation construction, maintenance, and operations. The tool should allow the user to enter information about the amount of use of equipment, in terms of hours or workdays, the type of equipment/fuel, and technologies employed, such as diesel retrofits. It should rely on GHG emission factors from the official U.S. GHG inventory. The tool should be able to be used to analyze changes in types of equipment used, technologies (e.g., retrofits, newer equipment), and use (e.g., reduced mowing, other maintenance, or construction activity). The tool could be combined as part of the tool described above to analyze the implications of non-road transportation strategies, in order to reduce the number of GHG analysis tools that transportation agencies may need to use.

Resource Requirements: Approximately $60,000, assuming a spreadsheet based tool (a web-based tool would require additional resources)

Timeframe: 8 months for development, initial user testing, and refinement.

5.4 CONCLUSION

In summary, existing tools provide most of the capabilities required by transportation agencies for valid GHG analysis. In particular, EPA's new MOVES model provides functionality to analyze the GHG implications of changes in vehicle use, operating characteristics (e.g., speeds), and vehicle fleet characteristics and technologies for on-road vehicles. However, there remains a need for additional functionalities and guidance regarding how to develop appropriate inputs for the tool, for addressing non-road modes and non-road equipment not currently addressed in the model, and to provide more information to help guide transportation practitioners to the most appropriate tools and methodologies for different types of analyses (e.g., developing GHG inventories, conducting regional emissions analysis, analyzing different types of projects, etc.).

In addition to the recommendations provided above, we believe the most important and useful next step would be to develop a basic guidance document for transportation agencies on transportation GHG analysis techniques. The product of this effort can be completed quickly and at relatively low cost. With additional resources, the results could be made into a web-based resource that could be a very useful reference for transportation practitioners. The other tools would also be helpful to transportation agencies, and should also be considered for implementation.

APPENDIX A: SUMMARY OF METHODOLOGIES

STATE INVENTORY TOOL (SIT)

Developer U.S. Environmental Protection Agency (EPA), prepared by ICF Consulting

Overview The State Inventory Tool (SIT) can be used to develop a comprehensive GHG inventory at the state level, including CO_2, CH_4, and N_2O emissions associated with transportation and mobile sources. The SIT permits users to enter their own state-specific activity data (in the case of transportation, users are asked to enter information on transportation fuel consumption and vehicle miles traveled). If state-specific data are not available, the SIT can still calculate emissions using default data developed from various governmental publications (e.g., EIA's *Annual Energy Review* and *FHWA's Highway Statistics*). All calculations are automated, so emission estimates can be created quickly once activity data have been obtained. The SIT estimates emissions from 1990 through 2002.

Main Purpose Automates GHG calculations once activity data (or default data) are inputted. Estimates are calculated for a specific state.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√	√	√	√	√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√	√		

Methodology The calculations are based on the same methodologies used in EPA's Inventory of *U.S. Greenhouse Gas Emissions and Sinks*, which are based on internationally accepted emission reporting guidelines. CO_2 emissions are calculated based on fuel consumption. CH_4 and N_2O emissions are calculated based on VMT, distributed among different control technology types.

Assessment

Strengths

- If state-specific data are not available, the SIT can calculate emissions using default data derived from national values.
- Emission estimates can be created quickly once activity data have been obtained.
- Methodology mirrors that of the national GHG inventory.

Limitations

- Does not output CO_2 by mode or vehicle type, only fuel type for the entire transportation sector. Results must be post-processed to develop a more detailed inventory for transportation sources.
- Default data are sometimes extrapolated from national data based on broad assumptions, and may not accurately depict state-level trends.

Date Released/Updated March 2005

Availability Tool is available through the EPA.

STATE INVENTORY PROJECTION TOOL

Developer U.S. Environmental Protection Agency (EPA), prepared by ICF Consulting

Overview The State Inventory Projection Tool is based on the SIT and forecasts emissions through 2020. The Projection Tool also allows users to compare trends back to 1990 by importing estimates from the SIT.

Main Purpose Forecast state-level GHG estimates through 2020.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√	√	√	√	√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√	√		

Methodology Projections are based in part on projected fuel consumption reported in the Energy Information Administration's *Annual Energy Outlook with Projections to 2020*. Other characteristics – such as fleet composition, the state's proportion of national transportation fuel use, and control technology distribution – are the same used in the *Inventory of Greenhouse Gas Emissions and Sinks*, and are assumed to remain constant in the future.

Assessment

Strengths

- Tool is very easy to use and can develop comprehensive GHG inventory projections for CO_2, CH_4, and N_2O with little user experience. All calculations are automated.
- Tool can retrieve results directly from SIT.
- If state-specific data are not available, the SIPT can calculate emissions using default data derived from national estimates.

Limitations

- Projections based on historical data and emission estimates. Projection methodology is generally based on linear trends; tool is not capable of predicting impacts of future policy changes on projected emissions.
- Does not output CO_2 by vehicle type, only fuel type.
- Tool not publicly available on the web. Must contact EPA.

Date Released/Updated March 2005

Availability Tool is available through the EPA.

MOBILE6

Developer U.S. Environmental Protection Agency (EPA)

Overview MOBILE6 is used to produce motor vehicle emission factors for use in transportation analysis, including State Implementation Plan (SIP) development, transportation conformity, and project-level analysis required under the National Environmental Policy Act (NEPA). It can be used at any geographic level within the U.S.

Main Purpose To develop emission rates for on-road vehicles for use in developing emission inventories, projections, and other analysis.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√				

The model identifies 28 vehicle classes, based on fuel type, vehicle type, and weight.

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√		+		√	√

+ Not directly reported, but can be calculated from difference between total VOC and non-methane VOC

Methodology MOBILE6 is based on emissions testing data and accounts for the impacts of factors such as vehicle emission standards, vehicle type, vehicle operating characteristics, and local conditions such as temperature, humidity and fuel quality on criteria pollutant emission factors. The model's output is in grams of pollutant per vehicle mile, which when combined with vehicle miles traveled (VMT) data produces emissions estimates. The model uses average fuel economy for the entire national fleet for each vehicle category and model year, and assumes future fuel economy stays constant for model years after 2001. Consequently, projections of CO_2 in future years do not account for future changes in fuel economy, and the model cannot be used to account for the impacts of changes in vehicle operating conditions on CO_2.

Assessment

Strengths

- Inputs and assumptions are generally available to transportation agencies.
- Standard emissions model used by transportation agencies for criteria pollutant analysis; as a result, GHG analysis assumptions would be consistent with criteria pollutant analysis assumptions.

Limitations

- Does not account for impacts of vehicles speeds or operating conditions on CO_2; thus, not able to adequately address the impacts of traffic flow improvements.
- Significant limitations in fuel economy data for developing projections. Much of the fuel economy data stops in 1996 and assumes fuel economy stays constant as model years progress for heavy-duty trucks; for passenger cars and light trucks, fuel economy data ends around 2001.

Date Released/Updated MOBILE was initially developed in the late 1970s and has gone a number of significant updates over time. MOBILE6.0 was released in draft form in 2002 and finalized as MOBILE6.2 in 2004.

Availability Downloadable at: http://www.epa.gov/OMSWWW/mobile.htm

NONROAD MODEL

Developer U.S. Environmental Protection Agency (EPA)

Overview The NONROAD model produces estimates of criteria pollutant emissions and CO_2 from all non-road sources, with the exception of commercial marine vessels, locomotives, and aircraft. The model calculates past, present, and future emission inventories for 80 basic and 260 specific non-transportation equipment categories. The model is designed to estimate emissions within the US from county to the national level, from 1970 to 2050.

Main Purpose To provide state and local pollution control agencies with the ability to create and forecast inventories of non-transportation mobile emissions for SIP development.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
						√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√				√	√

Methodology Multiplies equipment population, average load factor expressed as an average fraction of available power, available power in horsepower, and in hours of use per year, and emission factor with deterioration and/or new standards. Emissions are then temporally and geographically allocated using appropriate allocation factors.

Assessment

Strengths

- Produces CO_2 estimates for many non-road sources used in highway construction and maintenance and provides detail on specific construction equipment types. Consequently, can be used to develop CO_2 emissions factors for analyses of transportation agency activities at the project or program-level.
- Includes other transportation-related support equipment, such as airport ground support equipment and railroad equipment.
- Calculates emissions inventories within the U.S. from the county level to the national level, from 1970 to 2050. Allows for side-by-side comparison of different model runs.

Limitations

- Does not include aircraft, commercial marine vessels, or rail, which are the primary non-road transportation sources contributing to GHG emissions. Includes a wide range of other non-road sources, but most of the equipment types and vehicle types are not relevant to transportation agencies (e.g., commercial/industrial equipment, agricultural equipment).
- Background calculations not especially transparent.
- Activity data for transportation construction and maintenance may not be available; defaults in model are not specific to transportation-related activities.

Date Released/Updated Most recent version is the draft NONROAD2004 Model, released in 2004.

Availability Downloadable at: http://www.epa.gov/OMSWWW/nonrdmdl.htm

NATIONAL MOBILE INVENTORY MODEL (NMIM)

Developer U.S. Environmental Protection Agency (EPA)

Overview NMIM uses current versions of MOBILE6 and NONROAD to calculate emission inventories, based on multiple input scenarios that the user enters into the system. It was developed to produce, in a consistent and automated way, national, county-level mobile source emissions inventories for the National Emissions Inventory (NEI) and for EPA rule making. NMIM combines the capabilities of MOBILE6 and NONROAD into a single format suitable for the national inventories. NMIM can be used to calculate national, individual state or county inventories.

Main Purpose To develop national emissions inventories for mobile sources.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√				√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√				√	√

Methodology The NMIM user specifies a set of years and months, a geographic region (national, any combination of whole states, or any combination of particular counties), a set of pollutants, and categories of on-road vehicles and non-road equipment. Based on these specifications and information in the NMIM county database (NCD), NMIM writes input files for the MOBILE6 and NONROAD models, then runs these models, reads their output files, performs additional processing if necessary, and puts the inventories into an output database. Additional processing includes multiplying MOBILE6 emission factors by vehicle miles traveled (VMT) and estimating emissions of some other pollutants. The model's post-processing capabilities include aggregation over months, roadway types, vehicle types, and equipment types. NMIM extends MOBILE6's capabilities by producing inventories rather than just emissions factors, and provides consistency across both models and all pollutants by using a single input database for MOBILE6 and NONROAD and for criteria pollutants and HAPS.

Assessment

Strengths

- Includes county-level travel and activity data for the entire nation while postprocessing allows quick aggregation of emissions over months, roadway types, vehicle types, and equipment types.
- Distributed processing capability achieves faster run times over the two models individually.

Limitations

- Constrained by the same limitations as the NONROAD and MOBILE6 models in terms of CO_2 estimates and forecasts (especially lack of responsiveness to vehicle operating characteristics and limitations in fuel economy projections).
- No capability to conduct project-level analysis or generate hourly and by-model-year output tables.

Date Released/Updated Initial version completed in 2003, updated and released in 2005.

Availability Downloadable at: http://www.epa.gov/OMSWWW/nmim.htm

EMFAC MODEL

Developer California Air Resources Board (CARB)

Overview EMFAC is the approved emissions model used in the State of California, and is used for SIP development, conformity analysis, and other analyses that are typically conducted using MOBILE6 in other states. The model produces emission rates and inventories for criteria air pollutants and CO_2.

Main Purpose To develop emissions estimates for on-road vehicles for use in developing emission inventories, projections, and other analysis.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√				

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√				√	√

Methodology The EMFAC2002 model includes two basic modules: emission factors and vehicle activity. Emission factors vary by vehicle characteristics and ambient and driving conditions, and were developed based on emissions tests on new and used vehicles from the California fleet. Within the EMFAC model, these factors are combined with vehicle activity, or estimates of travel and vehicle demographics, for each county, local air district, and air basin in California, relying on data provided by regional transportation agencies, as well as Department of Motor Vehicles (DMV) vehicle registration data. These data are incorporated into EMFAC2002 as defaults and can be updated by the model user. The CO_2 base emission rates for gasoline passenger cars, light duty trucks, and medium duty trucks are based on emissions data collected through March 1999, while the diesel emissions data are based on more limited emissions tests comprised of model years through 1985; given limited data, the same emission factors are applied for diesel passenger cars, light duty trucks, and medium duty trucks.

Assessment

Strengths

- The CO_2 calculation methodology accounts for the effects of vehicle speeds and operating conditions on CO_2 emissions.
- CO_2 emissions factors vary by vehicle class, technology type, and model year group, and for each bag of the Federal Test Procedure (FTP) and Unified Cycle (UC).

Limitations

- Data are only available for counties in California.
- Gasoline vehicle test data include data collected through 1999 for autos, light-duty trucks, and medium-duty trucks; data for diesel vehicles come only from vehicles through model year 1985; although CARB staff believe these results are valid for later model years, the age of the diesel data is a potential source of concern.

Date Released/Updated Current version, EMFAC2002 was released in October 2002.

Availability Downloadable at: http://www.arb.ca.gov/msei/on-road/latest_version.htm. Documentation of CO_2 calculation is available at: http://www.arb.ca.gov/msei/on-road/downloads/tsd/CO2_Emissions.pdf

CLIMATE LEADERSHIP IN PARKS (CLIP)

Developer U.S. Environmental Protection Agency (EPA), prepared by ICF Consulting

Overview The Climate Leadership in Parks (CLIP) Tool allows for GHG and criteria pollutant emissions estimation at a more local level. Although default vehicle characteristics are geared toward travel situations at national parks, CLIP could be used to calculate emissions at other locales if users can enter in their own activity data. CLIP calculates emissions based on fuel consumption and and/or vehicle miles traveled.

Main Purpose Estimate GHG and criteria pollutant emissions for national parks.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√			√	√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√		√	

Methodology The calculations are based on the same methodologies used in EPA's Inventory of *U.S. Greenhouse Gas Emissions and Sinks*, which are based on internationally accepted emission reporting guidelines. Emissions can be calculated based on fuel consumption or VMT.

Assessment

Strengths

- Model is easy to use, requires inputs which should be available to practitioners.
- Inventory methods are based on the national GHG inventory.
- Specifically designed for use at national parks, but could be adapted for other local areas.
- Provides users ability to model impacts of mitigation actions on GHG and CAP emissions.

Limitations

- Very little default data available in the tool.
- Tool not publicly available on the web.

Date Released/Updated Draft completed Spring 2005.

Availability Not yet publicly available.

DRAFT NEW YORK STATE DOT GUIDANCE ON TRANSPORTATION GHG ANALYSIS

Developer New York State Department of Transportation

Overview NYSDOT developed a series of draft guidance documents to meet the goals and recommendations of the State Energy Plan (SEP) adopted in 2002. The documents provide recommended methodologies to calculate energy consumption impacts of transportation projects for project alternatives analysis and for metropolitan planning organizations' (MPO) Transportation Improvement Programs (TIPs) and long-range transportation plans.

Main Purpose To assist in calculating the fuel consumption and GHG impacts of transportation projects, programs, and plans.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√				

In addition, transit and vehicles used in the construction and maintenance of transportation infrastructure (referred to as "indirect" emissions) are also calculated.

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√					

Methodology Two methods are provided to calculate direct energy consumption from motor vehicles: 1) An urban fuel consumption method accounts for the effects of vehicle speeds on fuel consumption. Look-up tables are used to estimate a base year fuel consumption rate, which is then multiplied by VMT to approximate total fuel consumption. A corrections factor is applied to adjust the estimate for the analysis year, based on historical information on vehicle fuel economy by model year from Oak Ridge National Laboratory's "Transportation Energy Data Book", and future projections from DOE's "Annual Energy Outlook" 2) A VMT fuel consumption method is used when no other information than total VMT is known. Roadway maintenance energy is calculated based on a lookup table with values of energy consumption per lane mile by pavement type and urban/rural location. Roadway construction energy is also calculated based on Caltrans' methods.

Assessment

Strengths

- Geared toward the needs of transportation practitioners it includes methodology for analyzing both 'direct' emissions from vehicles and 'indirect' from construction equipment.
- Methodology is transparent and based on available data. Provides two different methods for each type of analysis, depending on whether or not speed data are available.

Limitations

- Effects of vehicle speeds are based on data from the early 1980s and may not be applicable for recent model year vehicles.
- Methodology for calculating direct emissions is somewhat cumbersome and confusing.
- Calculation methodology for indirect emissions also is based on a methodology and emission factors developed by Caltrans in the early 1980s, and may be applicable for current construction equipment.

Date Released/Updated November 2003.

Availability Available through New York State DOT.

GREET MODEL

Developer Argonne National Laboratory (sponsored by U.S. DOE)

Overview GREET is designed primarily for analyses of advanced technology and alternative fuel vehicles. It allows researchers and analysts to analyze and compare various vehicle and fuel combinations on a full fuel-cycle basis. It is an excel-based spreadsheet model that calculates energy consumption, gas emissions, and pollutants for any given vehicle and fuel system.

Main Purpose To fully evaluate the energy and emission impacts of advanced vehicle technologies and new transportation fuels (considering the fuel cycle from wells to wheels and the vehicle cycle through material recovery to vehicle disposal).

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√						

Vehicle technologies such as conventional spark- ignition engines, direct-injection spark- ignition engines, hybrid electric vehicles, battery-powered electric vehicles, and fuel-cell vehicles are modeled.

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√		√	

Methodology Vehicular emissions of baseline gasoline and diesel vehicles are lifted from MOBILE, and PART5. SO_x emissions are calculated from the sulfur contents of fuels, CO_2 emissions from carbon balance, and N_2O emissions are assumed with emissions testing results and technology potentials.

Assessment

Strengths

- To address technology improvements over time, fuels and vehicle technologies are separated into near- and long-term options over 30 fuel-cycle pathway groups.
- Developed to model advanced vehicle technologies and new transportation fuels. Analyses energy consumption from material recovery to vehicle disposal.
- In additional to total emissions, the 3 GHG are reported as global warming potential used to calculate CO_2 equivalents and urban emissions.

Limitations

- Does not have the capability to estimate energy consumption and emission totals over multiple calendar years and multiple advanced vehicle market penetration scenarios.

Date Released/Updated Released June 1996, Updated February 2000

Availability Downloadable at: http://www.transportation.anl.gov/software/GREET/download.html

LIFECYCLE EMISSIONS MODEL (LEM)

Developer University of California, Davis (Mark Delucchi)

Overview Estimates energy use, criteria pollutant emissions, and CO2-equivalent greenhouse-gas emissions from transportation and energy sources. Includes data for up to 20 countries from 1970 to 2050, and is fully specified for the US.

Main Purpose To aid the development of strategies to reduce emissions of urban air pollutants and greenhouse gasses.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√	√		√	√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√	√	√	√

Methodology The user specifies any year between 1970 and 2050 and the mode looks up or calculates energy-use intensities, emissions factors, or other data for that specific year. Projections in the model come from US DOE projections, constant percentage changes each year, and logistic functions. With these inputs the LEM produces results such as total life-cycle emissions by transportation source and by component of the life-cycle, and emissions per mile (from motor vehicles). It distinguishes emissions that are in-country vs. out-of-country in the lifecycle emissions analysis, and can be used for various transportation scenarios.

Assessment

Strengths

- Provides estimates and projections of emissions of all GHGs for any year 1970 to 2050 for the full life-cycle of transportation, including fuels (from feedstock production through fuel production through end use), materials associated with vehicle manufacture, vehicles (including vehicle assembly, operation and maintenance), and infrastructure construction.
- Includes not only on-road vehicles, but also heavy-rail transit, light-rail transit, diesel trains, freight tankers, cargo ships, and barges, and pipelines.
- Provides results in emissions per mile from motor vehicles and energy-use intensities for other modes, and can provide other types of outputs (percentage change).

Limitations

- Proprietary model is not publicly available.
- Emissions factor estimation is akin to a highly simplified version of EPA's MOBILE model, and does not account for as many factors.
- Does not include vehicle disposal in the lifecycle estimates.

Date Released/Updated Released 1993, updated December 2003.

Availability Not publicly available.

MOTOR VEHICLE EMISSIONS SIMULATOR (MOVES)

Developer U.S. Environmental Protection Agency (EPA)

Overview A draft version of this new model was released in January 2005. The model is intended to eventually replace MOBILE and NONROAD. EPA expects to make annual releases of upgraded versions of MOVES, adding pollutants and sources over the next four years and updating underlying data as needed. The model estimates energy consumption (total, petroleum-based and fossil-based) and emissions of methane and nitrous oxide for all on-road sources, over the entire US at the county level, from 1999 through 2050.

Main Purpose Intended to be a replacement for and improvement upon MOBILE and NONROAD.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√				

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√			

Future versions of the model will add criteria air pollutants and air toxics.

Methodology Estimates on-road "pump-to-wheel" energy consumption and emissions by the processes of running, start, and extended idle, and also includes fuel cycle "well-to-pump" energy and emissions via the GREET model. The model generates quantities of energy consumption (total, petroleum-based and fossil-based), emissions of nitrous oxide (N_2O) and methane (CH_4), and distance (e.g. vehicle miles traveled) for the geographic region and time period being modeled. It uses a physical emissions rate estimator (PERE) model to calculate energy consumption which allows for different energy consumptions for different speeds and facility types or duty cycles. MOVES can be used for project-level analyses, regional emissions analysis, or state or national inventory development.

Assessment

Strengths

- Calculation of energy consumption uses a physical emissions rate estimator (PERE), for all travel modes, accounting for the effects of vehicle speed, operating mode, and vehicle type.
- Combines GREET well-to-pump estimates for numerous fuel production and distribution pathways with capability to estimate energy consumption and emission totals over multiple calendar years and multiple advanced vehicle market penetration scenarios.

Limitations

- The MOVES2004 version does not directly calculate CO_2 emissions. It develops estimates of energy consumption, which must be converted into CO_2 off-model. In a future updates (MOVES2006), the tool will calculate CO_2 directly.
- While the model provides a user-friendly interface and default values, the vast amount of data contained in the model make it somewhat complex to use for certain types of simple project analyses and if the user wants to replace default values. There is currently limited documentation on how to use the tool to generate emission factors for project-level analyses.

Date Released/Updated Draft version was released in January 2005.

Availability Downloadable at: http://www.epa.gov/OMSWWW/ngm.htm.

COMMUTER MODEL

Developer U.S. Environmental Protection Agency (EPA), prepared by Sierra Research

Overview The COMMUTER Model is designed to analyze the impacts of transportation control measures (TCMs), such as regional and employer-based transportation demand management strategies and incentives (e.g., transit fare price reductions, increased transit frequency, ridesharing programs, telecommuting programs) on VMT, criteria pollutant emissions, and CO_2.

Main Purpose To analyze the vehicle travel and emissions impacts of TCM strategies.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√						

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√				√	

Methodology The model contains two components: analysis of travel impacts and analysis of emissions. The travel impacts component uses a logit mode-choice model ("pivot point" approach), which calculates the impacts of programs on mode share changes, based on starting mode shares; the approach allows analysis of the impacts of multiple strategies in combination. The changes in mode shares are then translated into changes in trips and VMT. The emissions component applies emission factors based on EPA's MOBILE5b model; the factors reflect several different location conditions. The model offers two levels of analysis: 1) regional analyses can be done on programs covering an urban area, a central business district or a highly-traveled corridor; 2) site-specific analyses enable impacts to be projected for programs at individual worksites. The CO_2 estimation is very simple, relying on an average emissions factor per vehicle mile.

Assessment

Strengths

- Relatively easy to use and requires few inputs.
- The tool analyzes the impacts of TDM and TCM strategies on VMT, criteria pollutant emissions, and CO_2 all in one package. It can also analyze packages of strategies.

Limitations

- Default CO_2 emissions factor does not account for important local factors, like vehicle fleet mix, vehicle age, or speeds, although the tool allows the user to link to emissions factor outputs from MOBILE.
- In addition to limitations in the CO_2 emissions factors, there is a relatively high level of uncertainty in the estimates of travel impacts.

Date Released/Updated Updated in 2006 to reflect MOBILE6 emission factors.

Availability Downloadable at: http://www.epa.gov/otaq/transp/traqmodl.htm

INTELLIGENT TRANSPORTATION SYSTEMS DEPLOYMENT ANALYSIS SYSTEM (IDAS)

Developer Federal Highway Administration

Overview IDAS is a sketch planning analysis tool that can be used to estimate the impacts, benefits and costs resulting from the deployment of ITS components. The tool estimates the benefits and costs of more than 60 types of ITS investments. Among the effects calculated are travel time, safety, and environmental benefits, including effects on criteria pollutant emissions and fuel consumption (which in turn can be used to calculate impacts on CO_2 emissions).

Main Purpose To assist in planning ITS investments.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√				

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√				√	

Methodology IDAS operates as a post-processor to travel demand forecasting models. It utilizes the modal split and traffic assignment results from the traditional planning model to estimate changes in modal, route, and temporal decisions of travelers, as well as induced/foregone demand resulting from ITS technologies. It then estimates the travel benefits of these traveler behavior changes.

Assessment

Strengths

- Designed to specifically address the impact of ITS on emissions through resulting travel behavior changes. These impacts include changes in user mobility, travel time/speed, travel time reliability (non-recurring congestion duration), fuel costs, operating costs, accident costs, emissions, and noise.

- Operates as a post-processor to traditional four-step travel demand forecasting models and relies upon modal split and traffic assignment results from the traditional planning models.

Limitations

- Application and policy sensitivity is largely limited to ITS.

- Effects of vehicle characteristics, speeds, etc. on fuel consumption and CO_2 emissions are limited.

Date Released/Updated Latest version released November 2003.

Availability Can be ordered by phone or online for a fee from: http://mctrans.ce.ufl.edu/featured/idas/.

NATIONAL ENERGY MODELING SYSTEM (NEMS)

Developer Energy Information Administration (EIA), U.S. Department of Energy (DOE)

Overview NEMS represents the behavior of energy markets and their interactions with the US economy. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior. Contains a transportation demand module (TRAN) that has several sub-modules including alternative-fuel vehicles, VMT, light-duty vehicles, and air travel demand. TRAN uses NEMS inputs such as energy prices, GDP, personal income, defense spending, and vehicle sales to project regional fuel consumption, travel demand and VMT, and fuel economy.

Main Purpose Developing annual projections and evaluating energy policies. TRAN's primary purpose is to forecast the consumption of transportation sector fuels by transportation mode and vehicle type.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√	√	√	√	√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√					

Analyzes fuel consumption, which can be used to calculate CO_2.

Methodology A series of submodules in TRAN build off of one another. For example, the Light Duty Vehicle (LDV) Module generates driving, fuel economy and fuel consumption estimates for light duty vehicles. This information is then passed to the Miscellaneous Energy Use Module, which uses additional inputs to calculate regional fuel consumption by mass transit vehicles and recreational boating. VMT per capita estimates are based on the fuel cost of driving per mile, per capita disposable personal income, and an adjustment for female-to-male driving ratios. Total VMT is calculated by multiplying VMT per capita by the driving age population.

Assessment

Strengths

- Travel demand and energy consumption estimates are based on inputs of demographic, geographic, and economic factors.
- Provides comprehensive database of vehicle types, including advanced and alternative fuel vehicles not yet on market, with model feedback influencing uptake/penetration rates.
- Provides a comprehensive well to pump energy consumption analysis, in addition to vehicle emissions estimates.

Limitations

- Complex to run for simple transportation analyses.
- All data are provided in the model at the national and/or multi-state level; it is not available at state or lower level without simplifying assumptions or extensive local data needs.
- Limited availability - proprietary portions such as the macroeconomic model and the optimization modeling libraries can be ordered but at high cost, and thus the tool is only used at a handful of places outside the DOE.

Date Released/Updated Current version was released January 2003.

Availability Proprietary portions such as the macroeconomic model and the optimization modeling libraries can be ordered.

VISION MODEL

Developer Argonne National Laboratory (sponsored by US DOE)

Overview VISION forecasts energy use including carbon emissions until 2050. It is an excel-based model that provides estimates for advanced light- and heavy-duty highway vehicle technologies and alternative fuels. The model was designed as a simplified and fast way to assess the potential impact of new fuel technologies on energy use and carbon emissions, and as a faster and simpler alternative to NEMS. It provides estimates of the potential energy use, oil use, and carbon emission impacts to 2050 of advanced light- and heavy-duty highway vehicle technologies and alternative fuels.

Main Purpose To provide DOE with a fast way to measure the potential impact of new fuel technologies on energy use and carbon emissions.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√					

The model accounts for the impact of advanced technology and alternative fuel vehicles.

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√			

Fuel consumption can be used to estimate CO_2 emissions, while total carbon-equivalent emissions account for the global warming potential of CO_2, N_2O, and CH_4.

Methodology The model consists of two Excel workbooks: a base case of U.S. highway fuel use and carbon emissions to 2050 and a copy of the base case that can be modified to reflect alternative assumptions about advanced vehicle and alternative fuel market penetration. It uses vehicle survival and age dependent usage characteristics to project total light- and heavy-vehicle stock, total VMT, and total energy use by technology and fuel type by year, given market penetration and vehicle energy efficiency assumptions developed exogenously. The model also estimates total carbon equivalent emissions, based on carbon coefficients representing full fuel-cycle emissions (i.e., includes carbon emissions from petroleum production, emissions at the refinery, and delivery to and use of the fuels in vehicles), based on coefficients in the GREET model.

Assessment

Strengths

- Models energy use, oil use, and carbon emissions through 2050 using a quick turnaround, easy to use format.
- Allows analysis of changes to transportation or energy policies, including share of advanced technology/alternative fuel vehicles, VMT growth, and fuel prices.

Limitations

- Assumptions, inputs, and most reports are calculated in 10 year intervals.
- Analysis is conducted at the national level, making post-processing or edits in default energy assumptions necessary for state or regional analysis.
- Unlike the NEMS model, this tool does not take into account the impacts of economic factors on consumer vehicle choices.

Date Released/Updated Released Spring 2002, periodically updated.

Availability Downloadable at: http://www.transportation.anl.gov/software/VISION/index.html

WORLD ENERGY PROTECTION SYSTEM (WEPS) TRANSPORTATION ENERGY MODEL (TEM)

Developer U.S. Department of Energy

Overview This is a structural accounting model for transportation energy use. The model generates mid-term (up to 2020) forecasts of transportation sector energy use as a component of WEPS, which is a model that forecasts world energy consumption. This allows the evaluation of the effect of changes in fuel economy on carbon emissions.

Main Purpose To provide a framework for integrating knowledge of energy use trends in industrialized countries with an analysis of potential energy demand growth in the developing world.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√	√	√	√	√	√

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√					

Methodology For a given set of assumptions, the model forecasts energy use by transport mode. Estimates of growth in energy use for each mode are built up from estimates of growth in travel and growth in energy intensity. Energy use totals by mode and region are distributed to fuel types based on historical trends and energy market developments (note: model was last updated in 1998).

Assessment

Strengths

- Takes into account world markets affecting energy supply and demand at the local and state level.

Limitations

- Country level and regional (multi-country) analysis limits this tool's usefulness at the local and state level.
- Places particular emphasis on the impact of developing countries' consumption patterns on future world energy and CO_2 emissions.

Date Released/Updated Initially developed in 1985, modern version released in September 1997, updated April 2002.

Availability Downloadable at: http://www.eia.doe.gov/oiaf/ieo/weps/

SYSTEMS FOR THE ANALYSIS OF GLOBAL ENERGY MARKETS (SAGE)

Developer U.S. Department of Energy

Overview SAGE is a newly developed model that is intended to replace WEPS. It is an integrated set of regional models that allows for the estimation of regional energy demand and supply.

Main Purpose To forecast 30 years of likely energy market behavior with and without new policy initiatives.

Modes Addressed

Light-duty vehicles	Heavy-duty trucks	Buses	Rail	Aircraft	Maritime vessels	Other Non-road
√	√					

Gases Analyzed

CO_2	N_2O	CH_4	HFCs	Criteria pollutants	Air toxics
√	√	√			

Methodology For each region, reference case estimates of end-use energy service demands (e.g., car, commercial truck, and heavy truck road travel; residential lighting; steam heat requirements in the paper industry) are developed on the basis of economic and demographic projections. Projections of energy consumption to meet energy demands are estimated on the basis of each region's existing energy use patterns, the existing stock of energy-using equipment, and the characteristics of available new technologies, as well as new sources of primary energy supply.

Assessment

Strengths

- Transportation submodel incorporates both qualitative and quantitative components including 'expert judgment'.

Limitations

- Designed to replace the WEPS model, SAGE also models energy markets at the country and regional (multi-country) level, which limits the tool's usefulness at the local and state level.

Date Released/Updated Not yet released.

Availability Not yet publicly available.

APPENDIX B: ASSESSMENT OF METHODOLOGIES

The following analysis presents an assessment by ICF Consulting of seventeen tools and standardized methodologies across several criteria.

Table 1 identifies the applicability of each of these tools across three dimensions.

1. **Geographic level of analysis***:* Whether or not the tool can be applied for analysis at the following levels:
   - State,
   - Region (e.g., a metropolitan planning organization or urbanized area level, such as analysis for a regional long range transportation plan or transportation improvement program),
   - Local (e.g., county, city, or municipality), and
   - Project (e.g., an HOV lane, signal improvement project, or new transit service).

2. **Type of analysis**: Whether or not the tool can be used for the following purposes:
   - Inventory development (e.g., development of historical or baseline inventories),
   - Projections (e.g., development of future forecasts of emissions levels), and
   - Strategy analysis (e.g., scenario testing, investment/project analysis, or program analysis).

3. **Transportation mode**: The table also identifies whether the tool can be used to analyze the following modes:
   1. light-duty vehicles (e.g., passenger cars, light-duty trucks),
   2. heavy-duty trucks (e.g., freight trucks),
   3. buses (e.g., transit buses, as well as school buses or intercity buses),
   4. rail (e.g., transit, passenger rail, or freight),
   5. boats and ships,
   6. aircraft, and
   7. other non-road mobile sources (e.g., airport ground service equipment, construction equipment, agricultural equipment).

Table 2 provides an assessment of the primary strengths and limitations of each tool for GHG analysis, based on the types of analyses they are capable of performing. It also provides a qualitative rating (high, medium high, medium low, or low) of each methodology across four criteria:

- **Availability of Data –** How readily available are the data required to use the method? Methodologies that require limited amounts of readily available data or provide a comprehensive internal data set will score "high", while those that require a large amount of data that may be difficult to obtain will score "low".
- **Ease of Application** – How simple or complex is the method to actually apply? Methodologies that are relatively easy to implement and have relatively simple procedures or calculations will score "high", while those that require a great deal of time, effort, and resources to apply will score "low".
- **Technical Robustness** – How reasonable are the results of the methodology believed to be for a variety of different circumstances? Methodologies that take into account a full range of factors that might affect emissions will score "high", while those that use a lot of simplifying assumptions and whose results do not vary in different circumstances will score "low".

- **Policy Sensitivity –** How sensitive are the results of the methodology to changes in highway investments, transit investments, or other policies? Methodologies that take into account the effect of transportation decisions will score "high" (e.g., a methodology that predicts a change in GHG emissions based on changes in highway investments and transit service improvements would exhibit high policy sensitivity). In contrast, methods that predict the same results regardless of relevant policy changes will score "low" (e.g., a method that does not account for the effects of vehicle speeds on GHG emissions would exhibit relatively low policy sensitivity).

Caution should be exercised in comparing tools on the basis of their qualitative ratings since the tools are applicable for different GHG analysis purposes. The evaluations provide a general indication of their relative strengths and weaknesses.

Table 1: Applicability of Tools for Transportation GHG Analysis

Model	Geographic Level of Analysis				Type of Analysis			Transportation Mode						
	State	Region	Local	Project	Inventory Develop-ment	Projections	Strategy Analysis	Light-duty Vehicles	Heavy-duty Trucks	Buses	Rail	Maritime	Aviation	Other Non-road
MOBILE6	■	■	■	■	■	■	■	■	■	■	-	-	-	-
NONROAD	■	■	■	-	■	■	■	-	■ off-road only	-	-	■ non-freight	-	■
NMIM	■	■	■	-	■	■	■	■	■	■	-	-	-	■
SIT	■	-	-	-	■	-	-	■	■	■	■	■	■	■
SIPT	■	-	-	-	-	■	-	■	■	■	■	■	■	■
CLIP	-	-	■	-	■	-	■	■	■	■	-	■ non-freight	-	■
MOVES	■	■	■	■	■	■	■	■	■	■	2007 release	2007 release	2007 release	2007 release
COMMUTER	□	■	■	■	-	-	■ TDM projects	■	-	-	-	-	-	-
IDAS	□	■	■	■	-	■	■ ITS projects	■	■	■	■	-	-	-
NEMS	□	-	-	-	-	■	■	■	■	■	■	■	■	■
VISION	□	-	-	-	-	■	■	■	■	-	-	-	-	-
WEPS	□	-	-	-	■	■	■	■	■	■	■	■	■	■
SAGE	□	-	-	■	■	■	■	■	■	■	-	-	-	-
GREET	■	■	■	■	■	■	■	■	-	-	-	-	-	-
LEM	□	-	-	-	■	■	■	■	■	■	■	■	-	■ pipelines
EMFAC	■	■	■	■	■	■	■	■	■	■	-	-	-	-
NYSDOT	■	■	■	■	-	■	■	■	■	■	■ non-freight	-	-	■

Key

■ Designed for this type of analysis
□ Not designed for this type of analysis but could potentially be applied
\- Not applicable

Table 2: Evaluation of Tools for Transportation GHG Analysis

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
MOBILE6	• Standard emissions model used by transportation agencies for conformity purposes and criteria pollutant analysis. Therefore inputs and assumptions are generally available and can be consistent for criteria pollutant analysis and GHG analysis.	• Procedures for calculating CO_2 do not account for the impacts of vehicle speeds or operating conditions on fuel economy. As a result, tool is not able to address the GHG impacts of traffic flow improvements, operational strategies, or congestion reduction measures. Uses average fuel economy for the entire national fleet for each vehicle category and model year. • Significant limitations in fuel economy data for developing projections. Much of the fuel economy data stops in 1996 and assumes fuel economy stays constant as model years progress for heavy-duty trucks; for passenger cars/light trucks, fuel economy data ends around 2001.	★★★ Inputs (VMT, VMT mix) are generally available to transportation agencies However, requires some data processing (e.g., converting HPMS VMT estimates into EPA vehicle categories)	★ Relatively complex to run	★★ Can account for impacts of local vehicle mix and age, but not speeds; also, does not take into account future changes in fuel economy	★★ Does not take into account impacts of vehicle speed and operating conditions on CO_2. Does not account for feedback effects (prices, distances, operating costs) impacting fuel economy.
NONROAD	• Produces CO_2 estimates for many non-road sources used in highway construction and maintenance. Provides detail on individual sources (e.g., construction equipment types include pavers, rollers, excavators, cranes, off-highway trucks, etc.; lawn & garden equipment include commercial tractors, rear engine riding mowers, front mowers). Consequently, can be used to develop CO_2 emission factors for analyses of transportation agency activities at the project or program-level. • Includes other transportation-related support equipment, such as airport ground support equipment and railroad equipment. • Calculates emissions inventories within the U.S. from the county level to the national level, from 1970 to 2050.	• Does not include aircraft, commercial marine vessels, or rail, which are the primary non-road transportation sources contributing to GHG emissions. Includes a wide range of other non-road sources, but most of the equipment types and vehicle types are not relevant to transportation agencies (e.g., commercial/industrial equipment, agricultural equipment). • Background calculations not especially transparent. • Activity data for transportation construction and maintenance may not be available; defaults in model are not specific to transportation-related activities.	★★ Data on transportation construction/ maintenance activity may not be readily available to transportation agencies Default data are provided for all parameters, but are not specific to transportation construction and maintenance	★★ Graphical user interface (GUI) familiar to PC users Can be difficult to install and become familiar with application Technical terminology requires users to be somewhat familiar with terms and abbreviations	★★★ Emission factors for equipment are based on extensive data Some estimates based on presumed number of hours of equipment use, rather than reported fuel consumption data	★★★ Can be used for analysis of policy changes, such as changes in non-road technologies and number of equipment/ vehicles

Key

★	Low	★★★	Medium-High
★★	Medium-Low	★★★★	High

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
NMIM	• Includes county-level travel and activity data for the nation and tools for inventory aggregation and post-processing. • Tool postprocessing allows quick aggregation of emissions over months, roadway types, vehicle types, and equipment types. • Distributed processing capability across several computers enhances performance run times over the NONROAD and MOBILE6 models individually.	• Constrained by the same limitations as the NONROAD and MOBILE6 models in terms of CO_2 estimates and forecasts (especially lack of responsiveness to vehicle operating characteristics and limitations in fuel economy projections). • No capability to conduct project-level analysis or generate hourly and by-model-year output tables.	★★★ Default data tables are included in the program	★★★ Improves the run time and GUI of other EPA models	★★ Can account for impacts of local vehicle mix and age, but not speeds; also, does not take into account future changes in fuel economy	★★ Does not take into account impacts of vehicle speed and operating conditions on CO_2. Does not account for feedback effects (prices, distances, operating costs) impacting fuel economy.
SIT	• Very easy to use and can develop a comprehensive GHG inventory for CO_2, CH_4, and N_2O with little user experience. All calculations are automated. • If state-specific data are not available, the SIT can calculate emissions using default data derived from national values. • Emission estimates can be created quickly once activity data have been obtained. • Methodology mirrors that of the national GHG inventory and is relatively transparent.	• Does not output CO_2 by mode or vehicle type, only fuel type for the entire transportation sector. Results must be post-processed to develop a more detailed inventory for transportation sources. • Default data are sometimes extrapolated from national data based on broad assumptions, and may not accurately depict state-level trends. • Tool not publicly available on the web. Must contact EPA.	★★★ Input data for motor vehicles (e.g. VMT and fuel consumption) are likely available, but inputs for non-road modes may not be Default data are included in the tool	★★★★ Very simple data entry process Estimates calculated automatically	★★★ Some state-level default data are extrapolated from national data CO_2 is calculated from fuel consumption estimates, which reflect fuel sales, not necessarily fuel consumption within the state, especially for non-road modes	★ Tool is not designed for policy analysis, but rather for inventory development. Policy impacts on CH_4, and N_2O can be reflected by user-inputted values for VMT and vehicle mix

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
SIPT	• Tool is very easy to use and can develop comprehensive GHG inventory projections for CO_2, CH_4, and N_2O with little user experience. All calculations are automated. • Tool can retrieve results directly from SIT. • If state-specific data are not available, the SIPT can calculate emissions using default data derived from national estimates.	• Projections based on historical data and emission estimates. Projection methodology is generally based on linear trends; tool is not capable of predicting impacts of future policy changes on projected emissions. • Does not output CO_2 by vehicle type, only fuel type. • Tool not publicly available on the web. Must contact EPA.	★★★ Users must enter historical emission estimates, either by importing directly from SIT or manually entering historical estimates	★★★★ Clear data import and calculation features	★ Projections methodology very simplified and does not account for economic, social, or technological changes Default historical estimates available to provide context, but are highly uncertain	★ Does not account for policy changes
CLIP	• Model is easy to use, requires inputs which should be available to practitioners. • Inventory methods are based on the national GHG inventory. • Specifically designed for use at national parks, but could be adapted for other local areas. • Provides users ability to model impacts of mitigation actions on GHG and CAP emissions.	• Very little default data available in the tool. • Tool not publicly available on the web.	★★★ Can estimate emissions using either VMT or fuel consumption Helpful reference sheet details where to find data sources Some default data available	★★★★ Simple to follow with optional methodology explanations	★★★ Quality of estimates driven in large part by quality of user-entered activity data and mpg values	★★★ Policy changes can be reflected by user-inputted values for VMT, mpg, etc.

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
MOVES	• Calculation of energy consumption uses a physical emissions rate estimator (PERE), for all travel modes, accounting for the effects of vehicle operating characteristics on emissions. • Emission rate data are very detailed - the emissions rate table has over 20,000 records broken down by speed, operating mode, and vehicle type. • Combines GREET well-to-pump estimates for numerous fuel production and distribution pathways with capability to estimate energy consumption and emission totals over multiple calendar years and multiple advanced vehicle market penetration scenarios.	• The MOVES2004 version does not directly calculate CO_2 emissions. It develops estimates of energy consumption, which must be converted into CO_2 off-model. In a future updates (MOVES2006), the tool will calculate CO_2 directly. • While the model provides a user-friendly interface and default values, the vast amount of data contained in the model make it somewhat complex to use for certain types of simple project analyses and if the user wants to replace default values. Moreover, there is currently limited documentation on how to use the tool to generate emission factors for project-level analyses.	★★★ Default data tables can be used or adjusted to reflect local conditions To take advantage of full capabilities requires substantial local data	★★★ Relatively easy to run using the provided GUI and reporting functions Includes the GREET model pathways analysis	★★★★ Uses second-by-second CO_2 emissions data for all source types Uncertainty analysis by EPA show relatively close results to fuel-based calculation methods	★★★★ Sensitive to VMT, vehicle operating characteristics, and vehicle characteristics
COMMUTER	• Relatively easy to use, requires few inputs. • Designed primarily to analyze the impact of TDM and TCM strategies on VMT, criteria pollutant emissions, and CO_2.	• Default CO_2 emission factor does not account for important local factors, like vehicle fleet mix, vehicle age, or speeds, although the tool allows the user to link to emission factor outputs from MOBILE. • Model focuses on analyzing mode shifts (for analysis of TDM projects and programs); calculation of CO_2 is very simple factor per mile traveled.	★★★★ Requires few inputs outside of transportation strategies selected for analysis	★★★★ Simple to install and run	★★ Uses a default CO_2 emission factor that does not take into account the effects of local vehicle mix, age, or speeds	★★★ Designed to address TDM; but does not account for effects of vehicle speed and operating conditions
IDAS	• Designed to specifically address the impact of ITS on emissions through resulting travel behavior changes. These impacts include changes in user mobility, travel time/speed, travel time reliability (non-recurring congestion duration), fuel costs, operating costs, accident costs, emissions, and noise. • Operates as a post-processor to traditional four-step travel demand forecasting models and relies upon modal split and traffic assignment results from the traditional planning models.	• Application and policy sensitivity is largely limited to ITS. • Effects of vehicle characteristics, speeds, etc. on fuel consumption and CO_2 emissions are limited	★★★ Data needs are the same as a traditional four step transportation model	★★★ Must order the program from McTrans Center. Easy to run and install	★★ Effects of vehicle characteristics, speeds, etc. on fuel consumption and CO_2 emissions are limited	★★★ Capable of analyzing over 60 different types of ITS investments

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
NEMS	• The model forecasts travel demand for all key transportation modes. • Travel demand and energy consumption estimates are based on inputs of several demographic, geographic, and economic factors, including fuel prices. Consequently, can be used to analyze implications of different scenarios and strategies that affect fuel prices and other factors. • Provides comprehensive database of vehicle types, including advanced and alternative fuel vehicles not yet on market, with model feedback influencing uptake and penetration rates. • Provides a comprehensive well to pump energy consumption analysis, in addition to vehicle emissions estimates.	• Complex, multi-layered model consists of many sub-modules, making if complex to run for simple transportation analyses. • All data are provided in the model at the national and/or multi-state level; it is not available at state or lower level without simplifying assumptions or extensive local data needs. • Limited availability - proprietary portions such as the macroeconomic model and the optimization modeling libraries can be ordered but at high cost, and is thus tool is only used at a handful of places outside the DOE.	★★ Accurate state or local analyses would require substantial data inputs or post-processing of multi-state results	★ Complex to run and generate reports	★★★ Covers details of vehicle types and GHG emission rates, and has sophisticated feedback mechanisms However, macro-level scale of analysis limits applicability at state or local levels.	★★★ Can assess changes resulting from shifts in energy policy, fuel prices, tax credits, and regulation. Can also be used to analyze impacts of user-specified changes in VMT and vehicle fuel economy at a national or multi-state level Not designed for analyses of transportation plans/projects that affect vehicle speeds/operations
VISION	• Models energy use, oil use, and carbon emissions through 2050 using a quick turnaround, easy to use format. Provides some of the same types of capabilities as NEMS but with some simplifications in a format that is publicly available. • Allows analysis of various changes that might be influenced by transportation or energy policies, including share of advanced technology/alternative fuel vehicles, VMT growth, and fuel prices.	• Assumptions, inputs, and most reports are calculated in 10 year intervals. • Analysis is conducted at the national level, making post-processing or edits in default energy assumptions necessary for state or regional analysis. • Unlike the NEMS model, this tool does not take into account the impacts of economic factors on consumer vehicle choices. The user must input shares of vehicles by technology/fuel type.	★★★ Easy to input data; data inputs primarily relate to factors being analyzed, such as VMT growth rates	★★★ Designed to produce fast results; analysis is done in Excel and automatically generates reports Some of the input terminology is technical (e.g., VMT elasticity to cost of driving)	★★ Does not account for the impacts of economic factors on vehicle choice.	★★★ Allows analyses of a range of policies – taking into account effects of VMT growth, fuel prices, and vehicle fleet mix on carbon emissions

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
WEPS	• Takes into account world markets affecting energy supply and demand at the local and state level.	• Country level and regional (multi-country) analysis limits this tool's usefulness at the local and state level. • Places particular emphasis on the impact of developing countries' consumption patterns on future world energy and CO_2 emissions.	★★ Data inputs include economic and other factors, which may not be readily available to transportation agencies.	★★★ Based in Excel for ease of use	★★ Macro-level scale of analysis limits applicability at state or local levels.	★★ Can be used for modeling global policy and market changes, but not designed for transportation investment/policy analysis.
SAGE	• Transportation submodel incorporates both qualitative and quantitative components including 'expert judgment'.	• Designed to replace the WEPS model, SAGE also models energy markets at the country and regional (multi-country) level, which limits the tool's usefulness at the local and state level.	★ Data inputs are extensive and not readily available	★★★ Uses a GUI for easier application and use	★★ Macro-level scale of analysis limits applicability at state or local levels.	★★ Can be used for modeling global policy and market changes, but not designed for transportation investment/policy analysis.
GREET	• To address technology improvements over time, fuels and vehicle technologies are separated into near- and long-term options over 30 fuel-cycle pathway groups. • Developed to model advanced vehicle technologies and new transportation fuels. Analyses energy consumption from material recovery to vehicle disposal. • In additional to total emissions, the 3 GHG are reported as global warming potential used to calculate CO_2 equivalents and urban emissions.	• Does not have the capability to estimate energy consumption and emission totals over multiple calendar years and multiple advanced vehicle market penetration scenarios.	★★★ Data are generally available to local practitioners	★★★★ Uses excel workbook format and recently added a user friendly GUI	★★★ Well to wheel analysis reflects differences by fuel and vehicle technology	★★ Sensitive to vehicle technologies and fuels . Not designed for analysis of transportation infrastructure.

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
LEM	• Provides estimates and projections of emissions of all GHGs for any given year 1970 to 2050 for the full life-cycle of transportation, including fuels (from feedstock production through fuel production through end use), materials associated with vehicle manufacture, vehicles (including vehicle assembly, operation and maintenance), and infrastructure construction. • Includes not only on-road vehicles, but also heavy-rail transit, light-rail transit, diesel trains, freight tankers, cargo ships, and barges, and pipelines. • Provides results in emissions per mile from motor vehicles and energy-use intensities for other modes, and can provide other types of outputs (percentage change).	• Emission factor estimation is akin to a highly simplified version of EPA's MOBILE model, and does not account for as many factors. • Does not include vehicle disposal in the lifecycle estimates. • Not publicly available on the web.	★★★ Data are provided in lookup tables, or calculated with user specifications	[Unrated] No information available (not publicly available)	★★★ Well to wheel analysis reflects differences by fuel and vehicle technology Lifecycle estimates involve many assumptions, which may not be representative of all circumstances, and is crude for the infrastructure lifecycle	★★ Can be used to analyze shifts in travel activity between different vehicle/ technology types and modes by applying emission factor outputs from the model Not designed specifically for analysis of transportation infrastructure investment
EMFAC	• Includes an emission factor module and vehicle activity inputs. • The CO_2 calculation methodology accounts for the effects of vehicle speeds and operating conditions on CO_2 emissions. • CO_2 emission factors vary by vehicle class, technology type, and model year group, and for each bag of the Federal Test Procedure (FTP) and Unified Cycle (UC).	• Data are only available for counties in California. • Gasoline vehicle test data include data collected through 1999 for autos, light-duty trucks, and medium-duty trucks; data for diesel vehicles come only from vehicles through model year 1985; although CARB staff believe these results are valid for later model years, the age of the diesel data is a potential source of concern.	★★★ Requires similar input data as in MOBILE6	★★★ A user friendly GUI	★★ Accounts for effects of vehicle speeds on CO_2, but is based on data from the 1980s for diesel vehicles.	★★★★ Very well defined "what if scenario" capability, including analysis of effects of changes in vehicle operating conditions.

Model	Primary Strengths	Primary Weaknesses	Data Input Availability	Ease of Application	Technical Robustness	Policy Sensitivity
NYSDOT	• Geared directly toward the needs of transportation practitioners to conduct analyses of transportation plans, TIPs, and projects. Includes methodology for analyzing both the emissions of vehicles ("direct" emissions) and construction equipment ("indirect" emissions). • Methodology is transparent and based on available data. Provides two different methods for each type of analysis, depending on whether or not speed data are available.	• Effects of vehicle speeds are based on data from the early 1980s and may not be applicable for recent model year vehicles. • Calculation methodology for direct emissions involves calculating base year energy consumption based on 1980 vehicle characteristics and then developing adjustments. This procedure is somewhat clunky and can be confusing for the analyst. • Calculation methodology for indirect emissions also is based on a methodology and emission factors developed by Caltrans in the early 1980s, and may be applicable for current construction equipment and procedures.	★★★★ Data inputs for either method are available to practitioners	★★★ Relatively simple procedures with look-up tables, but many calculations are done by hand	★★ Accounts for effects of vehicle speeds on CO_2, but is based on data from the 1980s.	★★★ Can account for the effects of policies and investments that change vehicle speeds and VMT.