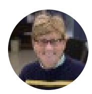
MOVES vs. EMFAC: A Comparison of Greenhouse Gas Emissions Using Los Angeles County

Song Bai
Sonoma Technology Inc.



Deb Niemeier
University of California, Davis

MOVES vs. EMFAC: A Comparison of Greenhouse Gas Emissions Using Los Angeles County

Song Bai, Douglas Eisinger, Deb Niemeier*

U.C. Davis-Caltrans Air Quality Project
Department of Civil and Environmental Engineering
University of California
One Shields Ave.
Davis, CA 95616
Phone: (530) 752-0586
Fax: (530) 752-7872
Email: sbai@ucdavis.edu, doug@sonomatech.com, dniemeier@ucdavis.edu

* Corresponding Author

Submitted to TRB's 2009 Annual Meeting
Revised version: November 6, 2008

Word Count:

Text	=	5,219
Tables (2 @ 250 words)	=	500
Figures (7 @ 250 words)	=	1,750
Total	=	7,469

ABSTRACT

The U.S. Environmental Protection Agency is developing a new generation emission model, MOVES (Motor Vehicle Emission Simulator), to replace MOBILE6. MOVES changes the basis for mobile source emissions estimation from average speed to modal activity. We examine differences in features, methods, and results between MOVES and EMFAC, the mobile source emissions model approved for California. Using a Los Angeles County, California application; two greenhouse gases, carbon dioxide (CO_2) and methane (CH_4); and two analysis years, 2002 and 2030, we analyzed how underlying activity data and emission factors contributed to observed differences between the two models. At the county level, for 2002 MOVES produced similar CO_2 emissions, but only 42% of the CH_4 emissions estimated by EMFAC; for 2030, MOVES produced 40% higher CO_2 emissions and CH_4 emissions were nearly double the estimates provided by EMFAC. Important contributing factors to these differences are the activity data and emission rates embedded in MOVES. The default vehicle activities indicated a younger fleet and higher miles traveled for light-duty trucks by 2030. The CO_2 emissions differences between the two models appear to be mainly affected by the magnitude of forecasted vehicle miles traveled; CH_4 emissions results tend to hinge on the base emission rates. EPA considers the underlying MOVES database for CO_2 and CH_4 emissions to be a draft and emissions results will likely change with upcoming model releases.

1. INTRODUCTION

Currently, two officially approved mobile source emission models are widely used in transportation conformity practice: the MOBILE model developed by the U.S. Environmental Protection Agency (EPA) (*1*) and the EMFAC model developed by the California Air Resources Board (*2*). The fundamental approach of these models is to a) specify vehicle emission rates for different vehicle classes based on dynamometer tests of predefined driving cycles, b) apply a set of correction factors to the base emission rates, to account for vehicle deterioration, temperature, humidity and Inspection/Maintenance (I/M) programs, and c) couple adjusted emission rates with associated vehicle activities. Although emissions vary by vehicle operating modes like cruise, acceleration and deceleration (*3, 4*), MOBILE and EMFAC use only average speed as the primary descriptor of a vehicle's driving to estimate stabilized running exhaust emissions. Without taking speed and vehicle operation modes into account, the average speed-based method may inaccurately reflect emissions from actual driving behavior (*5, 6, 7, 8, 9*).

Since 2001, the U.S. EPA has been developing a new generation mobile source emission model, MOVES (Motor Vehicle Emission Simulator), with the objective of creating a more comprehensive, science-based tool with improved software, which can produce emission estimates for a wider range of spatial applications than could be appropriately addressed by the traditional models (*10*). Compared to current models, the MOVES model represents a fundamental shift in the methodology used to estimate on-road vehicle emissions. MOVES is a modal emissions model: it derives emissions estimates based on second-by-second vehicle performance characteristics for various driving modes. The modal nature of MOVES's emission rates allows the model to, in concept, more accurately estimate emissions at analysis scales ranging from those associated with individual transportation projects to large regional emission inventories. Upon formal adoption by EPA, the MOVES model will serve as the approved model for developing on-road emissions estimates for state implementation plans (SIPs) and regional or project-level transportation conformity analyses (*11*).

In this study we conducted a comparative analysis of the MOVES model to the EMFAC model, California's approved mobile source emissions model. Our objective was to better understand the structure, algorithms, and assumptions behind the MOVES model and to identify its differences from the EMFAC model in data and emissions information. The study is important because the EMFAC and MOBILE models are conceptually similar – although there are important differences between the tools, both directly relate travel activity with average speed-based emission factors; therefore results from this study may also be applicable or provide practical insights to other states using MOBILE. In addition, the MOVES model currently estimates only greenhouse gasses (GHG); given that California is a large source of GHG, it is also critical that estimation be as robust as possible. We examined differences for Los Angeles County to improve our understanding of actual implementation considerations that will need to be addressed if MOVES were to be used to model local-specific conditions.

We begin with a brief description of the MOVES modeling framework, methodology of primary model functions, data management, and modeling outcomes. This is followed with a comparison of the EMFAC and MOVES models using greenhouse gas emissions estimates for Los Angeles County. The comparison is conducted for a base year (2002) and a future year (2030) from three perspectives: emission totals, vehicle activities and emission factors. Finally, we discuss the implications of the findings for modeling practices and important data issues regarding MOVES local applications.

2. A BRIEF REVIEW OF MOVES

The MOVES model incorporates input data that include vehicle feet composition, traffic activities, fuel information and meteorology parameters and conducts modal-based emissions calculations using a set of model functions. Based on the resulting modal-based vehicle emission rates, emission inventories or emission factors are then generated for the desired geographic scale (macro, meso or micro scales) as well as temporal resolution (year, day and hour).

Four major functions constitute the basic framework of MOVES (*12*): an activity generator, a source bin distribution generator, an operating mode distribution generator, and an emissions calculator (Figure 1).

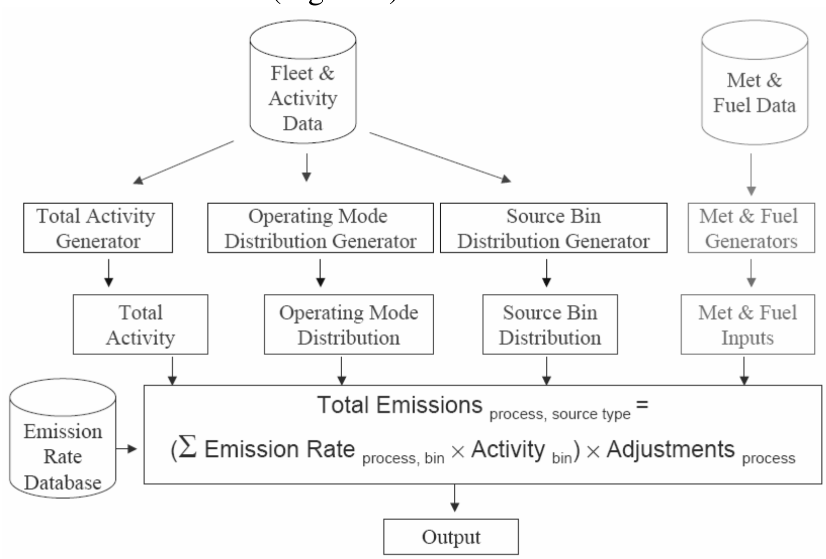


FIGURE 1 General model structure of MOVES
Source: reprinted from Beardsley, 2004 (*13*).

Total Activity Generator

The basic activity data in MOVES are vehicle population and vehicle miles traveled (VMT) for base year 1999 (*14*). The MOVES activity function, Total Activity Generator (TAG), first grows the base year vehicle population and VMT to a target analysis year using growth factors and then allocates them by road type, vehicle class, vehicle age and time period pursuant to nationwide observed and projected data from various sources. The MOVES activity function also conducts a data conversion process because all activities used for computing emissions in MOVES, except for vehicle starts, are specified in units of time. For example, the model defines source hours operating (SHO) as basic activities to estimate evaporative and running exhaust emissions, as well as tire and brake wear emissions (*12*). This is a significant methodological departure from MOBILE and EMFAC, which, for example, use VMT directly to estimate running exhaust emissions.

Source Bin Distribution Generator

MOVES classifies vehicles into different source bins. Source bins are defined to represent unique combinations of vehicle class, model year group, vehicle weight, engine size and technology, and fuel type (*12, 14*). The Source Bin Distribution Generator (SBDG) produces source bin fractions that are subsequently used to derive weighted emission rates.

Operating Mode Distribution Generator

The Operating Mode Distribution Generator (OMDG) classifies vehicle operating modes into different bins associated with vehicle specific power (VSP) and speed, and develops mode distributions based on 40 pre-defined driving schedules (*12*). Note that the emission rates in both EMFAC and MOBILE are directly related to average speeds that correspond to a fixed VSP distribution embedded in the underlying driving cycles used as the basis for the models. The MOVES emissions rates are a direct function of VSP, a measure that has been shown to have a better correlation with emissions than average vehicle speeds (*15, 16*), and users can input locally-specific VSP distributions. VSP represents the power demand placed on a vehicle when the vehicle operates in various modes and at various speeds. This function produces operating mode fractions for each bin, which are used as one of several inputs for computing base emission rates.

Emission Calculator

The emission calculator function in MOVES combines modal-based emission rates with the associated vehicle activities. In MOVES, base emission rates for each emission process, distinguished by source bin and operating mode, are first adjusted by a series of factors accounting for I/M programs, fuel supply, temperature and air conditioning. Weighted emission rates are then developed based on these adjusted emission rates, using source bin fractions and operating mode fractions, provided by the source bin distribution generator and operating mode distribution generator, respectively (*12*). Finally, weighted emission rates, in units of grams per second or grams per start, are matched with activities (e.g., source hours operating or vehicle starts) provided by the total activity generator. The model then generates emissions amount by area, time period, vehicle class, model year and fuel type.

Data Management

MOVES is built on a Java™ platform, and uses MySQL, a relational structure query language and database system (*12*). The input, output, default activities, base modal emission rates and all intermediate calculation data in MOVES are stored and managed in relational tables of the MySQL database. MOVES model functions query and manipulate MySQL data pursuant to scenario parameters specified in the graphical user interface.

Summary of MOVES Characteristics

Compared to the current mobile source emission models (EMFAC and MOBILE), MOVES has several notable characteristics:

- MOVES includes data for both emission rates and pre-specified vehicle activities. Therefore, in addition to producing detailed emission factors, MOVES produces national, state or county level emission inventories. MOVES emissions are aggregated from a more comprehensive breakdown of road types, engine technologies, and fuel source categories.
- MOVES develops running emission rates associated with vehicle operating modes. The emission rates are dependent on second-by-second VSP and speed. Accordingly, MOVES pairs travel activities with these modal-based emission rates, allocated in units of time. MOVES converts activity from vehicle miles traveled (VMT) or other activity

measurements into units called Source Hours Operating (SHO). An SHO unit is simply a measure of the number of hours a given travel activity occurs.

- MOVES distributes activity data using several temporal resolutions (hours of a day, weekday vs. weekend, each month of a year) and the final emissions inventory can be aggregated into various target time frames.
- MOVES expands, relative to the MOBILE and EMFAC models, the modeling applications available to users. When complete, the tool will estimate emissions for all criteria pollutants plus greenhouse gases and it will also estimate associated energy consumption. MOVES will address on-road plus off-road mobile sources and the "upstream" emission processes that accompany refining, production, and marketing of the conventional and alternative/advanced fuels used to power the on-road fleet (this is referred to as a Well-to-Pump assessment).
- MOVES classifies vehicles based on activity patterns as well as emissions performance and the classification results represent a subset of the Highway Performance Monitoring System (HPMS) vehicle types. This classification scheme better connects activity data and emission data in terms of characterizing vehicles.
- Finally, MOVES incorporates functions to quantify the uncertainties of the emissions modeling results (although it does not address uncertainty associated with the embedded travel activity data).

3. COMPARATIVE ANALYSIS OF MOVES AND EMFAC

We compared the latest available version of the MOVES model (MOVES-HVI Demo) and EMFAC model (EMFAC2007) using Los Angeles County, California as a case study. MOVES-HVI Demo is an intermediate version capable of conducting macroscale (i.e., national, state, and county level) analyses for energy consumption and three greenhouse gases at this time. Functions for criteria pollutants and mesoscale/microscale analyses with finer geographic resolution (e.g., to estimate emissions for traffic analysis zones or roadway segments) are scheduled for later implementation. EMFAC2007 (version 2.30) is an integrated mobile source emissions model, in which local-specific emission rates and vehicle activity are combined internally to generate hourly or daily total emissions for various geographic areas in California (*2*). Our comparison examines the differences in methods and analysis between EMFAC and MOVES. We compare the emission estimates produced by the two models for Los Angeles County and explore the basic factors that underlie these differences. It is important to note also that EPA considers the underlying MOVES database for CO_2 and CH_4 emissions to be a work in progress and as this database changes so will emissions estimates. This analysis serves to identify areas for potential model refinement, and alerts MOVES users of the critical need for substituting national defaults with local data.

Comparison of Basic Model Features

To estimate emissions, both MOVES and EMFAC apply a similar concept: total vehicle emissions are the product of vehicle activities, base emission rates and a series of adjustment factors. Differences between MOVES and EMFAC are mainly reflected in how vehicle activities are quantified, how emission rates are measured, and how vehicle activities and emission rates are paired spatially and temporally. Table 1 highlights modeling features of MOVES and EMFAC. Although not exhaustive, Table 1 helps to identify prominent features that differ between the two models.

TABLE 1 Comparison of EMFAC and MOVES Model Features and Scopes

	EMFAC[a]	MOVES[b]
Model Version	EMFAC2007 (November 2006)	MOVES-HVI Demo (April 2007)
Program language	Fortran	Java™
Data management	Model-embedded manipulation	MySQL relational database
Emission sources	On-road	On-road; off-road will be added in a future version
Geographic area	• State (California) • Air Basin • District • County	• Nationwide • State • County • Link (road type)
Road type	N/A	• Rural roadways with restricted vehicle access • Rural roadways with unrestricted vehicle access • Urban roadways with restricted vehicle access • Urban roadways with unrestricted vehicle access • Off-network
Spatial scale	Regional-level	Currently available: • Macroscale (regional-level) • Mesoscale look-up (regional-level) To be added in a future version: • Mesoscale (regional-level) • Microscale (project-level)
Temporal scale	• Analysis year: 1970 – 2040 • Daily emissions by season, month, or year; hourly emissions can be obtained indirectly by changing default activity data (both totals and distributions) • Season: summer/winter/annual • Month: each month of a year	• Analysis year: 1990, 1999 – 2050 • Month: each month of a year • Day: weekdays and weekends • Hour: each hour of a day
Vehicle class (in the study, vehicle classes are grouped into LDA, LDT, M&HDT, BUS and MCY categories to obtain a consistent comparison basis)	LDA • Light-Duty Auto LDT • Light-Duty Truck 1 • Light-Duty Truck 2 M&HDT • Medium-Duty Truck • Light-Heavy-Duty Truck 1 • Light-Heavy-Duty Truck 2 • Medium-Heavy-Duty Truck • Heavy-Heavy-Duty Truck • Motor Home BUS • Urban Bus • School Bus • Other Bus MCY • Motorcycle	LDA • Passenger Car LDT • Passenger Truck • Light Commercial Truck M&HDT • Refuse Truck • Single Unit Short-haul Truck • Single Unit Long-haul Truck • Combination Short-haul Truck • Combination Long-haul Truck • Motor Home BUS • Transit Bus • School Bus • Intercity Bus MCY • Motorcycle

	EMFAC[a]	MOVES[b]
Fuel type	• Gasoline • Diesel • Electricity	• Gasoline • Diesel • Compressed Natural Gas (CNG) • Liquid Propane Gas (LPG) • Ethanol (E85 or E95) • Methanol (M85 or M95) • Gaseous Hydrogen • Liquid Hydrogen • Electricity
Vehicle model year	1965 – 2040	1960 – 2050
Pollutant	• Hydrocarbon (TOG, ROG, THC and CH_4) • Carbon Monoxide (CO) • Oxides of Nitrogen (NOx) • Carbon Dioxide (CO_2) • Particulate Matter (PM30, PM10 and PM2.5) • Oxides of Sulfur (SOx) • Lead (Pb) • Fuel Consumption	Currently available: • Methane (CH_4) • Nitrous Oxide (N_2O) • Atmospheric Carbon Dioxide (CO_2) • CO_2 Equivalent • Energy Consumption (total, petroleum, fossil) To be added in a future version: • Hydrocarbons • Carbon monoxide (CO) • Oxides of Nitrogen (NOx) • Particulate Matter (PM10 and PM2.5) • Air toxics pollutants
Emission process	• Running Exhaust • Start Exhaust • Idle Exhaust • Diurnal • Hot Soak • Resting Loss • Running Loss • Tire Wear • Break Wear	Currently available: • Running Exhaust • Start Exhaust • Extended Idle Exhaust • Well-to-Pump To be added in a future version: • Evaporative Refueling Loss • Evaporative Permeation • Evaporative Fuel Vapor Venting/Fuel Leaks • Crankcase • Tire Wear and Break Wear
Operating modes (bins)	Trip-based vehicle average speed	Vehicle specific power (VSP) and instantaneous speed
Pre-loaded default activity data	County level totals, county-specific vehicle fleet and VMT distributions	Nationwide totals with county allocation factors, national default vehicle fleet and VMT distributions, national default driving schedules
Primary activity measurement	Vehicle miles traveled (VMT)	Vehicle operating time (SHO – Source Hours Operating)
Emission rate data	Dynamometer test data with speed corrections	Dynamometer test data and on-board test data for VSP-based mode bins
Meteorology data	County-specific hourly temperature and relative humidity profiles	County-specific hourly temperature and relative humidity by month; users can also define met data for sub-county zones if desired
I/M program parameters	Model default (pre-defined California I/M programs) or user-defined	County-specific I/M programs; users can also update I/M default values using "IM Editor", which is under development for future MOVES versions.

[a] Model features summarized based on EMFAC2007 User Guide (*2*).
[b] Model features summarized based on MOVES-HVI Demo documentation (*12, 14*)

Comparing the Models: Los Angeles County

We developed year 2002 and 2030 CO_2 and CH_4 inventories for Los Angeles County in California. MOVES scenario runs were specified in the "Macroscale" module in MOVES-HVI Demo for an annual daily average. EMFAC model runs were conducted using the "Burden" module in EMFAC2007 for an annual daily average as well.

In order to compare emissions on a consistent basis, different vehicle classes defined in MOVES and EMFAC were mapped into five common categories (see Table 1, "Vehicle class"). The comparison study presented here mainly focused on emissions results for light-duty autos (LDA), light-duty trucks (LDT) and medium- and heavy-duty trucks (M&HDT).

4. RESULTS

Comparison of Total Emissions

The daily county totals are presented in Table 2. For year 2002, MOVES and EMFAC produce similar estimates of VMT and CO_2 emissions for Los Angeles County. However, year 2002 CH_4 emissions in MOVES are less than half of that estimated by EMFAC. The year 2030 forecasts produced by the two models appear quite different – daily VMT and CO_2 emissions produced by MOVES are about 40% greater than those produced by EMFAC, while CH_4 emissions produced by MOVES are nearly double the estimates provided by EMFAC.

TABLE 2 Comparison of Los Angeles County Totals in EMFAC and MOVES

Year	County Totals	Unit	EMFAC	MOVES	Difference
2002	VMT	1000 miles	213,296	226,024	+ 6%
	CO_2	tons/day	125,690	128,280	+ 2%
	CH_4	tons/day	19.25	8.10	– 58%
2030	VMT	1000 miles	253,015	365,478	+ 44%
	CO_2	tons/day	153,970	215,018	+ 40%
	CH_4	tons/day	3.93	7.63	+ 94%

Note: 1 ton = 907 kg; 1 mile = 1.61 km

To better understand the underlying factors contributing to the differences, we examined the county totals by vehicle class (LDA, LDT and M&HDT) and emission process (running exhaust and start exhaust) in the two models. As shown in Figure 2, year 2030 higher CO_2 emissions in MOVES are mainly a result of the significant growth in LDT emissions, which are more than double of that estimated in EMFAC. Los Angeles County year 2002 CH_4 running exhaust emissions produced by MOVES are only one third of those estimated by EMFAC; by 2030 however, MOVES projects substantially higher start exhaust CH_4 emissions (Figure 3).

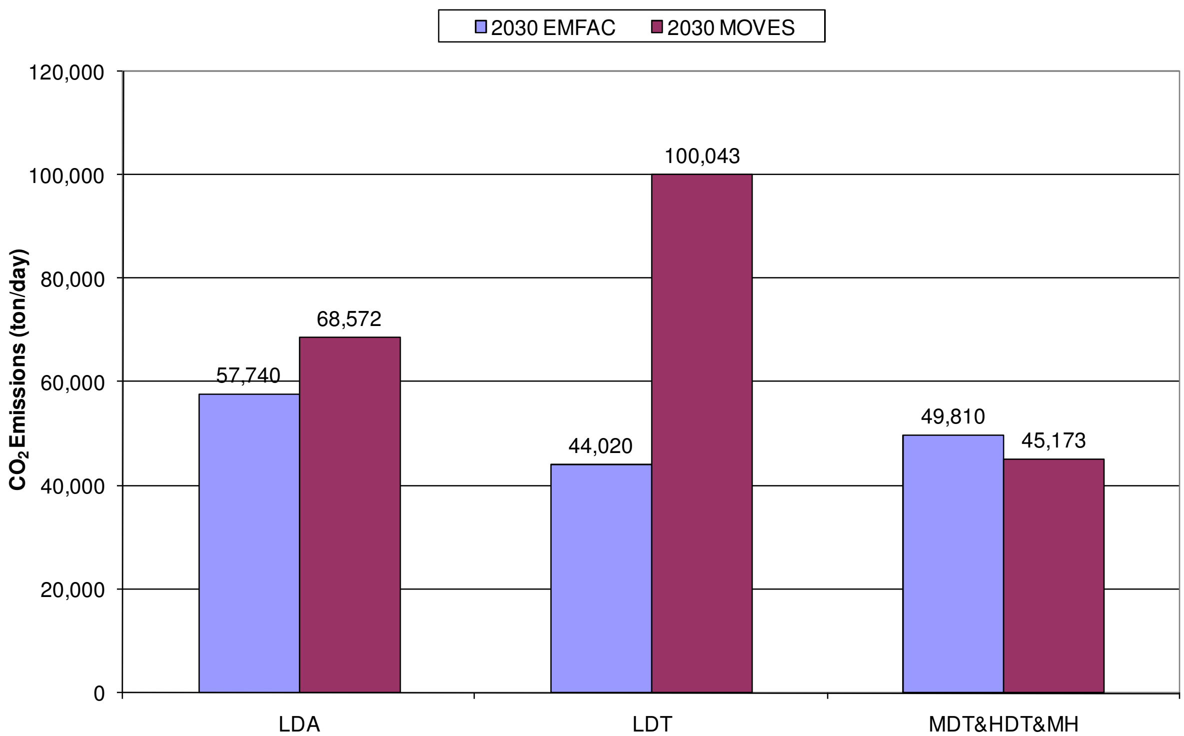


FIGURE 2 Year 2030 Los Angeles County daily CO_2 emissions by vehicle class

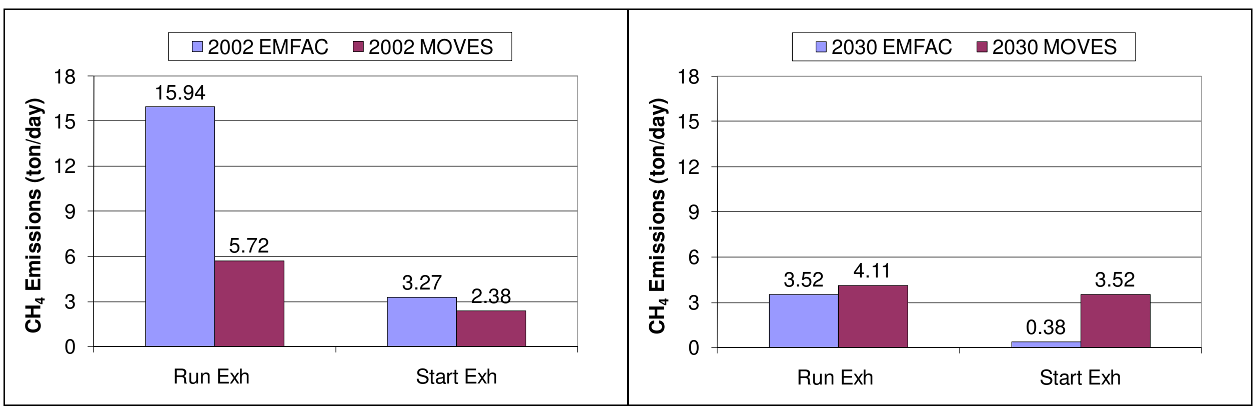


FIGURE 3 Los Angeles County daily CH_4 emissions by emission process

Comparison of Vehicle Activities

As discussed earlier, emissions estimated by either MOVES or EMFAC are dependent on vehicle activities and associated emission factors. Important activity information in emissions models typically includes fleet compositions, age distributions and VMT distributions. It should be noted that, in MOVES, county-level vehicle activities are developed by simply applying a county spatial allocation factor to nationwide activity data. The allocation factor is a function of the fraction of total U.S. VMT that occurs in the sub area (e.g., the county), based on the Highway Performance Monitoring System (HPMS) data collected by the Federal Highway Administration (*14*). Therefore, default activity distributions (e.g., percentage of fleet by different age and vehicle types) in MOVES are proportionally similar across all U.S. counties, although the absolute value of the activity varies by the scaling factor applied.

Looking at the proportions of different vehicle classes within the total vehicle population, we found that the proportion of LDAs in MOVES and EMFAC are close in both 2002 and 2030. However, MOVES defaults reflect a significantly higher proportion of LDTs (i.e., personal light-duty trucks and light commercial trucks, accounting for 35-40%). In MOVES, vehicle population changes over time (2002-2030) reflect the entry of new vehicles and vehicle scrappage rates. MOVES estimates the population of new vehicles using sales growth factors derived from the U.S. Department of Energy (DOE) Transportation Energy Data Book (TEDB) and the Annual Energy Outlook (AEO) (*14*). These data indicate that the LDA fleet grows more slowly from 2013 to 2030 than from 2000 to 2012 (approximately); in contrast, the LDT fleet grows more consistently over time with a higher rate. As a result, the MOVES vehicle fleet reflects an increased proportion of LDT over time.

Vehicle age distributions for Los Angeles County are presented in Figure 4, for the base year and future year. Including all vehicle classes, there appear to be more vehicles aged 4 to 20 years represented in the MOVES 2002 fleet than in the EMFAC fleet. However, by year 2030, MOVES defaults assume a younger vehicle fleet and projects a much lower proportion for vehicles aged 30 or more years than EMFAC.

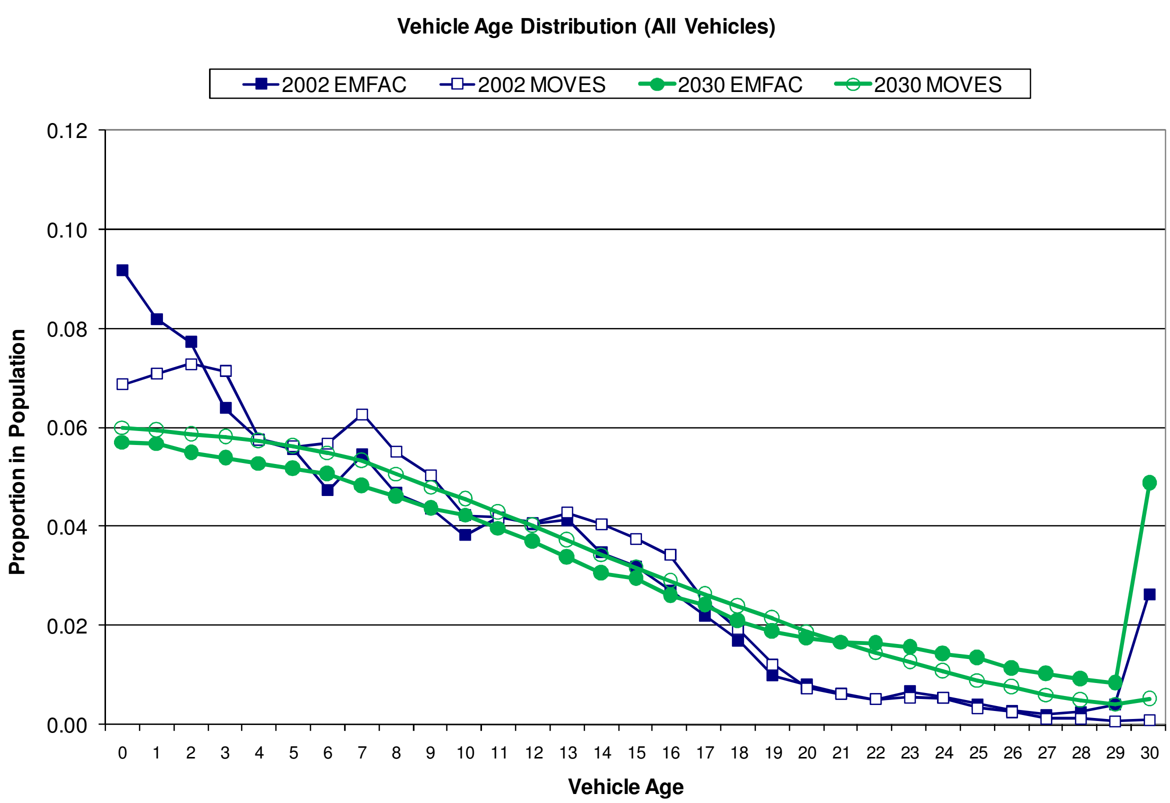


FIGURE 4 Los Angeles County 2002 and 2030 fleet age distributions

The VMT by speed distribution patterns in EMFAC and MOVES also appear very different. Vehicle activities in EMFAC are not separated by road type. As can be seen in Figure 5, EMFAC suggests that, in Los Angeles County, a larger proportion of VMT occurs within the 20-30 mph and 70 mph speed bins. EMFAC uses county specific estimates of VMT and speeds provided by local transportation planning agencies. These local agencies typically utilize travel demand models to estimate link-level VMT and disaggregate them into speed bins for several time periods such as morning peak, afternoon peak and off-peak periods. In Los Angeles County, congested traffic conditions result in more VMT within the 20 to 30 mph speed bins during day time; most nighttime (between 7 pm and 6 am) travel is uncongested high-speed freeway activity. The VMT distribution included in MOVES, in contrast, fluctuates far more than the distribution included in EMFAC, and includes greater fractions of VMT in speed bins ranging from 30 to 60 mph. The VMT distribution patterns shown in Figure 5 include four roadway types modeled in MOVES: urban freeways, urban arterials, rural freeways and rural arterials. The fluctuations reflect national data mainly from the urban freeway and arterial VMT distributions.

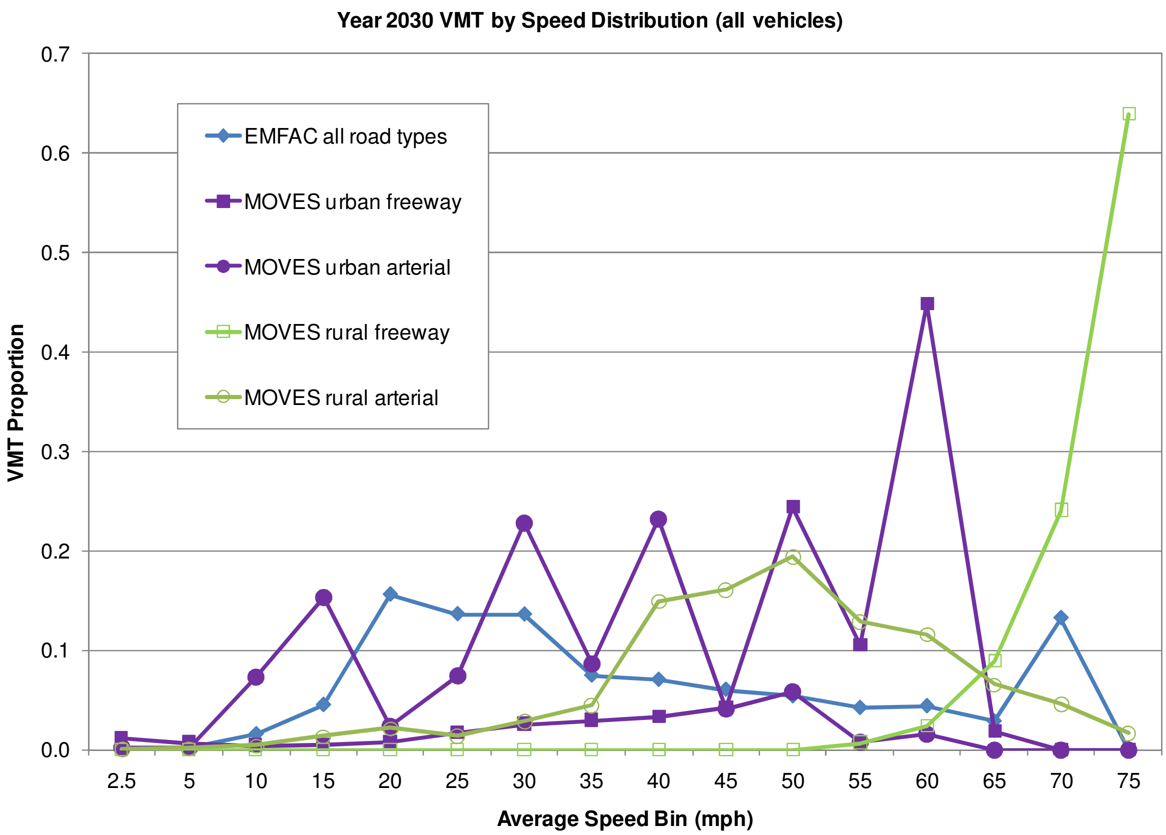


FIGURE 5 Los Angeles County VMT by speed distributions in EMFAC vs. MOVES

Comparison of Emissions Factors

Emission factors from EMFAC and MOVES are developed in different ways. In EMFAC, running exhaust emission factors are quantified in the unit of grams per mile for a specific speed bin. These factors are composite emissions rates, aggregated from base rates by vehicle class, technology group and model year. In contrast, CO_2 running emission rates in MOVES are based on energy consumption associated with a VSP/speed bin. The CH_4 emission rates generated by MOVES-HVI Demo are still a function of the "old style" speed-based rates from dynamometer test data (as is done with EMFAC and MOBILE), rather than from VSP information. The latest MOVES-demo model provides a "meso-scale look up" module that can generate detailed emission factors by road type, source type, and speed bin. To compare emission factors on the same basis, Los Angeles County emissions, detailed emission factors, and vehicle activity outcomes were post-processed to obtain speed-bin-based grams per mile running emission factors as well as start emission factors for CO_2 and CH_4 by vehicle class, fuel type and model year.

The comparison of CO_2 running emission factors suggests only small variations between EMFAC and MOVES in most cases. Specifically, the average MOVES CO_2 emission factor in grams per mile is slightly lower for gasoline LDA and LDT, but slightly higher for diesel M&HDT in both years 2002 and 2030. Using LDAs in the 2030 vehicle fleet as an example, Figures 6 shows that MOVES and EMFAC also produce very close CO_2 emission factors associated with speeds ranging between 25 and 45 mph. In general, running emission factors in MOVES continuously decline as average vehicle speeds increase. EMFAC emission factors, however, tend to increase once speeds exceed approximately 50 mph (depending upon the pollutant and vehicle class). In a transportation project-level analysis context, these differences can be important because they will result in different estimates of emissions benefit from speed improvements. EPA has indicated that it is working to improve the speed-emissions relationship in upcoming versions of MOVES (*17*).

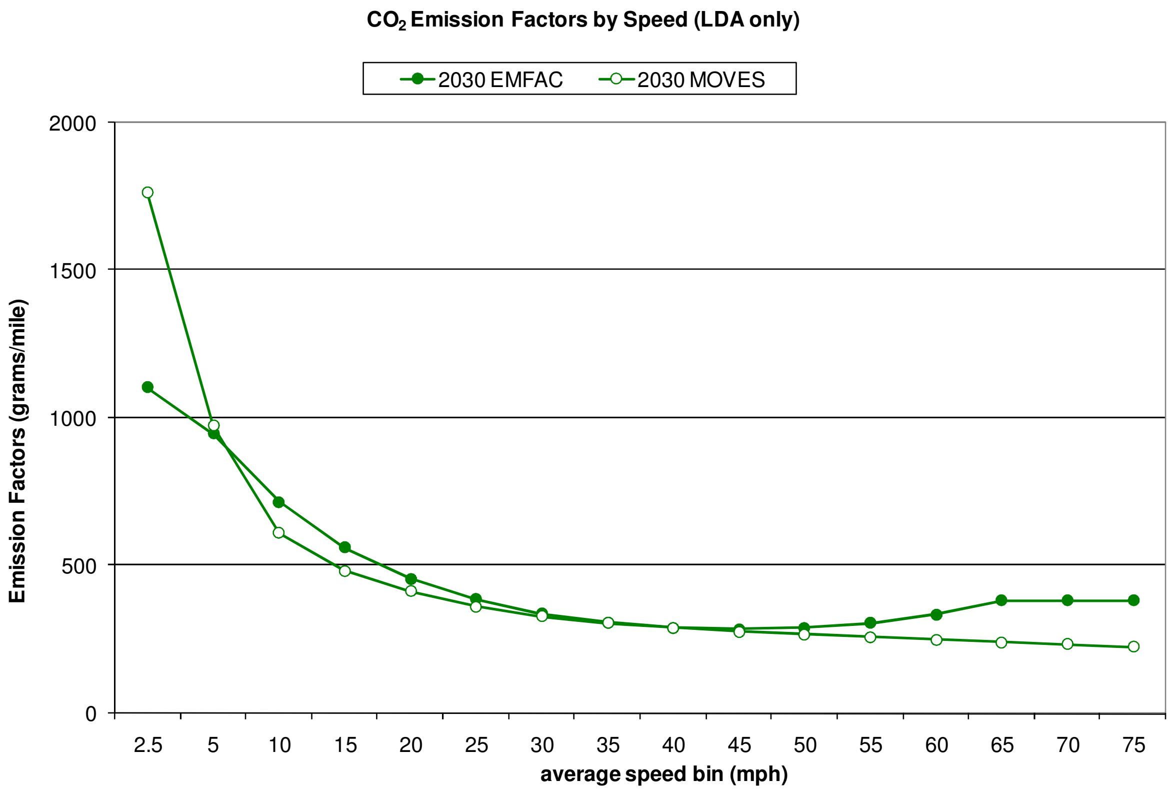


FIGURE 6 Los Angeles County CO_2 running emission factors against speed bins

MOVES has much lower CH_4 running emission factors for the 2002 vehicle fleet (less than half of those produced by EMFAC for gasoline LDA and LDT; only 7.4% of those estimated by EMFAC for diesel M&HDT). EPA's validation report has stated that CH_4 emissions provided by MOVES were much lower than estimations in previous emission models (*18, 19*). For year 2030, MOVES projected slightly lower CH_4 emission factors than EMFAC for gasoline vehicles; for diesel powered vehicles, MOVES suggests no reduction of CH_4 emissions per mile from year 2002 to year 2030.

As shown in Figure 7, in both year 2002 and 2030, average CO_2 start emission factors in MOVES are around three times larger than those estimated by EMFAC. For CH_4, MOVES does not show much improvement in per start emission factors from year 2002 to year 2030. This is due to several factors: 1) MOVES uses the same emission rates for vehicles of model year 2001 to 2050; 2) MOVES forecasts an increased proportion of LDTs as a fraction of the total light-duty fleet – LDTs have higher start emission rates than LDAs; and 3) MOVES assumes increased use of alternative fuels in the future – alternative fuels are associated with higher CH_4 start emission rates. In contrast, EMFAC assumes a significant reduction in per start emission rates over time (see Figure 7); by year 2030, average CH_4 emissions per vehicle start are only 10% of those estimated for year 2002.

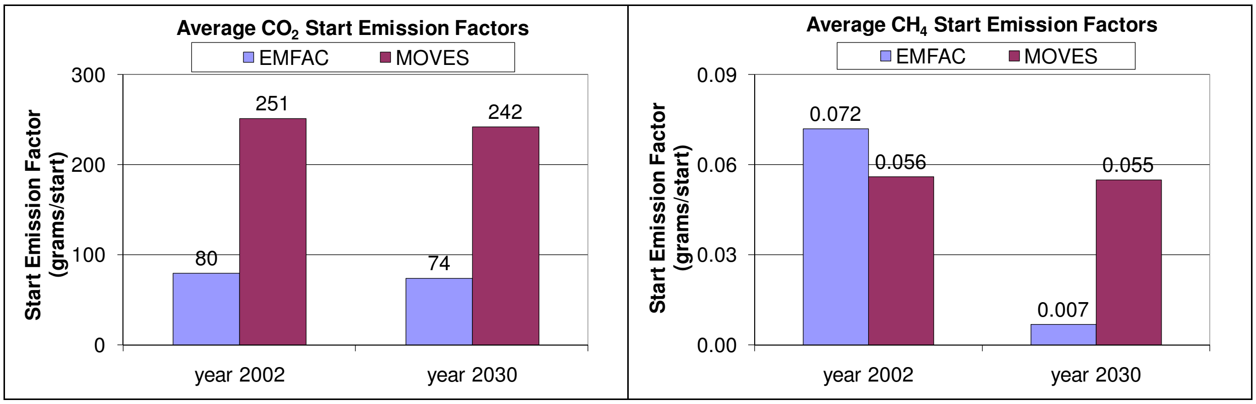


FIGURE 7 Los Angeles County start emission factors in EMFAC and MOVES

5. DISCUSSION

MOVES and EMFAC use different modeling approaches in terms of specifying vehicle activities and measuring per activity emission rates. The macroscale module in the latest version of MOVES employs national average default data to represent activity patterns and couples them with "bottom-up" running exhaust emission factors and energy consumption rates based on VSP and instantaneous speed for a road type. EMFAC's emission rates are derived from average speed and emissions measurements for trip-based driving cycles, and are adjusted for individual speed bins; they are best applied at a regional scale encompassing complete trip activities.

Using Los Angeles County as a case study, we found that, for the 2002 base year, MOVES generated comparable CO_2 emissions outcomes to EMFAC, but significantly lower CH_4 emissions. However, for year 2030, MOVES estimated higher CO_2 and CH_4 emissions than did EMFAC. More specifically, modeled CO_2 emissions differences appear to be a function of VMT estimation – with similar CO_2 emission factors in both models, higher CO_2 emissions projected in MOVES for year 2030 mainly result from a substantial increase in the forecasted light-duty truck VMT. The CH_4 emissions differences are largely dependent on their embedded base emission rates. Using comparatively recent vehicle test data, MOVES estimates lower CH_4 running emission factors for the base year vehicle fleet. However, MOVES assumes higher CH_4 start emission factors for the year 2030 vehicle fleet, which, paired with MOVES's faster-growing future vehicle population, result in significantly higher county total CH_4 emissions.

An important caveat should be noted when reviewing these comparison results: although the comparison presented here used the latest available version of the MOVES model (MOVES-HVI Demo), its underlying database for both vehicle activities and emissions is still considered draft by EPA and will likely change in future versions of MOVES. Personal communication with federal agency staff and other researchers (*17, 20*) indicates that technical updates and improvements of MOVES are undergoing, such as a) developing a GUI-driven "Domain Importer" to allow direct input of county-level vehicle activity information, rather than allocating national data in the top-down manner; b) disaggregating the high-VSP/speed data into more operation mode bins, with the result that future versions of MOVES may better characterize the increase in energy use and CO_2 emissions at high speeds and produce high-speed emissions more in line with the findings from EMFAC2007; c) adjusting the calculation of start energy consumption and CO_2 emissions to account for soak time, with the expectation of reducing per start vehicle emissions; and d) investigating critical assumptions embedded in MOVES regarding VMT by speed distributions, VMT growth and scrappage rates and vehicle fleet mix.

The comparative assessment conducted in this paper therefore focused more on broad methodological and data differences between EMFAC and MOVES that result in differing activity and emissions estimates, and less on issues related to accuracy or ease of use with respect to MOVES. The case study findings suggest some important implications for emissions modeling practices.

- MOVES incorporates more features and functions than traditional emission models. Its modal-based approach allows analyses to be completed at various spatial scales that range from the link- to regional-level. Thus, based solely on the flexibility with which MOVES can be applied at various regional scales, MOVES represents a major modeling improvement. In addition, since VSP has been shown to be more closely correlated with on-road emissions than speed, use of MOVES-generated emissions factors should represent a more accurate characterization of on-road vehicle emissions than emission factors generated using MOBILE or EMFAC. However, an important premise is that the final MOVES model will be populated with sufficient VSP data to generate robust emission factors. It is unclear yet which portions of the MOVES VSP dataset are most robust, and which require supplemental data to augment the creation of reasonable emission factors. In general, EPA has specified that the medium- and heavy-duty truck portions of the MOVES dataset are less populated than those applicable to the light-duty fleet (*21*).
- The importance of locality-specific data cannot be overstated for MOVES applications. Although MOVES includes national defaults for vehicle activity data, the model requires highly resolved local vehicle activity data to generate appropriate emission estimates at the regional and project scales. Depending upon the datasets included in the final version of MOVES, considerable effort may be needed to obtain the local data required to take advantage of MOVES's capabilities, as well as to quality-assure its use and validity at the project-scale.
- Activity data needed for MOVES can be obtained from various sources. For example, EMFAC is already populated with California activity data generated and quality-assured by metropolitan planning organizations and the state Air Resources Board; local data for MOBILE (e.g., age distributions) is also available in some cases when conformity modeling is conducted. However, it may be difficult to map these existing activity data to the MOVES model. An important example is the use of different vehicle class definitions – MOVES classifies vehicles by axle and wheel counts to better connect to HPMS data; EMFAC and MOBILE, in contrast, classify vehicles by weight.

6. CONCLUSIONS

In this study we presented a comparative assessment of the features and methods of MOVES and EMFAC. Using a Los Angeles County, California example application and two greenhouse gases (CO_2 and CH_4), we analyzed how underlying activity data and emission factors contributed to the observed differences between the two models.

In contrast to traditional mobile source emission models such as EMFAC or MOBILE, MOVES uses a combination of VSP and speed bins, rather than speed correction factors, to quantify running exhaust emissions; uses vehicle operating time rather than vehicle miles traveled as the unit of measure for various vehicle activities and emissions; and uses a relational database to manipulate data and enable multi-scale emissions analyses from regional down to link-level applications. In light of these new features, MOVES is anticipated to be a superior analysis tool – certainly, it should be more responsive to variations in traffic dynamics and roadway congestion levels.

Preparing appropriate local specific data is critical for the application of MOVES. Given the wide range in data availability, ease of substitution, and cost for data acquisition, users will need a roadmap to prioritize which local information to acquire. Future work is needed to prioritize which default data to replace, and to give guidance as to how best to obtain and translate locally available data into MOVES model inputs.

The MOVES development schedule anticipated release of a new draft model version by the end of 2008, and a final version of MOVES by late 2009. As the final version of MOVES takes shape, further analyses will be needed to compare MOVES, MOBILE, and EMFAC. At a minimum, such analyses will need to illustrate and explain how emission results vary when the models employ consistent local data inputs. Such work should also explore the State Implementation Plan and transportation conformity implications of the model output differences.

Acknowledgements

This research was partly funded through the UC Davis-Caltrans Air Quality Project. The authors gratefully acknowledge Dr. Oliver Gao in the School of Civil and Environmental Engineering at Cornell University, and John Koupal and Megan Beardsley at the U.S. Environmental Protection Agency for their valuable comments and suggestions. The findings presented are based on assessments by the authors and do not reflect the opinions of EPA or other organizations.

References

1. USEPA. *User's Guide to MOBILE6.1 and MOBILE6.2: Mobile Source Emission Factor Model*. Publication EPA420-R-03-010. Office of Air and Radiation, U.S. Environmental Protection Agency, 2003.
2. CARB. *EMFAC2007 Version 2.30 User Guide: Calculating Emission Inventories for Vehicles in California*. California Air Resource Board, 2006.
3. Sturm, P., G. Kirchweger, S. Hausberger, and R. Almbauer. Instantaneous Emission Data and Their Use in Estimating Road Traffic Emissions. *International Journal of Vehicle Design*, Vol. 20, No. 3, 1998, pp. 181-191.
4. Barth, M., G. Scora, and T. Younglove. Estimating Emissions and Fuel Consumption for Different Levels of Freeway Congestion. In *Transportation Research Record: Journal of the*

Transportation Research Board, No. 1664, Transportation Research Board of the National Academies, Washington, D.C., 1999, pp. 47–57.
5. Andre, M. and C. Pronello. Relative Influence of Acceleration and Speed on Emissions under Actual Driving Conditions. *International Journal of Vehicle Design*, Vol. 18, 1997, pp. 340–353.
6. Haan, P., and M. Keller. Emission Factors for Passenger Cars: Application of Instantaneous Emission Modeling. *Atmospheric Environment*, Vol. 34, No. 27, 2000, pp. 4629–4638.
7. Ito, D., D. Niemeier, and G. Garry. Conformity: How VMT-Speed Distributions can Affect Mobile Emission Inventories. *Transportation*, Vol. 28, No. 4, 2001, pp. 409–425.
8. Bai, S., Y. Nie, and D. Niemeier. The Impact of Speed Post-processing Methods on Regional Mobile Emissions Estimation. *Transportation Research Part D: Transport and Environment*, Vol. 12, Issue 5, 2007, pp. 307–324.
9. Bai, S., Y.C. Chiu, and D. Niemeier. Using Dynamic Assignment to Improve Regional Mobile Emissions Estimation. Presented at 87rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
10. USEPA. *EPA's New Generation Mobile Source Emissions Model: Initial Proposal and Issues*. Publication EPA420-R-01-007, Office of Air and Radiation, Office of Research and Development, Region 4, U.S. Environmental Protection Agency, 2001.
11. USEPA. *Draft Design and Implementation Plan for EPA's Multi-Scale Motor Vehicle and Equipment Emission System (MOVES)*. Publication EPA420-P-02-006, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2002.
12. USEPA. *Motor Vehicle Emission Simulator Highway Vehicle Implementation (MOVES-HVI) Demonstration Version: Software Design and Reference Manual Draft*. Publication EPA420-P-07-001, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2007.
13. Beardsley, M. MOVES Fleet and Activity Inputs: 1999 Base Year. Presented at the CRC On-road Emissions Workshop, San Diego, California, 2004.
14. USEPA. *MOVES2004 Highway Vehicle Population and Activity Data (Draft)*. Publication EPA420-P-04-020, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2004.
15. Koupal, J., H. Michaels, M. Cumberworth, C. Bailey, and D. Brzezinski. *EPA's Plan for MOVES: A Comprehensive Mobile Source Emissions Model*. U.S. Environmental Protection Agency, 2002.
16. USEPA. *Methodology for Developing Modal Emission Rates for EPA's Multi-Scale Motor Vehicle and Equipment Emission System*. Publication EPA420-R-02-027, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2002.
17. Beardsley, M. Personal communication with Megan Beardsley, U.S. Environmental Protection Agency. June 4 and July 7, 2008.
18. USEPA. *MOVES2004 Validation Results: Draft Report*. Publication EPA420-P-05-002, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2005.
19. USEPA. *Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles.* Publication EPA420-P-04-016, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2004.
20. Gao, O. Personal communication with Oliver Gao, Cornell University. April 13, 2008.
21. USEPA. *MOVES2004 Energy and Emission Inputs: Draft Report*. Publication EPA420-P-05-003, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2005.