MOVES vs. EMFAC: A COMPARATIVE ASSESSMENT BASED ON A LOS ANGELES COUNTY CASE STUDY

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By

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Abstract

Background: For many years, on-road vehicle emissions have been estimated using the EMFAC (in California) and MOBILE (in the rest of the U.S.) modeling tools. The U.S. Environmental Protection Agency is developing a new generation emission model, called MOVES, that changes the way vehicle emission estimates are generated. Planning agencies need to understand the implications of using the new model compared to traditional models.

Methods: This study investigated the differences between EMFAC and MOVES. We modeled on-road emissions of the greenhouse gas pollutants carbon dioxide (CO_2) and methane (CH_4) using Los Angeles County, California as a case study. We compared year 2002 and 2030 emissions generated by EMFAC2007 and MOVES-HVI Demo – the latest version of the MOVES model available as of mid-2008 – and analyzed how underlying activity data and emission factors contributed to observed differences.

Results: MOVES produced emission estimates substantially different from those generated by EMFAC. MOVES and EMFAC produced similar CO_2 emissions for 2002; MOVES produced 40% higher CO_2 emissions by 2030. For 2002, MOVES generated only 42% of the CH_4 emissions estimated by EMFAC; however, for the year 2030, MOVES CH_4 emissions were nearly double the estimates provided by EMFAC. Important contributing factors are that MOVES embeds travel activity data that differs substantially from EMFAC data – MOVES assumes a younger vehicle fleet, and by 2030 includes more vehicle miles traveled (VMT), especially for light-duty trucks. MOVES and EMFAC have similar CO_2 fleet-average g/mi emission factors; however, MOVES has higher fleet-average CO_2 start emission factors than does EMFAC, and MOVES emission factors differ from EMFAC for some vehicle types. For 2030, MOVES estimated higher CH_4 start emissions. MOVES also adjusted emissions differently than EMFAC to account for speed and deterioration. 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.

About The U.C. Davis-Caltrans Air Quality Project

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Mission: The Air Quality Project (AQP) seeks to advance understanding of transportation related air quality problems, develop advanced modeling and analysis capability within the transportation and air quality planning community, and foster collaboration among agencies to improve mobility and achieve air quality goals.

History: Since the 1990s, the U.S. Federal Highway Administration and Caltrans have funded the AQP to provide transportation-related air quality support. Caltrans and AQP researchers identify and resolve issues that could slow clean air progress and transportation improvements.

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1. INTRODUCTION

1.1 Background

The Motor Vehicle Emission Simulator (MOVES) is the next generation mobile source emission model being developed by the U.S. Environmental Protection Agency (EPA). Ultimately, the MOVES model will serve as a single comprehensive system for estimating emissions from both on-road and non-road mobile sources. This report examined the on-road emissions modeling components of a version of the MOVES model known as MOVES-HVI Demo (Demonstration Version for MOVES Highway Vehicle Implementation). As of this writing (mid-2008), MOVES-HVI Demo was the latest available version of the MOVES model. MOVES-HVI Demo addressed only on-road mobile source energy consumption and greenhouse gas emissions; it lacked features applicable to non-road emissions and it lacked other capabilities, such as microscale modeling options, envisioned for the final model version.

Compared to EMFAC and MOBILE, the currently approved on-road motor vehicle emission models used, respectively, in California and the rest of the U.S., the MOVES model represents a fundamental shift in the methodology used to estimate on-road vehicle emissions. EMFAC and MOBILE generally derive their emissions estimates from trip-based travel activities; they link gram per mile emissions rates to speeds by vehicle types and technologies, taking into consideration model years and vehicle deterioration over time. MOVES, in contrast, is a modal emissions model; that is, MOVES derives its emissions estimates based on second-by-second vehicle performance characteristics for various driving modes (e.g., cruise and acceleration). MOVES emissions rates are a function of vehicle specific power, or VSP—a measure that has been shown to have a better correlation with emissions than trip-based average vehicle speeds (Koupal et al. 2002, EPA 2002a, EPA 2002b). VSP represents the power demand placed on a vehicle when the vehicle operates in various modes and at various speeds. 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 replace MOBILE as the approved model for developing on-road emissions estimates for state implementation plans (SIPs) and regional or project-level transportation conformity analyses (EPA, 2002a).

The motivation to develop the MOVES model can be traced back to May 2000, when the National Research Council (NRC) published a detailed review of EPA's mobile source emissions modeling programs. The NRC review identified several deficiencies associated with MOBILE and recommended development of a new modeling platform that facilitated consistent estimation at the regional scale, mesoscale and microscale emissions modeling levels (NRC, 2000).

Responding to the NRC review, the U.S. EPA proposed, in April 2001, development of a new generation mobile source emission model (EPA, 2001). EPA's model development objectives included creating a more comprehensive, science-based tool with improved software (EPA, 2001). Furthermore, EPA specified that the new model needed to produce emission estimates for a wider range of spatial applications than could be appropriately addressed by the MOBILE model (Table 1.1).

Table 1.1. Analysis categories and proposed modeling scales of the new model system.

Analysis Categories	Modeling scales	*Example applications*
Large area inventory generation	Macroscale	• *Emission trends* • *Regional / national inventories* • *Regulatory support*
Local area inventory generation	Macroscale and Mesoscale	• *SIP inventory development* • *Conformity analysis* • *Rate of progress analysis*
Transportation scenario evaluation	Mesoscale and Microscale	• *SIP inventory* • *Conformity analysis* • *Transportation control measure evaluation*
Corridor/intersection analyses	Microscale	• *Project level environmental analysis* • *Hot-spot analysis* • *Exposure assessment*

Source: adapted from EPA, 2001.

After release of its initial proposal, EPA led a cross-agency team to define the basic theoretical foundation for the model, evaluate modeling methodologies, specify input/output data, and design model software. A timeline shown in Figure 1.1 illustrates some of the key model development milestones that EPA has established during the MOVES development process (note that the milestones are periodically revised, however Figure 1.1 illustrates the broad sequence of activities required to complete the new model).

As of mid-2008, two intermediate versions of MOVES, MOVES2004 and MOVES-HVI Demo, have been released. However, both models were incomplete in terms of modeling functions and data sources. MOVES2004 offered the capability to conduct only macroscale analyses for the greenhouse gases methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The MOVES-HVI Demo model added a mesoscale function to provide finer geographic resolution (e.g., to estimate emissions for traffic analysis zones); it also included placeholder values for criteria pollutants to illustrate how the model would function. To date, however, criteria pollutant analyses cannot yet be undertaken.

One of the fundamental methodology changes that has been incorporated into MOVES is the application of modal level, VSP emission algorithms to estimate second-by-second emission rates. When finished, MOVES will use modal emission algorithms to estimate emissions not only of greenhouse gases but also pollutants such as hydrocarbons (HC)[1], carbon monoxide (CO), oxides of nitrogen (NO_x) and particulate matter (PM) (EPA, 2002b; EPA, 2005a). Another significant change in MOVES is the addition of advanced technology vehicles (e.g., hybrid gasoline-electric vehicles) which are evaluated in more detail than previous emission models (EPA 2004a). EPA is also integrating into the model pre-specified county-level regional activity data, forecasted through year 2050 (EPA 2004b). These features (the modal approach, the more detailed characterization of advanced technology vehicles, and forecasted county-level activity) are expected to substantially affect emission results at the regional- and project-level of analysis, the scales at which transportation conformity is determined.

[1] New functions are being developed for future versions of MOVES to calculate different hydrocarbon forms including NMHC (non-methane hydrocarbons), NMOG (non-methane organic gases), TOG (total organic gases) and VOC (volatile organic compounds).

1.2 Research Goals

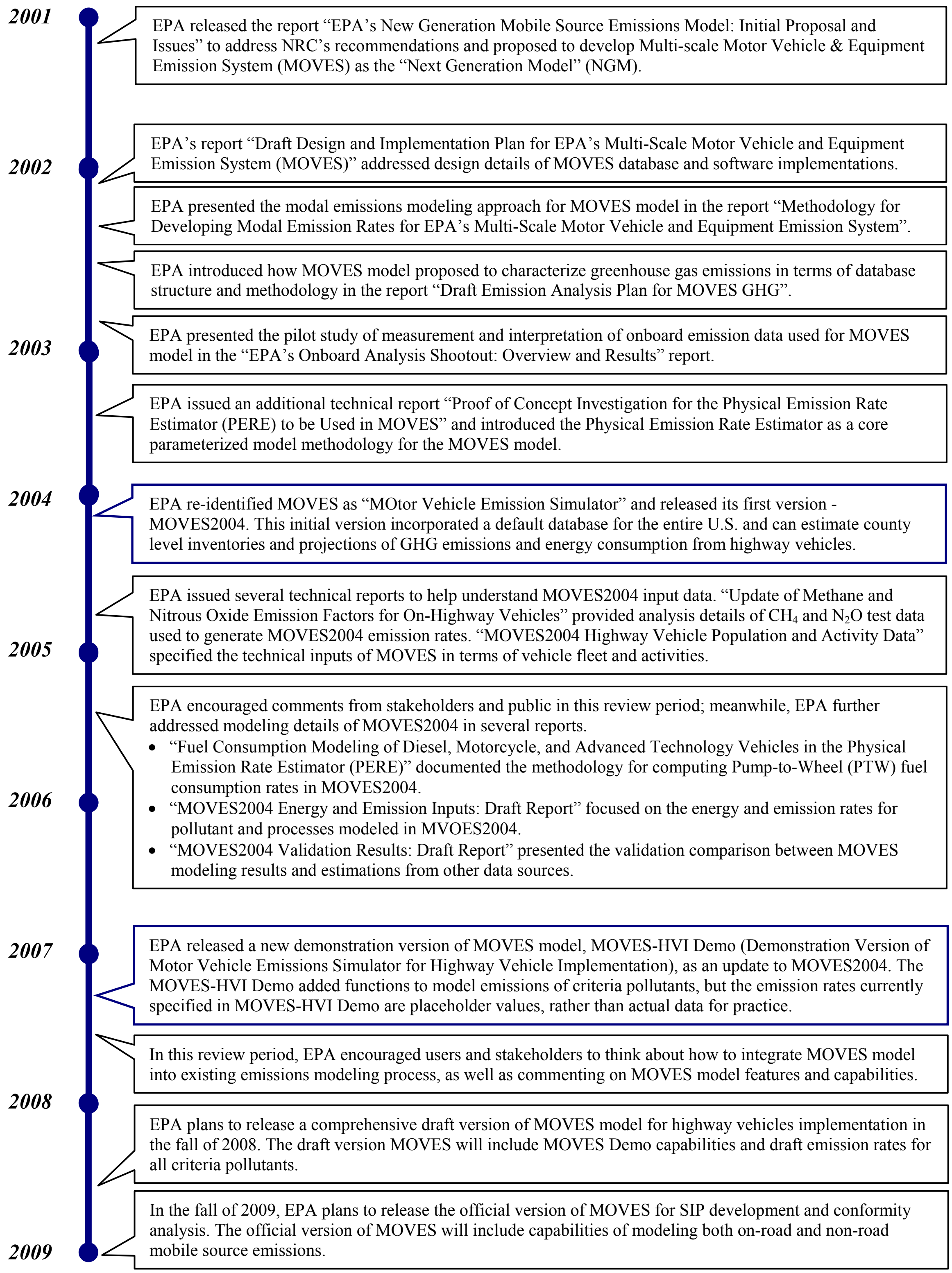
The purpose of this study is to better understand the structure, algorithms and assumptions behind the MOVES model and to identify and complete a preliminary assessment of application issues affecting any use of MOVES in California. The official mobile source emission model used in California is EMFAC, which is a trip-based model best applied at a regional level. MOVES offers the promise of enabling consistent project- as well as regional-level emissions analyses. Caltrans has expressed interest in determining whether MOVES, or a California-based model that might be similarly constructed, would be useful when completing California SIP and regional- and project-level conformity analyses. For example, use of MOVES to address issues such as mobile source air toxics (MSATs), greenhouse gas and heavy-duty diesel vehicle (HDDV) PM emissions could yield regional and project-specific insights currently unavailable under EMFAC. This review compared MOVES and EMFAC data and emissions information and identified implementation considerations that will need to be addressed if MOVES were to be used to model California conditions.

We used MOVES-HVI Demo to conduct our comparison. Given that MOVES-HVI Demo does not yet include empirical data for criteria pollutants, we contrasted MOVES and EMFAC data for carbon dioxide (CO_2) and methane (CH_4). As documented in later sections, we found that, in several cases, MOVES-HVI Demo produces emission estimates substantially different from those generated by EMFAC. Highlights of our emissions findings include: MOVES and EMFAC produce similar CO_2 emissions overall, once adjusted by VMT. However, in absolute terms, MOVES produces 40% higher CO_2 emissions by 2030. For 2002, MOVES generates lower CH_4 emissions than EMFAC (42% of the EMFAC value); however, by the year 2030, CH_4 emissions produced by MOVES are nearly double the estimates provided by EMFAC. We evaluated important contributing factors to our findings and found that: MOVES embeds default travel activity data that differs substantially from EMFAC's region-specific assumptions. MOVES assumes a younger vehicle fleet, and includes more light-duty truck vehicle miles traveled (VMT). MOVES produces higher start emissions of CO_2 than EMFAC in both of the analysis years examined (2002, 2030), once adjusted by vehicle starts. Also, by 2030, MOVES estimates higher CH_4 start emissions than EMFAC. MOVES and EMFAC have similar CO_2

fleet-average g/mi emission factors; however, MOVES has higher fleet-average CO_2 start emission factors than does EMFAC, and MOVES emission factors differ from EMFAC for some vehicle types. MOVES also adjusts emissions differently than EMFAC by speed bin – as vehicle speeds increase above 50 mph, MOVES shows declining g/mi CO_2 emission rates, compared against EMFAC's increasing g/mi rates. MOVES also assumes more travel activity in the 30-50 mph speed range than does EMFAC. In addition, MOVES emission factors do not consider vehicle deterioration for model year 2001 and later vehicles.

1.3 Report Organization

The report is organized into three chapters beginning with a general review of the MOVES structure, methodology of primary model functions, data management, and modeling outcomes. Chapter 3 compares EMFAC and MOVES using greenhouse gas emissions estimates for Los Angeles County. The comparison was conducted for a base year and a future year from three perspectives: vehicle activities, emission factors and emission totals. Chapter 4 presents the implications of our findings for modeling practices; Chapter 4 focuses on the application of MOVES for regional- and project-level analyses and identifies those data issues that must be addressed to successfully complete these analyses. Finally, we conclude with recommended future research topics regarding future MOVES application.

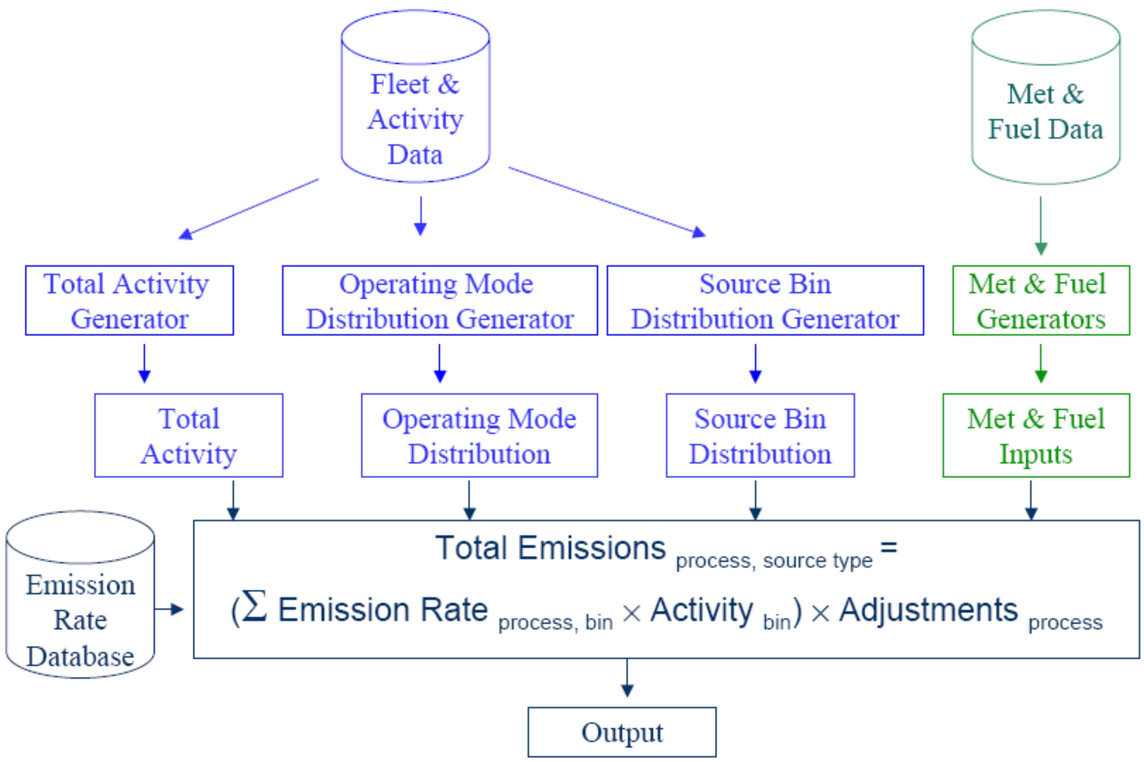


Source: adapted from EPA, 2007 (http://www.epa.gov/otaq/ngm.htm#movesdemo).

Figure 1.1. Timeline of MOVES model development.

2. A REVIEW OF THE MODEL STRUCTURE OF MOVES

MOVES is designed to estimate emissions at scales ranging from individual roads and intersections to large regions. As shown in a general model structure (Figure 2.1), MOVES incorporates input data that include vehicle feet composition, traffic activities, and meteorology parameters at the macro, meso or micro level and conducts modal-based emissions calculations using a set of model functions. The outputs of emissions inventories or emissions factors are functions of modal-based vehicle emission rates (stored in the emission rate database) and activities specified for the desired geographic scale.



Source: Beardsley, 2004 (presentation at the CRC On-road Emissions Workshop, slide 9).

Figure 2.1. General model structure of MOVES.

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 emission *inventories*. The model's output capabilities are somewhat analogous to, but more geographically expansive than the Burden model in the California EMFAC model. MOVES can produce national, state or county level inventories. In contrast to EMFAC, however, 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 (e.g., vehicles operating on an uncongested freeway at a VSP of 12).
- 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).

In terms of software design, MOVES is built on a Java^{TM} platform, and uses MySQL, a relational structure query language and database system (Koupal et al, 2002). All MOVES core functions and its graphical user interface (GUI) were written in Java and must be executed in a Java environment. MOVES input, output, default activities, base modal emission rates and all intermediate calculation data are stored and managed in the MySQL database. MOVES model functions query and manipulate MySQL data pursuant to scenario parameters specified in the graphical user interface. To improve execution speed performance of the Java programs, MOVES also employs something known as a master-worker configuration approach to allow for faster model scenario runs using multiple computers (EPA, 2007a, page 14).

MOVES integrates a wide range of functions to conduct calculations applicable to vehicle activities, emission processes, pollutant types, and emission sources. A complete list of MOVES functions is documented in detail in the MOVES-HVI Demo Software Design and Reference Manual (EPA, 2007a). Among these functions, four major categories constitute the basic framework of MOVES: an activity generator, a source bin distribution generator, an operating mode distribution generator, and an emissions calculator.

Activity Generator

The basic activity data in MOVES are vehicle population and vehicle miles traveled (VMT) for base year 1999 (EPA, 2004b). 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 population and VMT by road type, vehicle class, vehicle age and time period pursuant to nationwide observed and projected data from various sources (see Table 2.1). The MOVES activity function also conducts a data conversion process because all activities used for computing emissions in MOVES, except for vehicle starts, need to be specified in units of time. For example, the SHO is calculated from the allocated VMT and associated roadway-specific average speed (EPA, 2007a). The model uses activities in units of time (hours, SHO) to estimate evaporative and running exhaust emissions, as well as tire and brake wear emissions.

This approach is a significant methodological departure from MOBILE and EMFAC, which, for example, use VMT directly to estimate running exhaust emissions.

Table 2.1. Data sources of vehicle activities used in MOVES.

Data source	Data description	Purpose
U.S. Census Bureau	1997 and 2002 Vehicle Inventory and Use Survey (VIUS), including activity of private and commercial trucks.	To characterize source types and estimate age distributions for trucks.
R.L. Polk & Co.	1999 National Vehicle Population Profile (NVPP®) and Trucking Industry Profile (TIP®Net), including state vehicle registration data for light-duty cars and trucks, and medium/heavy-duty trucks.	To develop base year vehicle population.
Federal Highway Administration (FHWA)	1999-2002 Highway Statistics, including vehicle registrations and vehicle miles traveled (VMT) data.	To develop base year vehicle population and VMT.
Federal Transit Administration (FTA)	1999 National Transit Database (NTD) – Age Distribution of Active Revenue Vehicle Inventory: Details by Transit Agency.	To characterize bus source types.
Bobit Publications	The School Bus Fleet 1999 Fact Book, including estimates of number of school buses and total miles traveled by state.	To compare school bus population estimation.
Environmental Protection Agency (EPA)	MOBILE6 data, mainly based on “Update of Fleet Characterization Data for Use in MOBILE6 – Final Report.”	To develop urban area VMT by speed distribution.
Department of Energy (DOE)	2004 Annual Energy Outlook (AEO) – The National Energy Modeling System (NEMS).	To develop vehicle sales projections.
Oak Ridge National Laboratory	2002 and 2003 DOE Transportation Energy Data Book (TEDB).	To develop vehicle sales data.
Oak Ridge National Laboratory Center for Transportation Analysis	Light-duty vehicle database, combining EPA Test vehicle data and Ward's Automotive Inc. data spanning 1976 – 2001.	To determine weight distributions for light trucks by model year.

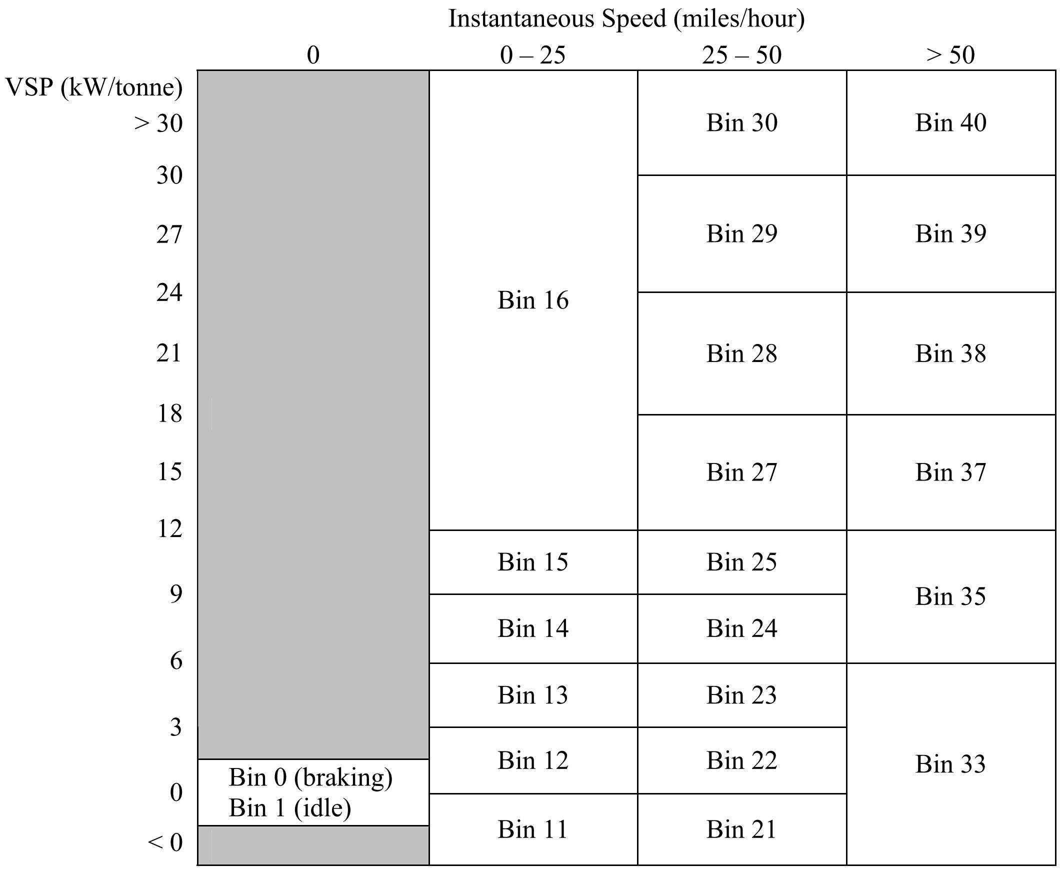
Source: summarized from (EPA, 2004b).

Source Bin Distribution Generator

MOVES uses source bins to determine base emission rates. Source bins are defined to represent unique combinations of vehicle class, model year group, vehicle weight, engine size and technology, and fuel type (EPA, 2005b; EPA, 2007a). The source bin distribution generator produces source bin fractions that are used later to derive weighted emission rates.

Operating Mode Distribution Generator

The Operating Mode Distribution Generator (OMDG) classifies vehicle operating modes into different bins associated with VSP and speed (Figure 2.2), and develops mode distributions based on 40 pre-defined driving schedules[2] (EPA, 2007a). This function produces operating mode fractions for each bin[3], which are used as one of several inputs for computing base emission rates.



Source: Derived from (EPA, 2007a, Table 9-4 and 9-5).

Figure 2.2. Definition of vehicle operating bins in MOVES.

[2] These driving schedules, or driving cycles, are specified in the form of second-by-second vehicle speeds, which aim to represent typical operation of various vehicle classes at different average speeds on each road type. Based on driving schedules, second-by-second VSP is quantified and operating modes are associated with VSP-Speed bins.

[3] The operating bins shown in Figure 2.2 were defined for modeling criteria pollutants in future versions of MOVES. In the existing MOVES2004 and MOVES-HVI Demo models, a smaller group of operating modes (i.e., two aggregated bins, Bin 26 and Bin 36, representing Bin 27-30 and Bin 37-40, respectively) were used for energy and CO_2 calculations. EPA is revising the binning of some operating modes in future MOVES versions to better characterize the increase in energy use and emissions at high VSP and speed bins.

Emission Calculator

The emission calculator function in MOVES performs emissions calculations by combining emission rates with 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. After that, weighted emission rates are 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). Finally, weighted emission rates, in units of grams per second or grams per start, are matched with activities (e.g., SHO 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.

MOVES is a data-driven model in that producing a given analysis run involves querying and manipulating the default database. Comprehensive data flow diagrams can be found in the EPA's documentation (EPA, 2002b, Figure 5-1 and 5-2). In the latest version of the MOVES model, MOVES-HVI Demo, the national level database consists of 99 MySQL relational data tables. These tables store historical and projected vehicle activity data, vehicle technology and fuel data, meteorological data, as well as detailed emission test data, and are organized into three functional types (EPA, 2007a):

- Category Value List – represent values of fundamental entities for the MOVES database, such as lists of states, counties, and calendar years.
- Associations – represent appropriate combinations of different variables and database entities – for example, combinations of fuel type and engine type that are valid for each vehicle class or pollutants that are emitted from different emission processes.
- Information – stores the detailed values of subject variables – for example, distribution data with fractions that add to unity, such as vehicle population by age, VMT by time, and speed distribution by road type; base year VMT by vehicle type, VMT growth factors by calendar year, and base emission rates.

The output from individual modeling runs of MOVES-HVI Demo is also managed in a MySQL database using relational data tables. MOVES provides four types of output tables (EPA, 2007a):

- MOVESRun Table – includes specifications for each MOVES model run such as time period, run file name and description of the specified run scenario;
- MOVESError Table – includes error messages for a MOVES model run;
- MOVESActivityOutput Table – stores vehicle activities (mainly vehicle distance traveled) modeled for the desired analysis year by time period (year, month, day or hour), location (nationwide, state or county), source type (13 vehicle classes), fuel type (9 fuel types), model year (age 0 to 30), and road type (freeway and arterial in urban or rural areas);
- MOVESOutput Table – stores vehicle emissions results and energy consumption estimates, with a similar data format as the MOVESActivityOutput Table.

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A wide range of review comments have been provided to EPA addressing different modeling subjects and approaches (e.g., Lindhjem et al, 2004). However, to date, there are very few studies publicly available that examine how well the MOVES model performs. This is not totally unexpected given that the model is still under development and only GHG emission outcomes are available in its latest versions.

One of the studies of MOVES was a comparative analysis of GHG emissions by EPA; the study was undertaken as part of validation work during model development (EPA, 2005b). The focus was mainly evaluating MOVES estimates for fuel consumption and national-level GHG emissions for methane and nitrous oxide (CH_4 and N_2O). The results showed that:

- Nationwide fuel consumption provided by MOVES2004 was comparable with that estimated by the Federal Highway Administration (FHWA).
- Between years 1999 and 2002, the annual gasoline and diesel consumption estimated by MOVES was 1-2% and 2-4% lower, respectively, than FHWA estimates. However, a state-by-state comparison suggested large differences, ranging from -19% to +23% for gasoline and -57% to +146% for diesel, respectively.

- Nationwide CH_4 and N_2O emissions from MOVES2004 were much lower than that provided in the Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA, 2004c).
- From 1999 to 2002, the annual inventory in MOVES2004 was around half for CH_4 and two thirds for N_2O, compared with other national inventory estimates (e.g., see EPA's *Emissions and Sinks* report: EPA, 2005b).

EPA identified two factors contributing to the state-by-state fuel consumption differences: 1) cross-border traffic, and 2) variation between national default and state-specific fleet composition and activity patterns (EPA, 2005b). For CH_4 and N_2O inventories, EPA concluded that MOVES estimated lower emissions than other inventories due to the updated CH_4 and N_2O emission factors included in the MOVES model (based on more recent vehicle test data).[4]

[4] Note that, as stated earlier, criteria pollutant and air toxic pollutant evaluation results were not yet available as of this writing, since the MOVES model has yet to incorporate real emission values for those pollutants.

3. COMPARATIVE ANALYSIS OF MOVES AND EMFAC

In California, on-road mobile source emissions modeling is performed using the EMFAC model (as of this writing, the latest version was EMFAC2007, released in November 2006). In this chapter, we show the results of a comparison of MOVES with EMFAC, using Los Angeles County, California as a case study. The comparison focused on the following questions:

- What are the main differences between MOVES and EMFAC in terms of modeling features, analysis options and data?
- Does MOVES generate emission estimates comparable to those produced by EMFAC?
- How different are the emission estimates from the two models for a given geographic area?
- What basic factors underlie the emissions differences between EMFAC and MOVES?

The next section starts with a side-by-side comparison of model features. This overview is followed by a Los Angeles County case study, focusing on carbon dioxide (CO_2) and methane (CH_4) emissions from on-road vehicles for a base year 2002 inventory and a future year 2030 inventory.

It is important to note that, although the comparison presented here used the latest available version of the MOVES model (MOVES-HVI Demo, for Highway Vehicle Implementation), future versions of the MOVES model will be substantially different. Future versions of MOVES will incorporate criteria and other pollutants, and the model structure itself is expected to evolve to facilitate more user-friendly manipulation of default and input data. Thus, this analysis focused more on broad methodological differences between EMFAC and MOVES that result in differing activity and emissions estimates, and less on issues related to ease of use with respect to MOVES.

3.1 Comparison of Basic Model Features

Emissions estimation in MOVES and EMFAC follows a similar underlying concept, in which total vehicle emissions are the product of vehicle activities, base emission rates and a series of adjustment factors. Differences between MOVES and EMFAC mainly reflect how vehicle activities are quantified, how emission rates are measured, and how vehicle activities and emission rates are paired spatially and temporally. Table 3.1 highlights modeling features of MOVES and EMFAC. Although not exhaustive, Table 3.1 helps to identify prominent features that differ between the two models. Important observations from Table 3.1 include:

- Spatial resolution: MOVES integrates a multi-scale computation framework so that, once the final version of MOVES becomes available, vehicle emissions can be estimated in a consistent way for a region (e.g., state, metropolitan area or county), a user-defined zone, or a particular roadway link. This is, conceptually, superior to the approach taken by EMFAC. EMFAC produces emissions based on underlying trip-based information; EMFAC does not distinguish roadway links in modeling either emission inventories or emission factors. Therefore, EMFAC emission estimates are better suited for regional-scale rather than link-level application. However, a shortcoming in MOVES macroscale analyses is that the model does not quantify state or county level vehicle activities directly. Instead, state or county vehicle activities are derived by applying top-down spatial allocation factors to national-scale statistics (unless default data are replaced with local data). In contrast, all vehicle activity data in EMFAC, including both totals and distributions, are locally collected and county-specific.
- Temporal resolution: MOVES generates hourly emissions inventory output for weekdays, weekends, months, or years. EMFAC provides hourly or daily inventories for an average day by month, season and year..
- Vehicle classification: MOVES and EMFAC classify vehicles differently. MOVES identifies vehicle classes as a subset of the classes used in the federal Highway Performance Monitoring System (HPMS), and also includes vehicles using alternative fuels. EMFAC vehicle classes are defined independently of the categorization scheme used by HPMS. From a transportation planning perspective, the MOVES approach is superior in that it offers better synchronization with reported travel activity data.
- Coverage of pollutants and energy consumption: In addition to estimating criteria pollutants, future versions of MOVES will also calculate energy consumption, greenhouse gas emissions, and mobile source air toxics (MSAT) emissions. EMFAC lacks energy consumption information; also, EMFAC does not estimate MSAT

emissions, although CARB does make MSAT speciation factors available to post-process EMFAC Total Organic Gases (TOG) data.

- Emission rate form: A main departure from EMFAC is that MOVES measures second-by-second emission rates using a binning method based on VSP and instantaneous speed. The associated vehicle activities for running exhaust emissions are vehicle operating time (named Source Hours Operating), rather than the commonly used VMT. MOVES therefore has the ability to model microscale emissions given detailed vehicle operating characteristics.

Table 3.1. Comparison of EMFAC and MOVES model features and scopes.

	EMFAC[a]	MOVES[b]
Versions Compared	EMFAC2007 (November 2006)	MOVES-HVI Demo (April 2007)
Program language	Fortran	Java™
Data management	Model-embedded manipulation	MySQL relational database
GUI available	Yes	Yes
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) 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	• Light-Duty Auto • Light-Duty Truck 1 • Light-Duty Truck 2 • Medium-Duty Truck • Light-Heavy-Duty Truck 1	• Motorcycle • Passenger Car • Passenger Truck • Light Commercial Truck • Intercity Bus

	EMFAC[a]	MOVES[b]
	• Light-Heavy-Duty Truck 2 • Medium-Heavy-Duty Truck • Heavy-Heavy-Duty Truck • Motor Home • Urban Bus • School Bus • Other Bus • Motorcycle	• Transit Bus • School Bus • Refuse Truck • Single Unit Short-haul Truck • Single Unit Long-haul Truck • Motor Home • Combination Short-haul Truck • Combination Long-haul Truck
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 CH4) • Carbon Monoxide (CO) • Oxides of Nitrogen (NOx) • Carbon Dioxide (CO2) • Particulate Matter (PM30, PM10 and PM2.5) • Oxides of Sulfur (SO_x) • Lead (Pb) • Fuel Consumption	Currently available: • Methane (CH4) • Nitrous Oxide (N2O) • Atmospheric Carbon Dioxide (CO2) • CO2 Equivalent • Total Energy Consumption • Petroleum Energy Consumption • Fossil Energy Consumption To be added in a future version: • Total Gaseous Hydrocarbons • Carbon monoxide (CO) • Oxides of Nitrogen (NOx) • Particulate Matter (PM10 and PM2.5) • Air toxics pollutants

	EMFAC[a]	MOVES[b]
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 • Evaporative Fuel Leaks • Crankcase • Tire Wear • Break Wear
Operating modes (bins)	Trip-based vehicle average speed	Vehicle specific power (VSP) and instantaneous speed
Pre-loaded 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 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 (CARB, 2007).
[b] Model features summarized based on MOVES-HVI Demo documentation (EPA, 2007a).

3.2 Design of the Los Angeles County Case Study

To compare MOVES and EMFAC estimates for county-level emissions, 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" and "Mesoscale Lookup" modules 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. A summary of scenario specifications is presented in Table 3.2.

Table 3.2. Scenario construction in EMFAC and MOVES.

	EMFAC2007	MOVES-HVI Demo	
Area	Los Angeles County	Los Angeles County	
Analysis years	2002 and 2030	2002 and 2030	
Pollutants	CH_4 and tailpipe CO_2	CH_4 and total atmospheric CO_2	
Emission processes	Running exhaust, idle exhaust and start exhaust	Running exhaust, idle exhaust and start exhaust	
Model runs	Burden	Macroscale	Mesoscale Lookup
Outcomes	Total activities, emissions and emission factors	Total activities and emissions	Emission factors by model year
Vehicle class	All 13 vehicle types specified in Table 3.1	All 13 vehicle types specified in Table 3.1	
Fuel type	Gasoline and diesel	Gasoline, diesel and others	
Vehicle age	Age 0, 1, …, 29, 30 and above	Age 0, 1, …, 29, 30 and above	
Average temperature*	67 ºF	69 ºF	
Average relative humidity*	56%	54%	

*MOVES and EMFAC temperature and relative humidity values were selected based on the default information provided by the models to represent average conditions.

In order to compare emissions on a consistent basis, different vehicle classes defined in MOVES and EMFAC were regrouped into five categories, as shown in Table 3.3. 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).

Table 3.3. Mapping of vehicle classes in EMFAC and MOVES to facilitate model comparisons.

Vehicle Class (for comparison)	Vehicle Type in EMFAC		Vehicle Type in MOVES		Vehicle Type in HPMS
LDA	1	Passenger Cars	21	Passenger Cars	Passenger Cars
LDT	2	Light-Duty Trucks 1	31	Passenger Trucks (personal use)	Other Two-Axle/Four Tire, Single Unit
	3	Light-Duty Trucks 2	32	Light Commercial Trucks (other use)	Other Two-Axle/Four Tire, Single Unit
M&HDT	4	Medium-Duty Trucks	51	Refuse Trucks	Single Unit
	5	Light-Heavy-Duty Trucks 1	52	Single Unit Short-haul Trucks	Single Unit
	6	Light-Heavy-Duty Trucks 2	53	Single Unit Long-haul Trucks	Single Unit
	7	Medium-Heavy-Duty Trucks	61	Combination Short-haul Trucks	Combination
	8	Heavy-Heavy-Duty Trucks	62	Combination Long-haul Trucks	Combination
	13	Motor Homes	54	Motor Homes	Single Unit
BUS	9	Other Buses	41	Intercity Buses (non-school, non-transit)	Buses
	10	Urban Buses	42	Transit Buses	Buses
	12	School Buses	43	School Buses	Buses
MCY	11	Motorcycles	11	Motorcycles	Motorcycles

Note: This study compared EMFAC and MOVES results primarily for LDA, LDT, and M&HDT vehicle classes. In some cases, such as passenger cars, there is direct overlap between model classes; in other cases, such as M&HDTs, we selected individual vehicle types that would best constitute a match between the two model classes. Although we selected individual vehicle types to best compare models by class, it is possible that vehicle class differences between each model contribute to some of the activity and emission differences reported in later sections of this report.

3.3 Comparison of County Total Greenhouse Gas Emissions

The daily county totals (Table 3.4 and Figures 3.1 to 3.3) indicate that, 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 3.4. 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%
	CO2	tons/day	125,690	128,280	+ 2%
	CH4	tons/day	19.25	8.10	– 58%
2030	VMT	1000 miles	253,015	365,478	+ 44%
	CO2	tons/day	153,970	215,018	+ 40%
	CH4	tons/day	3.93	7.63	+ 94%

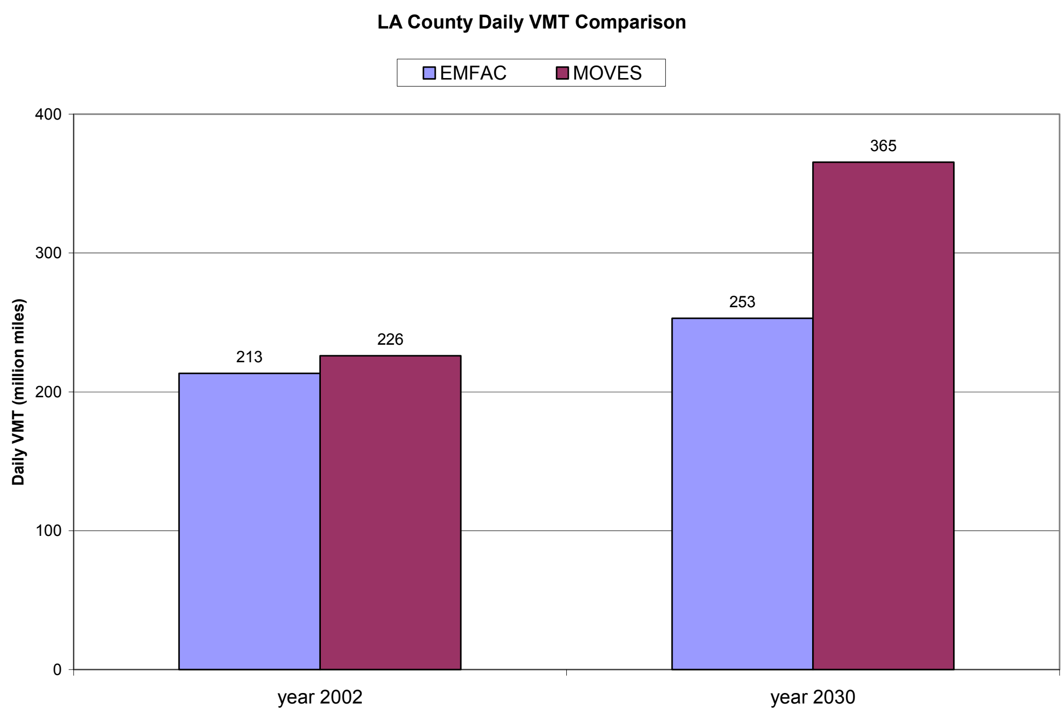


Figure 3.1. LA County daily VMT estimated in EMFAC and MOVES.

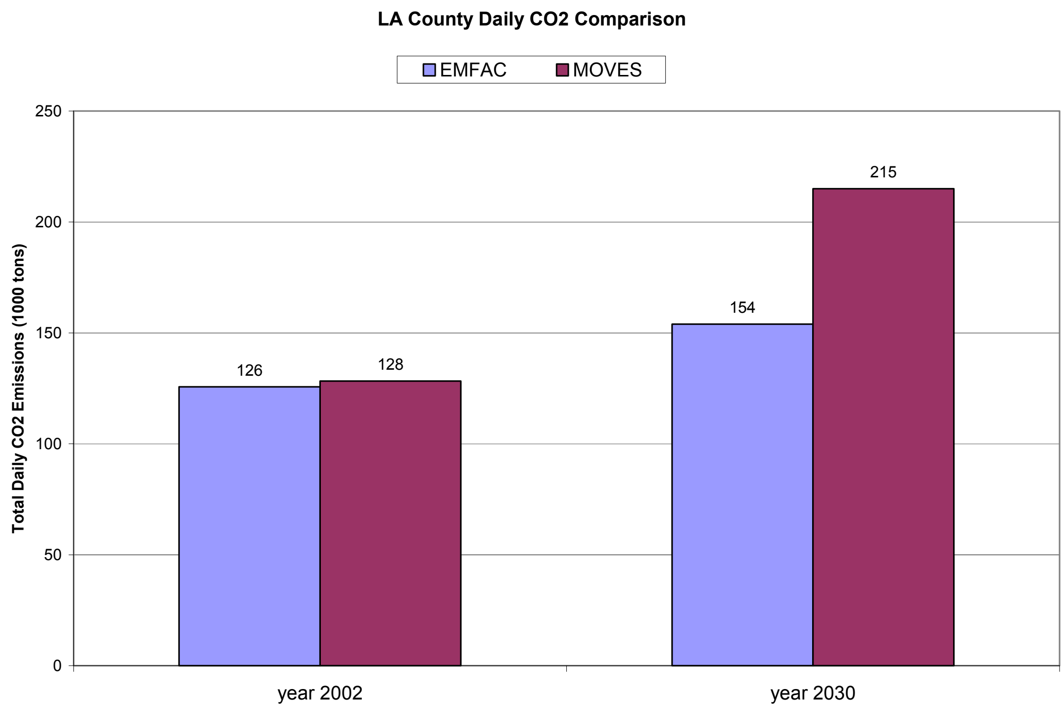


Figure 3.2. LA County daily CO_2 emissions estimated in EMFAC and MOVES.

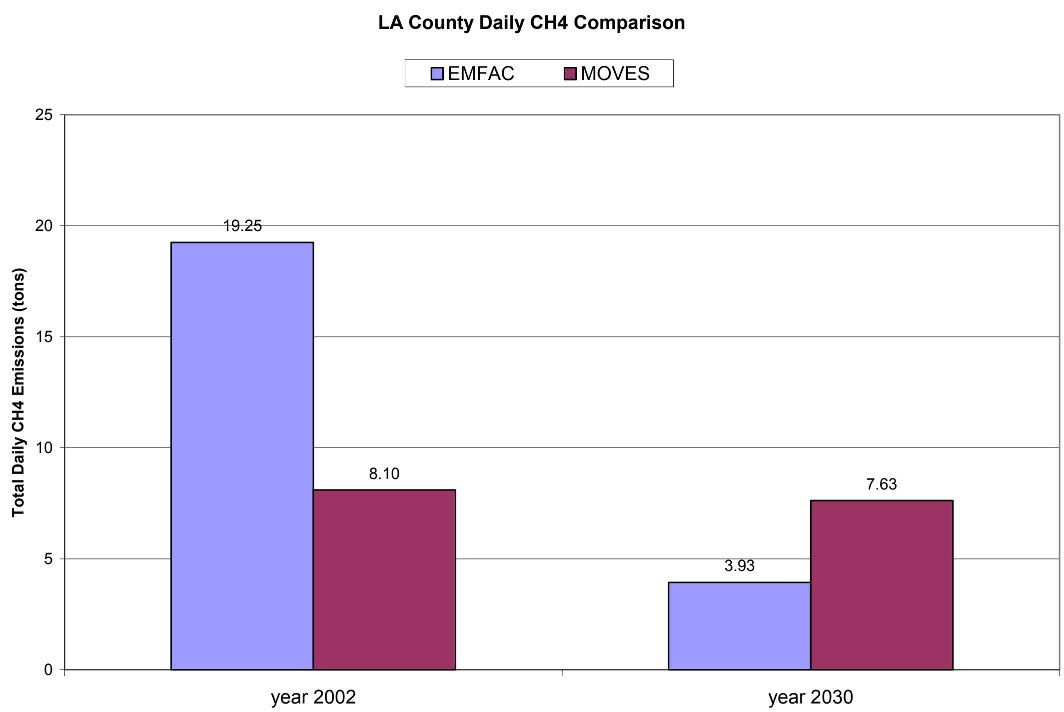


Figure 3.3. LA County daily CH_4 emissions estimated in EMFAC and MOVES.

To better understand the underlying factors contributing to differences between the two models, we examined the county totals by different categories, such as emission process and vehicle class. Various factors contributed to the model differences including (see Figures 3.4 through 3.11):

- From year 2002 to 2030, CO_2 emissions in MOVES grow more significantly than that estimated in EMFAC (see Figure 3.2); the increase is mainly contributed by the running exhaust process. MOVES also produces considerably higher start emissions of CO_2 than EMFAC in both analysis years, by a factor between three and four (see Figures 3.4 and 3.5).

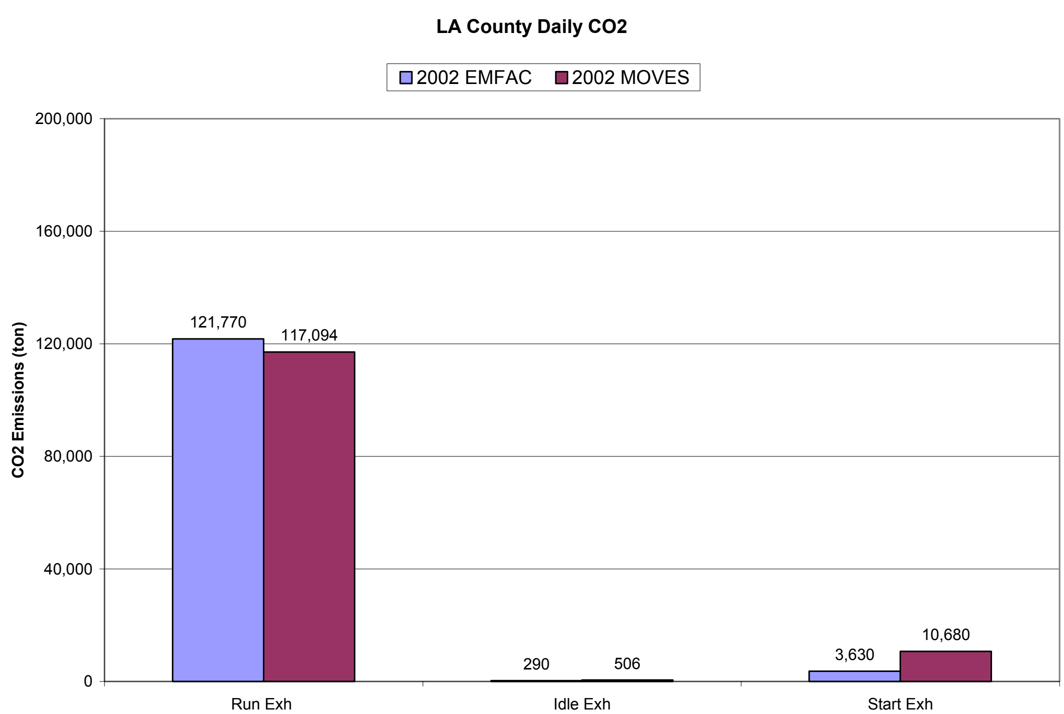


Figure 3.4. Year 2002 LA County CO_2 emissions by emission process.

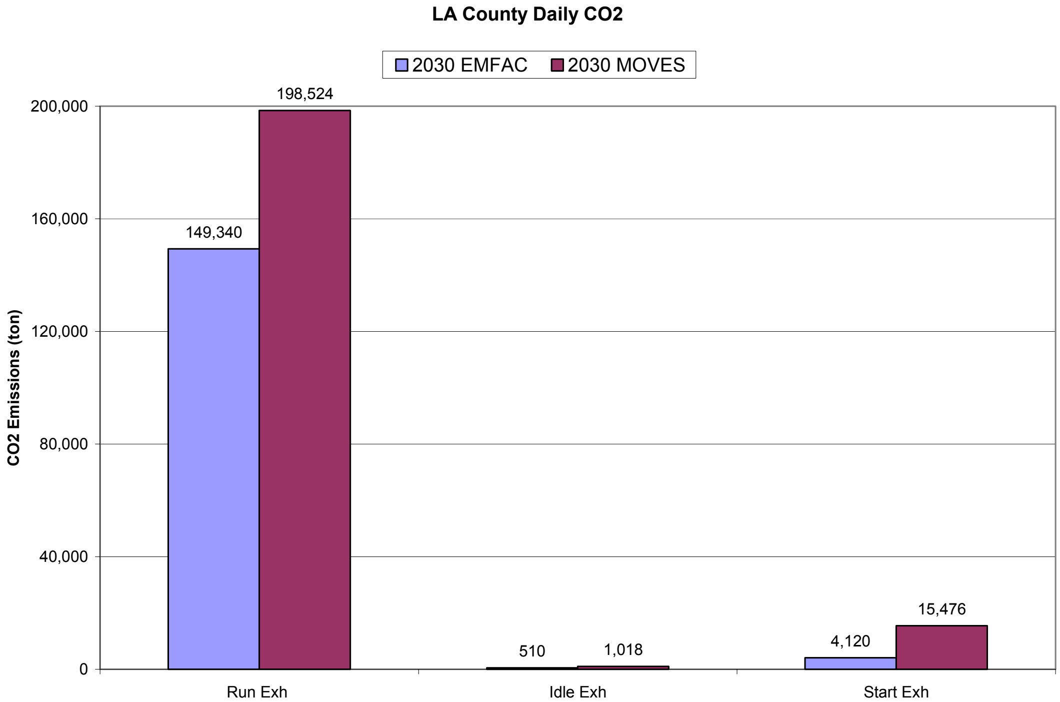


Figure 3.5. Year 2030 LA County CO_2 emissions by emission process.

- For year 2002, MOVES has slightly higher CO_2 emissions from LDT and slightly lower CO_2 emissions from M&HDT than EMFAC; however, for year 2030, MOVES projects significant growth in LDT CO_2 emissions, more than double of that estimated in EMFAC (see Figures 3.6 and 3.7).

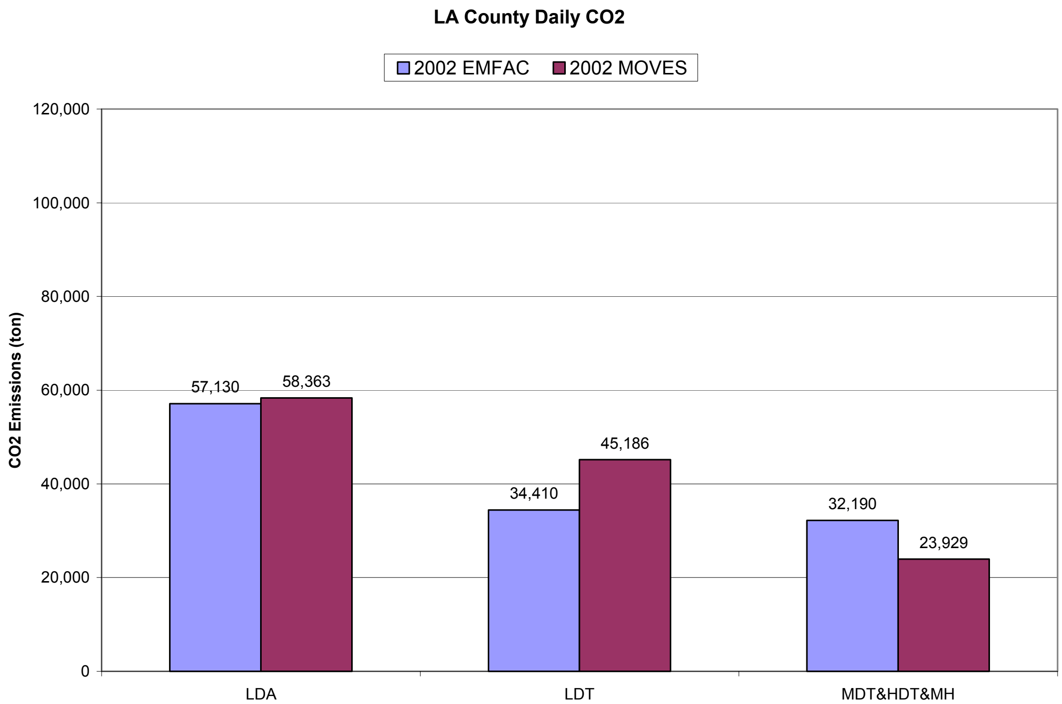


Figure 3.6. Year 2002 LA County CO_2 emissions by vehicle class.

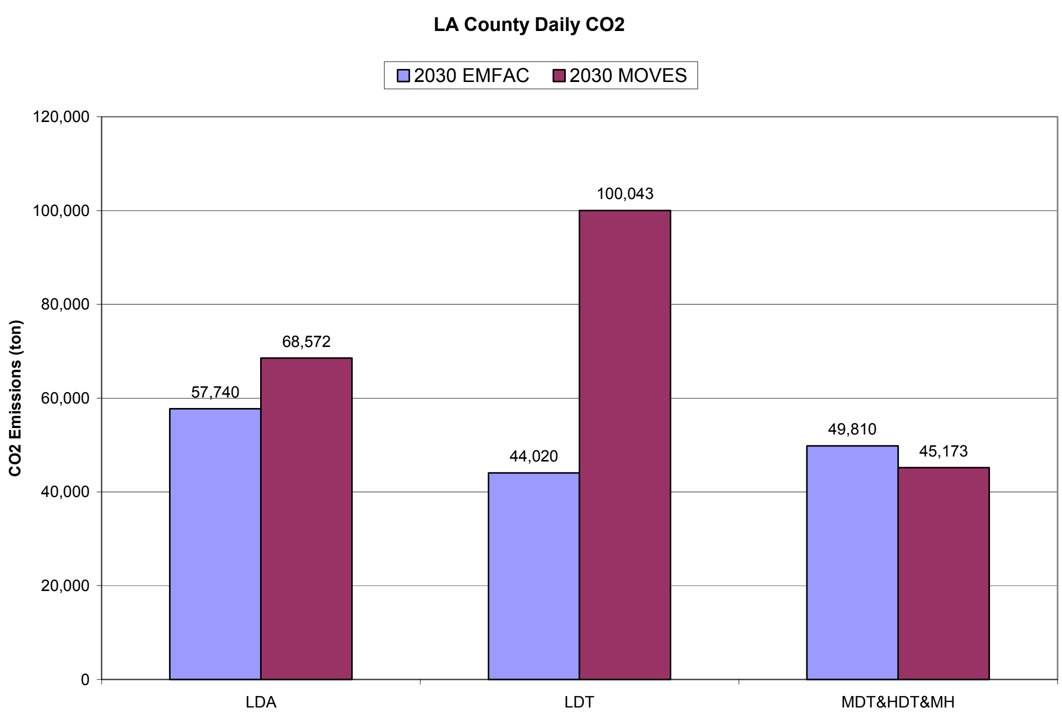


Figure 3.7. Year 2030 LA County CO_2 emissions by vehicle class.

- For year 2002, Los Angeles County CH_4 running exhaust emissions produced by MOVES are only one third of those estimated by EMFAC; for year 2030, MOVES projects similar running exhaust CH_4, but substantially higher start exhaust CH_4 (see Figures 3.8 and 3.9 – by 2030, start exhaust CH_4 accounts for nearly half of the total CH_4 inventory in MOVES).

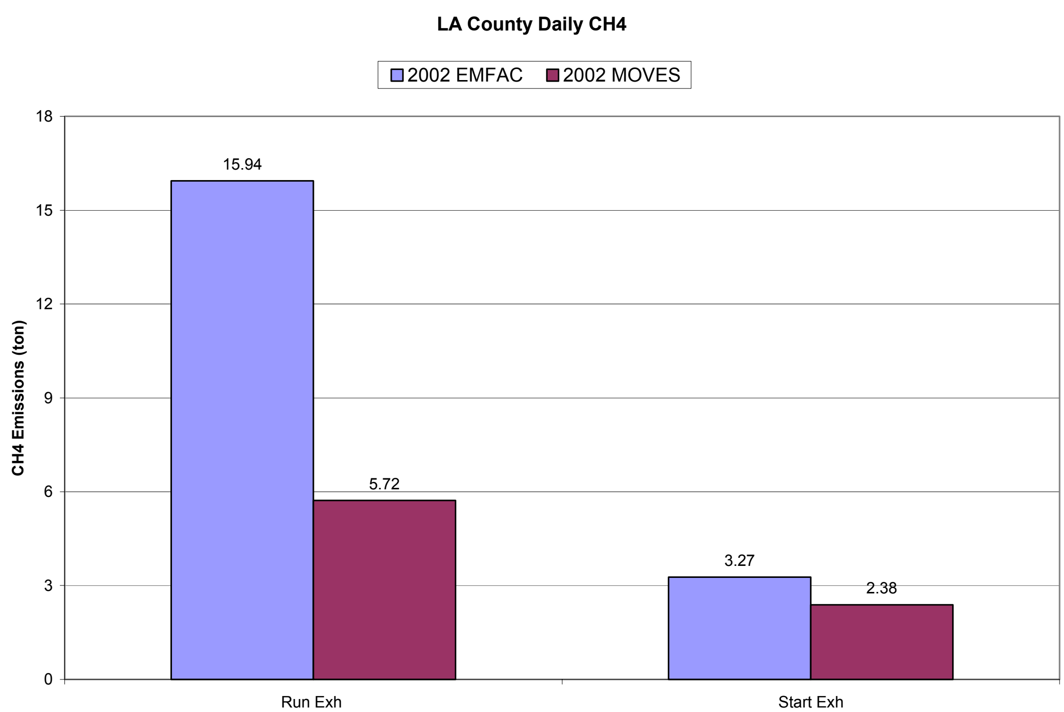


Figure 3.8. Year 2002 LA County CH_4 emissions by emission process.

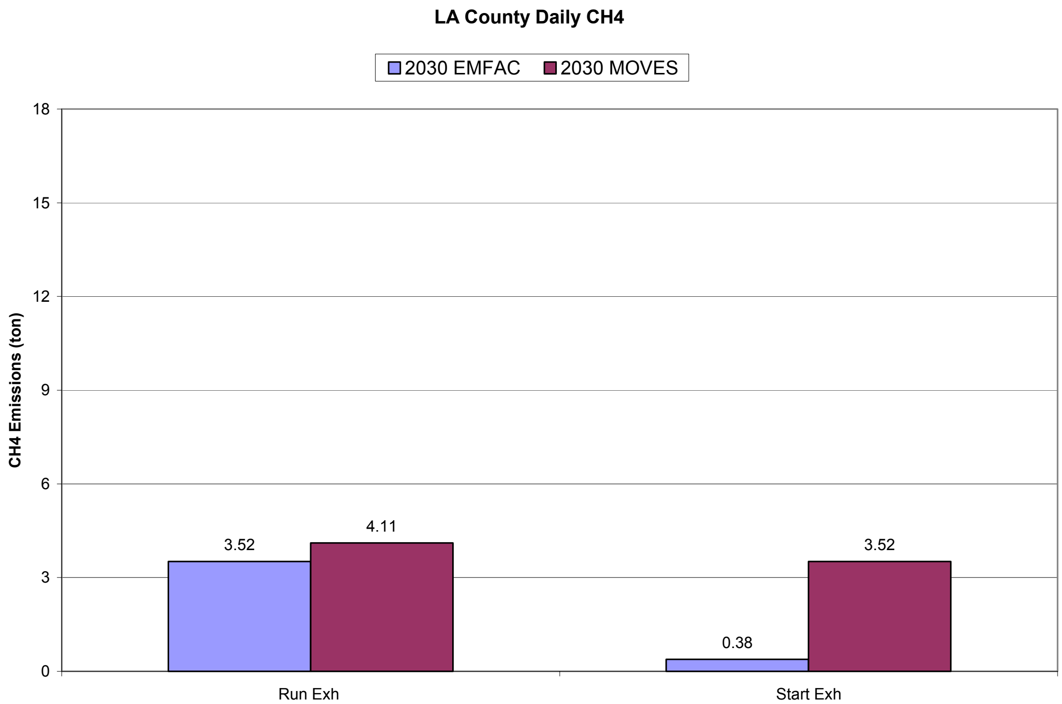


Figure 3.9. Year 2030 LA County CH_4 emissions by emission process.

- EMFAC forecasts a significant decrease in CH_4 emissions from year 2002 to 2030 for each vehicle class. MOVES forecasts a CH_4 reduction only for LDA vehicles, and forecasts slight CH_4 increases for LDT and M&HDT vehicles in year 2030 relative to 2002 (see Figures 3.10 and 3.11).

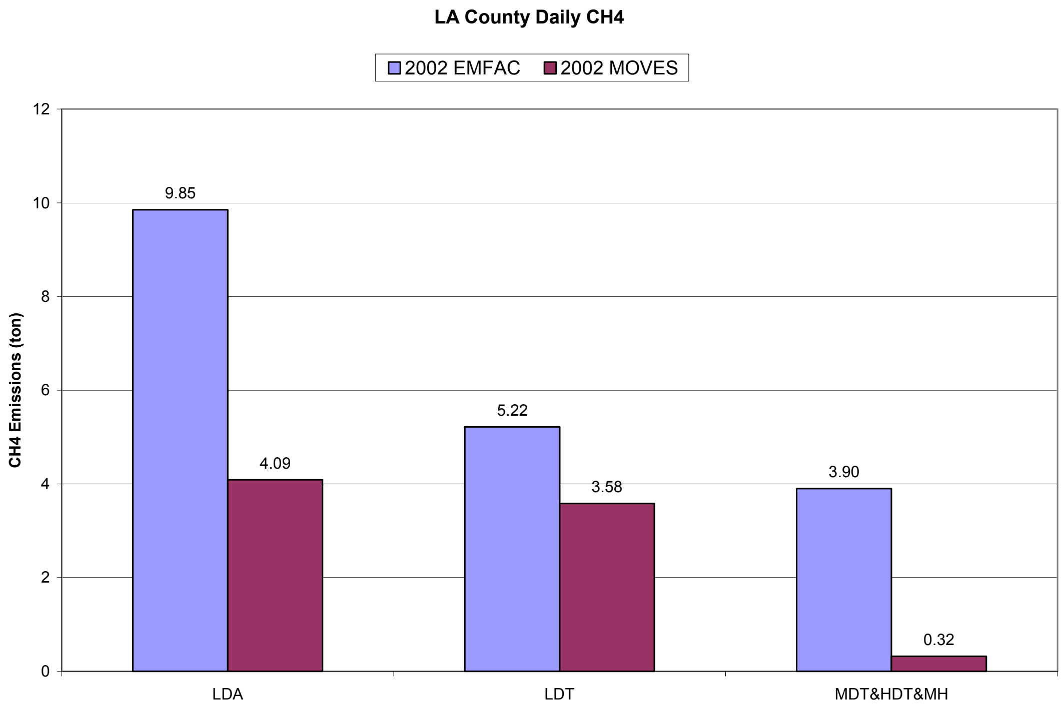


Figure 3.10. Year 2002 LA County CH_4 emissions by vehicle class.

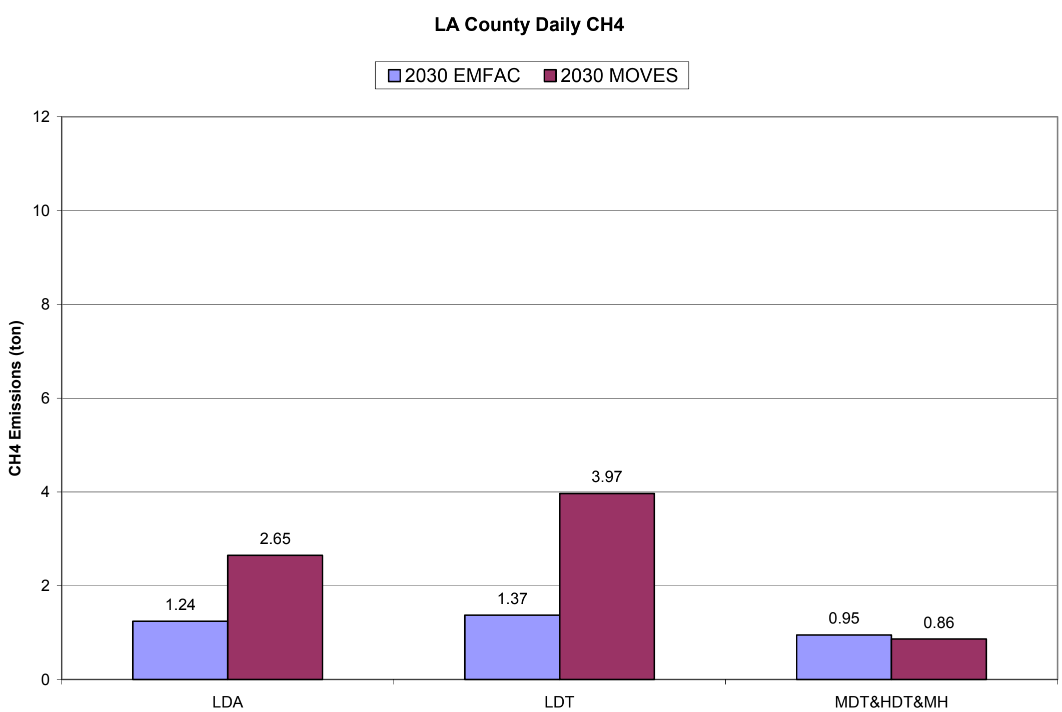


Figure 3.11. Year 2030 LA County CH_4 emissions by vehicle class.

3.4 Comparison of Vehicle Activities

As discussed earlier, emissions estimated by either MOVES or EMFAC are dependent on vehicle activities and associated emission factors. The following comparison between MOVES and EMFAC focuses on vehicle activities, including fleet compositions, age distributions, mileage accrual rates and VMT distributions. The purpose of the comparison is to examine how default vehicle activities in MOVES contribute to the differing emission results observed between EMFAC and MOVES.

It should be noted that, in MOVES-HVI Demo, county-level vehicle activities are developed by simply applying a county spatial allocation factor to nationwide activity data[5]. The allocation factor is a function of the fraction of total U.S. VMT that occurs in the sub area (e.g., the county). Therefore, default activity distributions (e.g., percentage of fleet by different age and vehicle types) in MOVES-HVI Demo are proportionally similar across all U.S. counties, although the absolute value of the activity varies by the scaling factor applied.

3.4.1 Vehicle fleet composition

The vehicle fleet composition is represented by proportions of different vehicle classes within the total vehicle population. As shown in Figure 3.12, 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%) but a lower proportion of M&HDT in the vehicle fleet (only 3.3%), compared to EMFAC.

[5] Personal communication with EPA staff indicates that a GUI-driven function named "Domain Importer" is under development for future versions of MOVES; it will allow users to directly specify and input county-level vehicle activities, rather than applying county allocation factors to the national default activities (Beardsley, 2008).

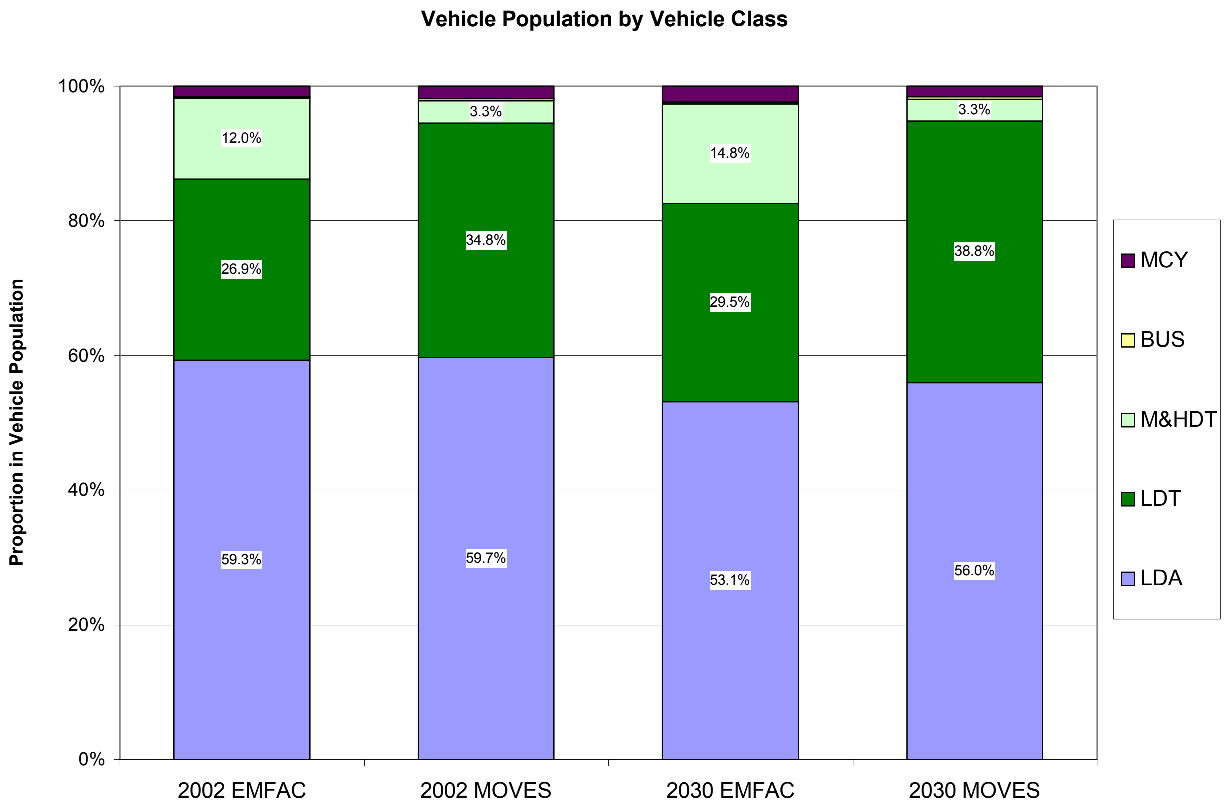


Figure 3.12. LA County vehicle population fractions in EMFAC and MOVES.

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 DOE Transportation Energy Data Book (TEDB) and the Annual Energy Outlook (AEO). These data indicate that the LDA fleet grows more quickly from 2000 to 2012 (approximately) than from 2013 to 2030; in contrast, the LDT fleet grows more consistently over time (see Figure 3.13). As a result, the MOVES vehicle fleet reflects an increased proportion of LDT over time.

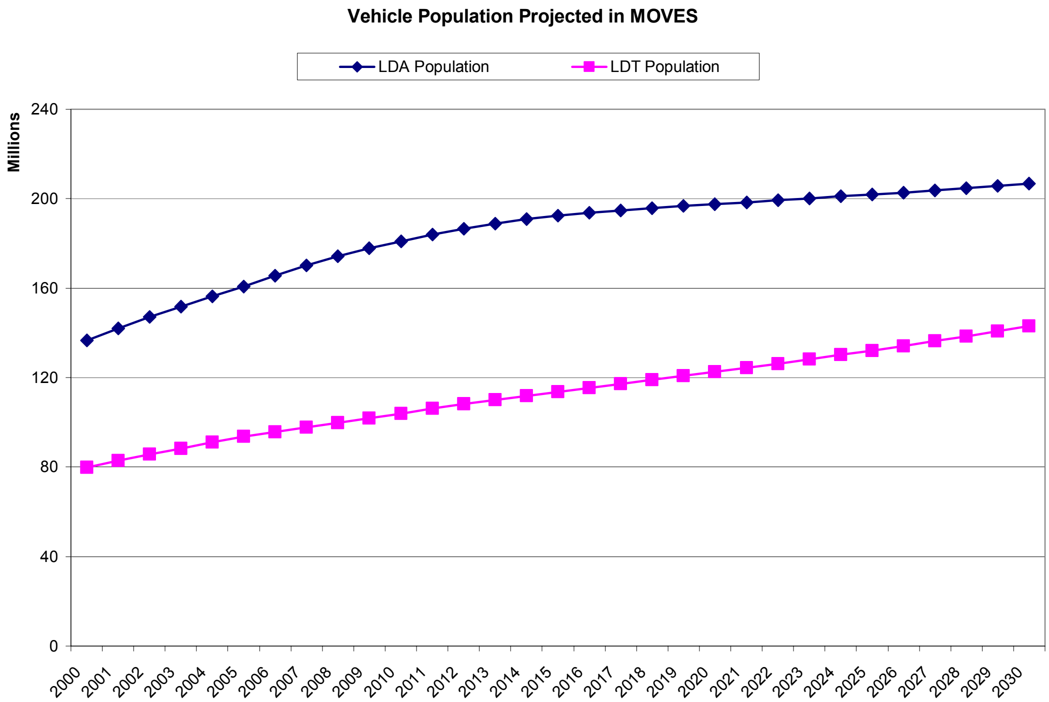


Figure 3.13. LA County LDA and LDT population growth.

3.4.2 Vehicle age distribution

Vehicle age distributions for Los Angeles County are presented in Figures 3.14 and 3.15, for the base year and future year, respectively. 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 assumes a younger vehicle fleet than EMFAC, especially for LDT (see Figure 3.16). In particular, the MOVES fleet projects a much lower proportion than EMFAC for vehicles aged 30 or more years.

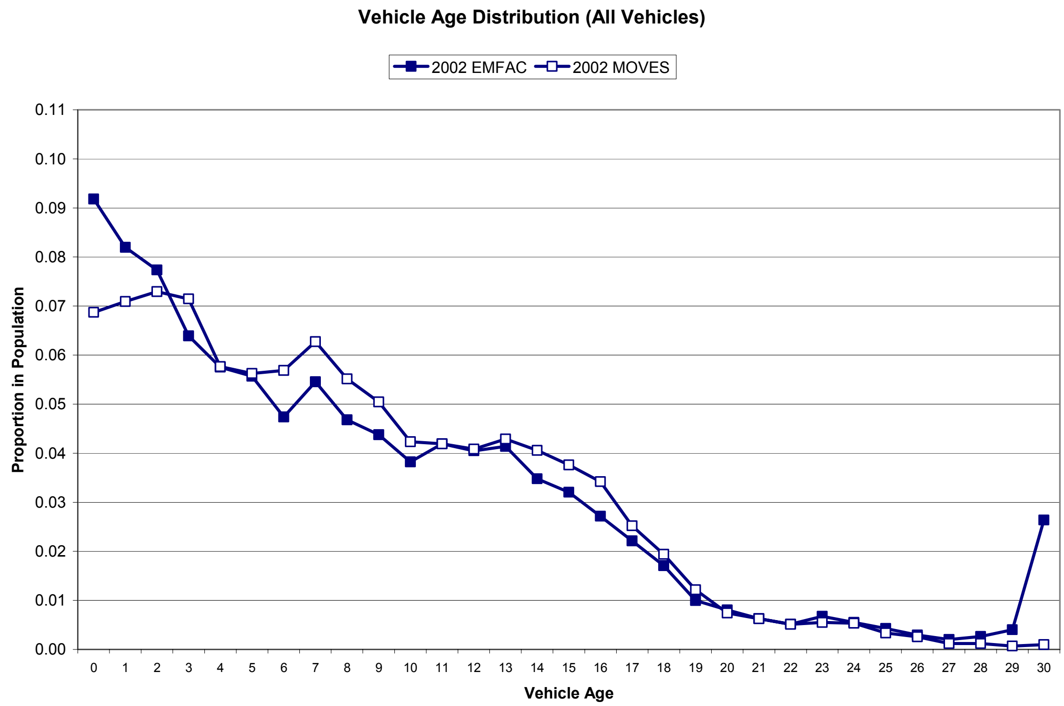


Figure 3.14. LA County 2002 fleet age distributions in EMFAC and MOVES.

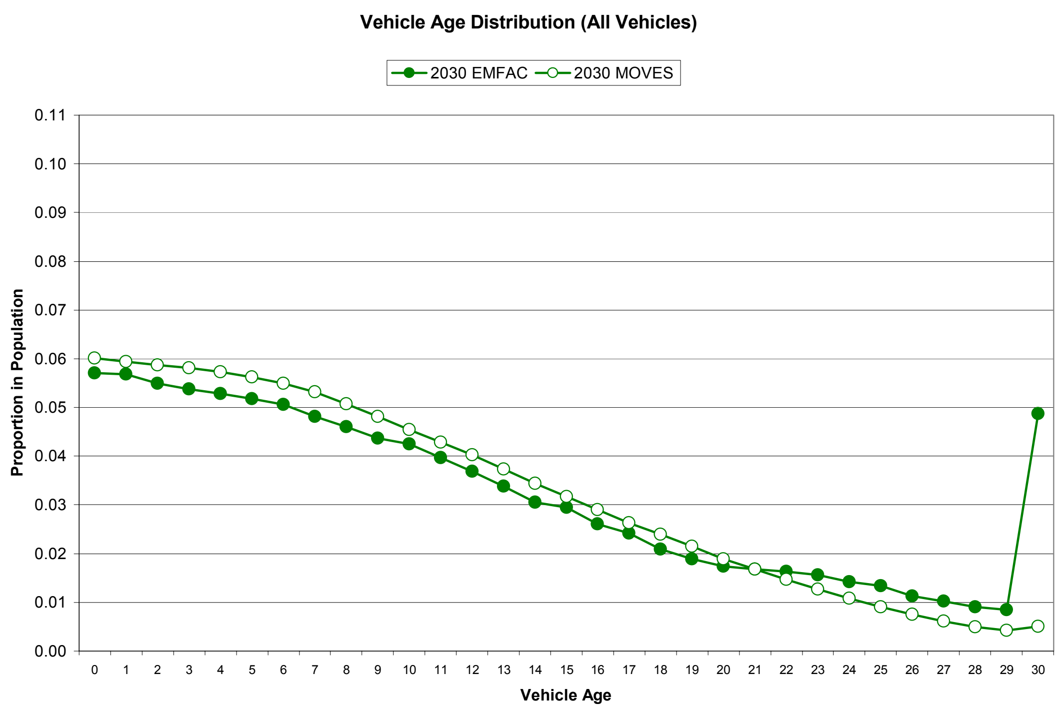


Figure 3.15. LA County 2030 fleet age distributions in EMFAC and MOVES.

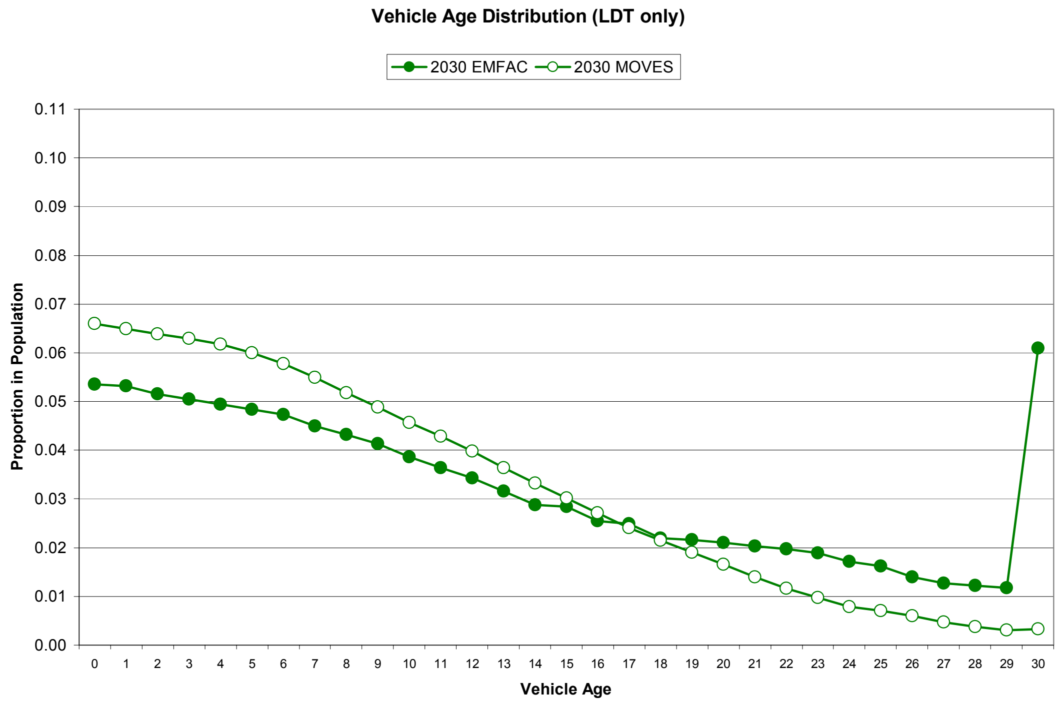


Figure 3.16. LA County 2030 LDT age distributions in EMFAC and MOVES.

3.4.3 Vehicle mileage accrual rates

In EMFAC, the vehicle mileage accrual rate plays an important role in determining VMT. EMFAC assumes accrual rate is a function of vehicle age and this function does not change by analysis year. To develop comparable accrual rates in MOVES, we calculated an average accrual rate based on annual VMT and vehicle population for each vehicle class as well as vehicle age. As shown in Figures 3.17 to 3.20, in general, older vehicles in MOVES tend to have lower accrual rates than that in EMFAC for both the 2002 and 2030 fleet. These findings are consistent with generally observed vehicle age and deterioration information. Historically, California vehicles have tended to be in service longer than vehicles in the rest of the U.S.[6]

[6] Based on year 2005 EMFAC data and U.S. vehicle statistics, California average vehicle age is 9.7 and 9.2 years for LDA and LDT, respectively, compared to a U.S. average of 9.0 and 6.6 years. See: Transportation Statistics Annual Report (US Department of Transportation); http://www.bts.gov/publications/transportation_statistics_annual_report/.

Contrary to expectations, MOVES shows that, over time (2002-2030), LDA accrual rates decline for all vehicle ages (Figures 3.17 and 3.18). As an illustration, note the fourth data point from the left for the MOVES model in Figures 3.17 and 3.18 (three-year old vehicles); the 2002 data point shows vehicles traveling 14,000 miles per year, while the 2030 data point shows vehicles traveling fewer miles per year. In contrast, and consistent with expectations, accrual rates of younger LDT increase considerably from 2002 to 2030. The shift over time in LDT accrual rates has important implications for MOVES-based emissions estimates: the shift implies that, in future years, more of the LDT miles driven in a given year will come from the youngest (and lowest emitting) portions of the LDT fleet (Figures 3.19 and 3.20).

The mileage accrual findings presented here are influenced by the methodology used to identify mileage accrual rates in MOVES. Unlike EMFAC, which incorporates explicit accrual assumptions, MOVES does not embed specific accrual assumptions. We processed MOVES data to develop mileage accrual estimates based on the independent estimates of vehicle sales growth and VMT growth embedded in MOVES (explained below).

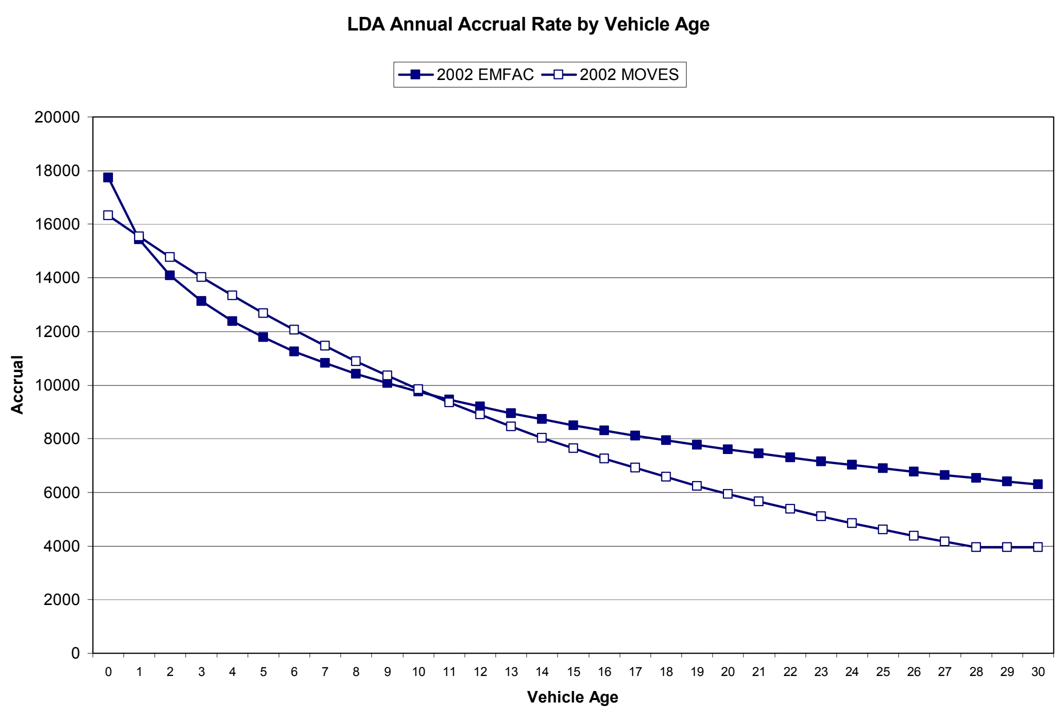


Figure 3.17. LA County LDA accrual rates in year 2002 fleet.

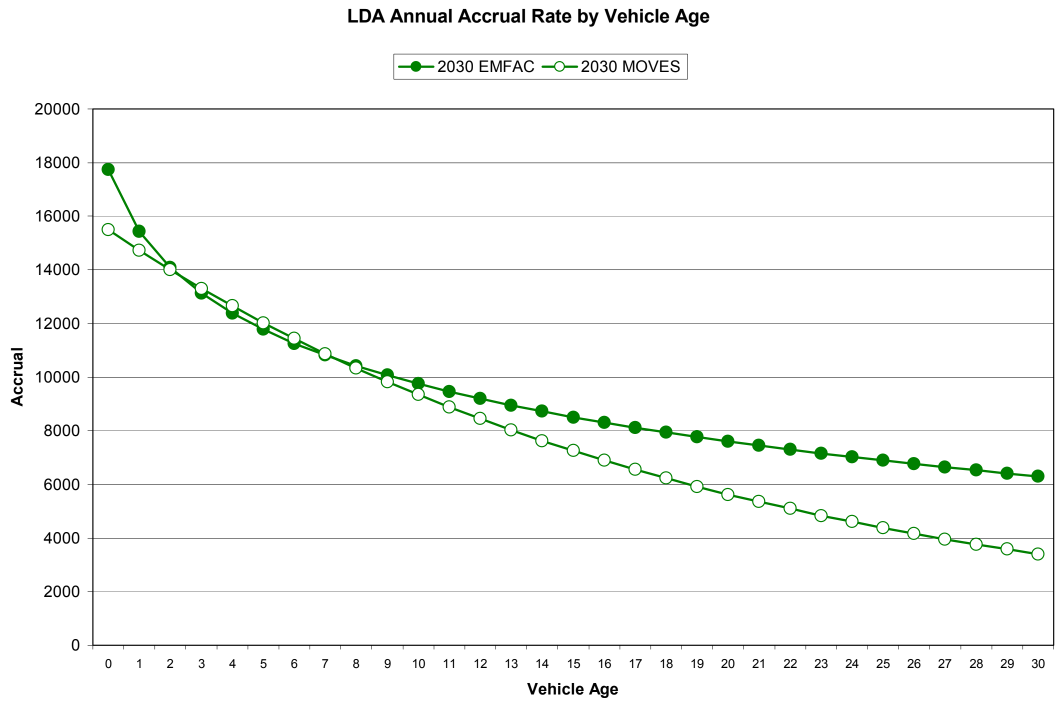


Figure 3.18. LA County LDA accrual rates in year 2030 fleet.

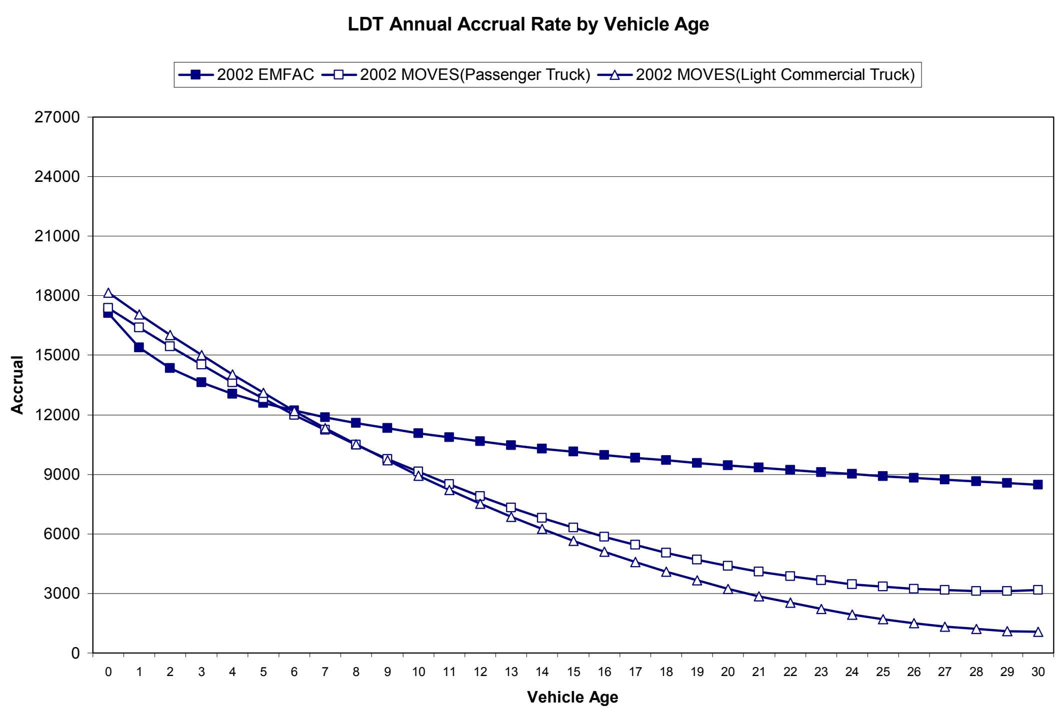


Figure 3.19. LA County LDT accrual rates in year 2002 fleet.

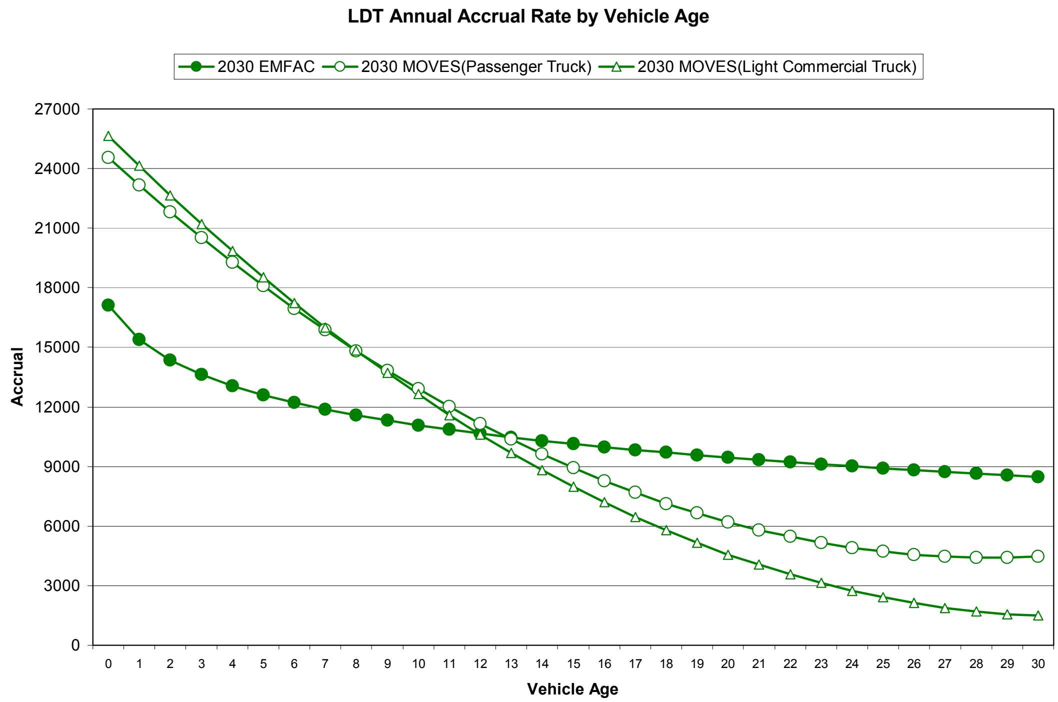


Figure 3.20. LA County LDT accrual rates in year 2030 fleet.

The opposing LDA and LDT accrual rate patterns in MOVES are a result of using different growth data in vehicle population and VMT. The base year 1999 vehicle population used in MOVES is from 1) FHWA Highway Statistics, and 2) the National Vehicle Population Profile (NVPP®) and the Trucking Industry Profile (TIP®Net). MOVES grows new vehicles based on sales growth factors derived from the DOE Transportation Energy Data Book (TEDB), and other vehicles (age of 1 year to 30 years) based on pre-defined survival rates. The base year 1999 VMT in MOVES is from HPMS data. MOVES predicts future year VMT using growth factors calculated from FHWA Highway Statistics for 2000-2002 and Annual Energy Outlook (AEO) data for 2003 onward.

As illustrated in Figures 3.21 and 3.22, using 1999 data as the base, over time, the LDA population grows faster than VMT, while the LDT population grows slower than VMT. As a result, MOVES activity data result in a substantially higher LDT mileage accrual rate for the future vehicle fleet, compared to LDAs (see Figure 3.23).

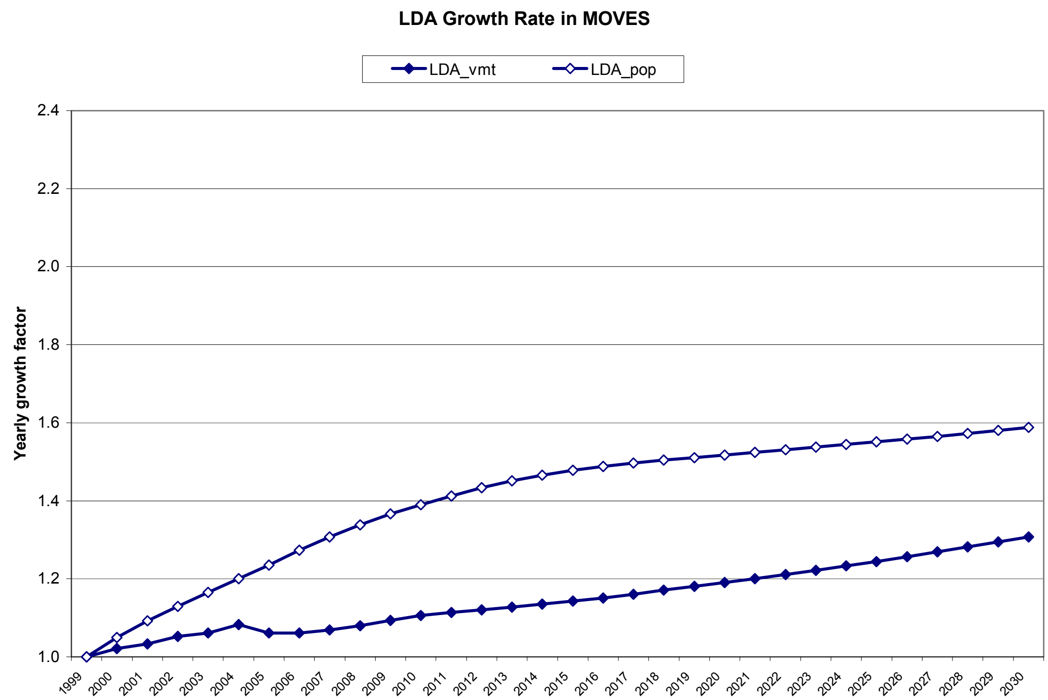


Figure 3.21. LA County annual growth factors of LDA in MOVES.

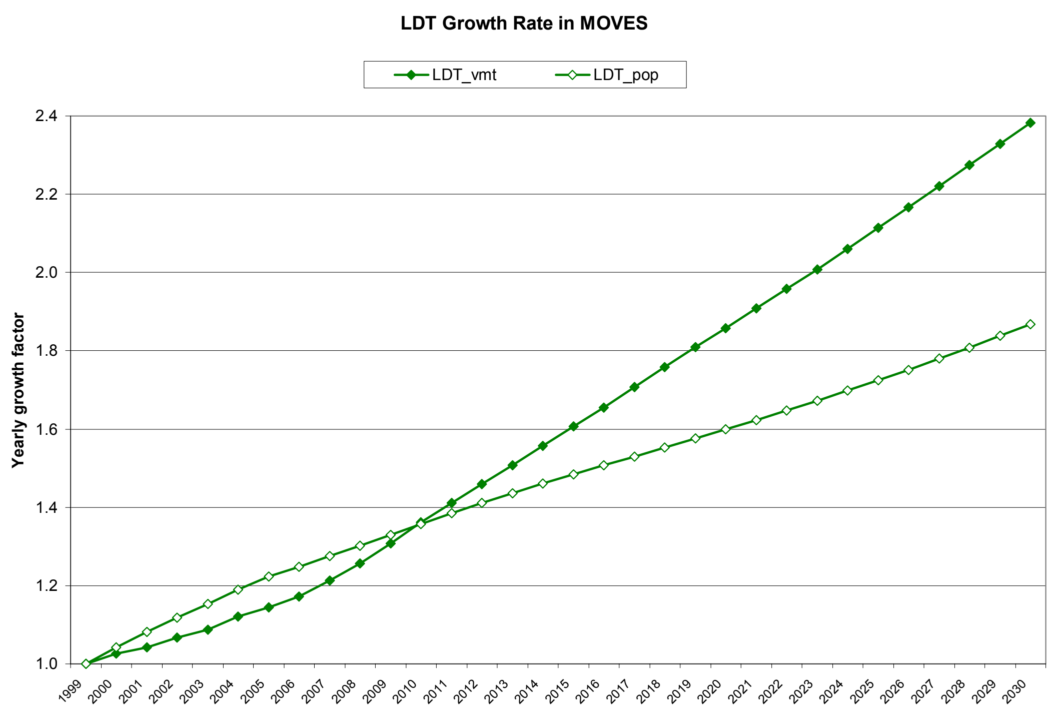


Figure 3.22. LA County annual growth factors of LDT in MOVES.

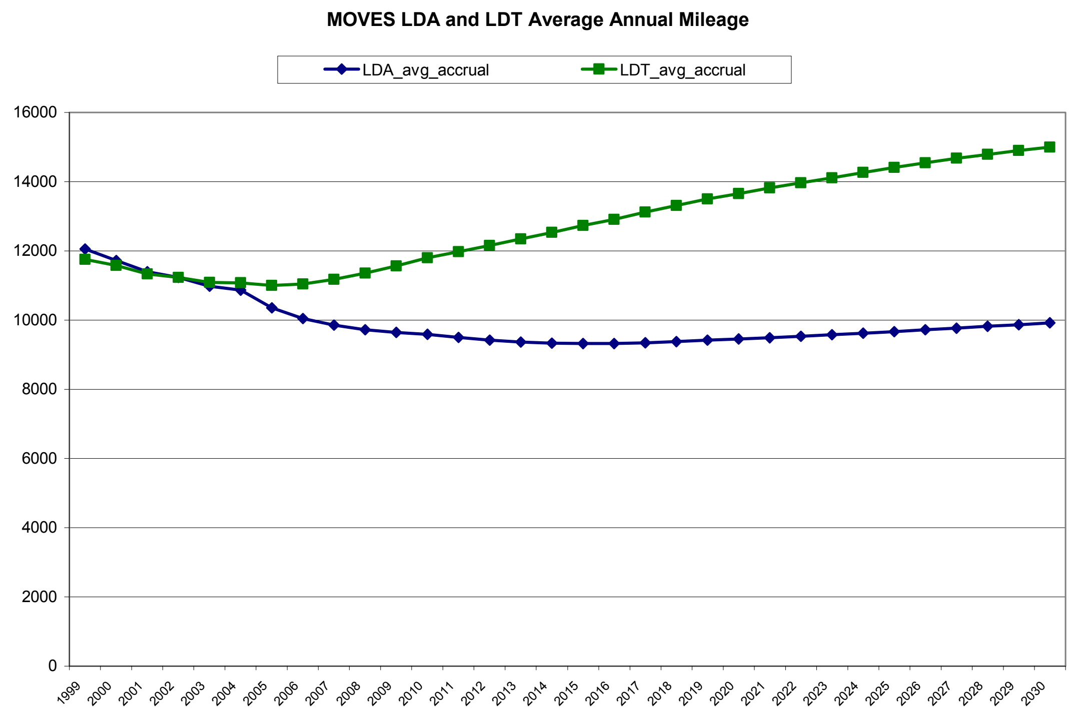


Figure 3.23. LA County fleet average accrual rates estimated in MOVES.

Given the counter-intuitive results presented here (effective LDA mileage accrual dropping over time), further investigation is warranted to determine whether alternative approaches should be used to grow the vehicle populations and vehicle VMT data included in MOVES. Alternatively, the MOVES model documentation could include a discussion about whether the model implicitly assumes that, in the future, there are calendar years when portions of the vehicle fleet are assumed to drive fewer miles per year than their counterparts did in prior years.[7]

3.4.4 VMT distributions

Higher LDT accrual rates and increased LDT population numbers imply that, by 2030, VMT from LDTs account for a significant proportion of total fleet VMT estimated by MOVES (see Figure 3.24). Figures 3.25 and 3.26 present the comparison of VMT by vehicle class for year 2002 and 2030, respectively. The projected year 2030 LDT VMT in MOVES is more than

[7] The data portrayed in Figures 3.21 through 3.23 may be partly based on historical material (e.g., for 1999-2005); however, the bulk of the information presented (through 2030) is based on future-year forecasts.

double of that estimated in EMFAC for Los Angeles County. MOVES also estimates nearly 30% higher VMT from LDAs by year 2030. However, MOVES estimates VMT contributed by medium-duty and above trucks as being less than that in EMFAC for both analysis years.

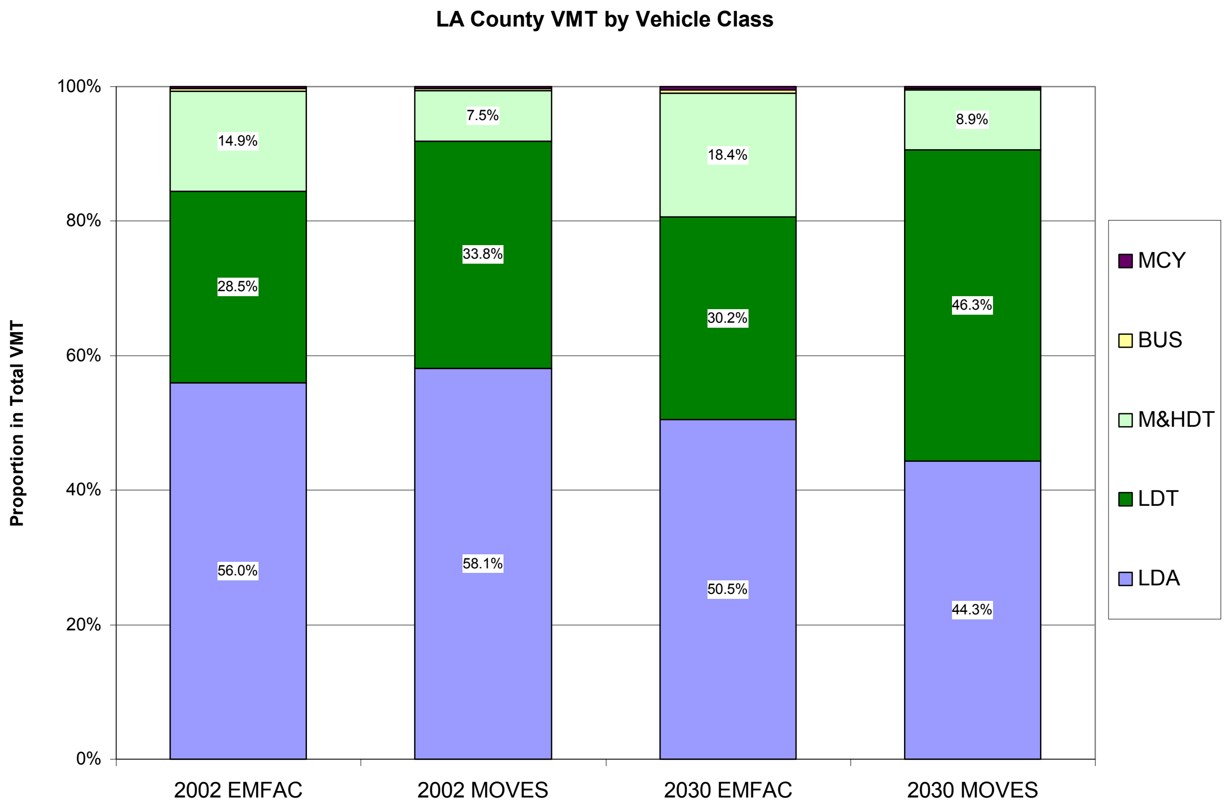


Figure 3.24. LA County VMT proportions in EMFAC and MOVES.

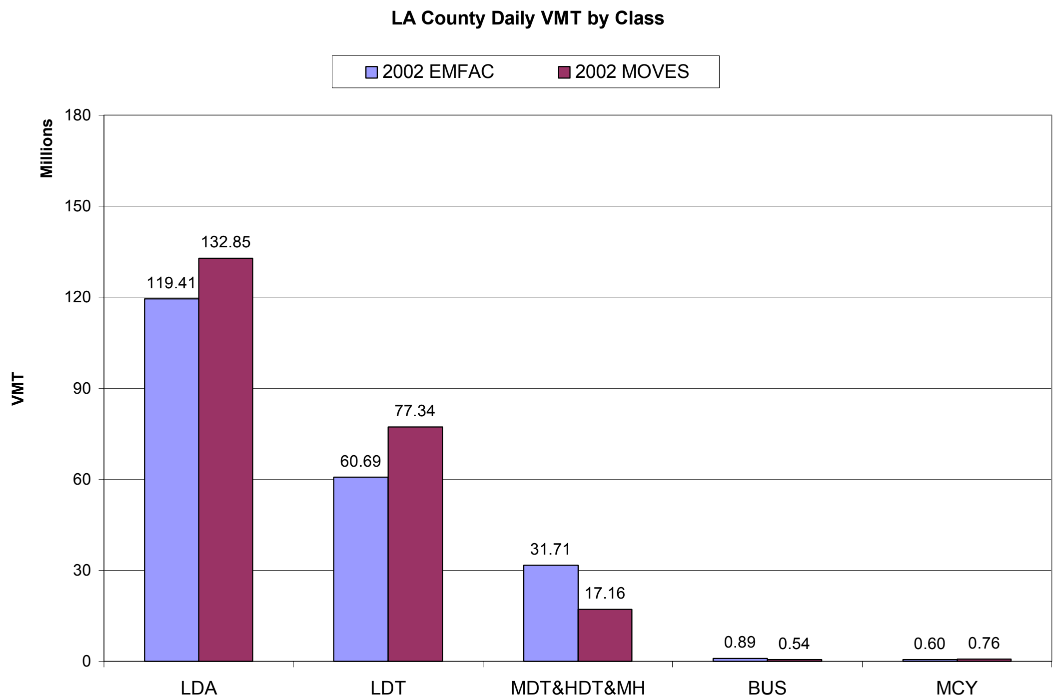


Figure 3.25. LA County 2002 VMT by vehicle class in EMFAC and MOVES.

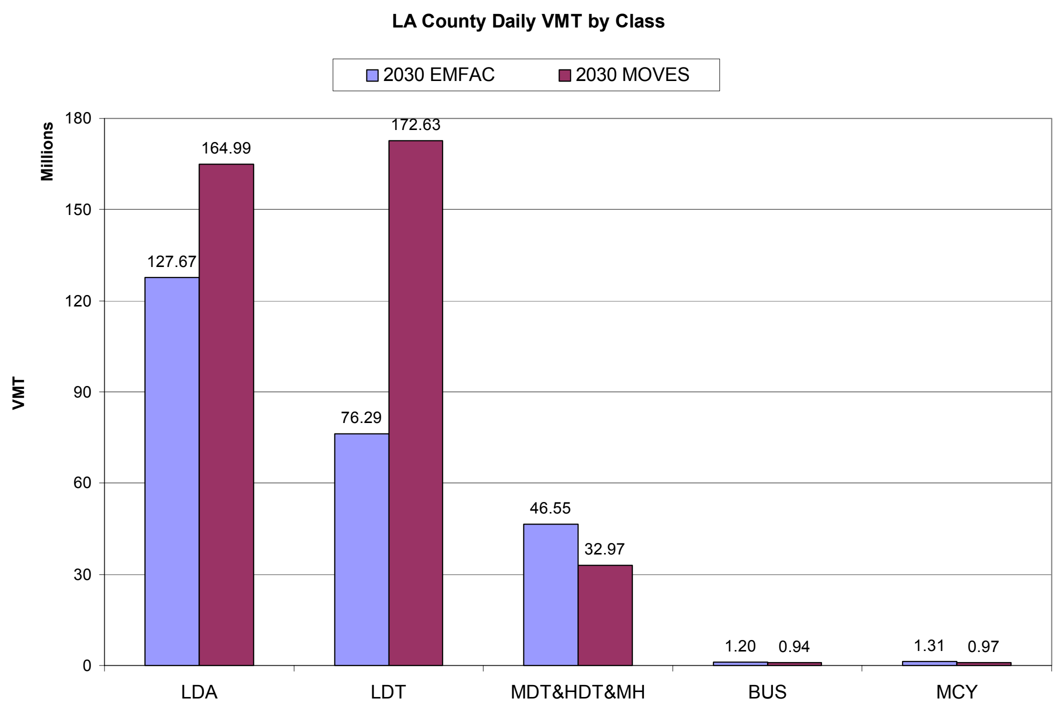


Figure 3.26. LA County 2030 VMT by vehicle class in EMFAC and MOVES.

The VMT by speed distribution patterns in EMFAC and MOVES also appear very different. As can be seen in Figure 3.27, EMFAC suggests that, in Los Angeles County, a larger proportion of VMT occurs within the 20-30 mph and 70 mph speed bins. 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 40 to 60 mph.

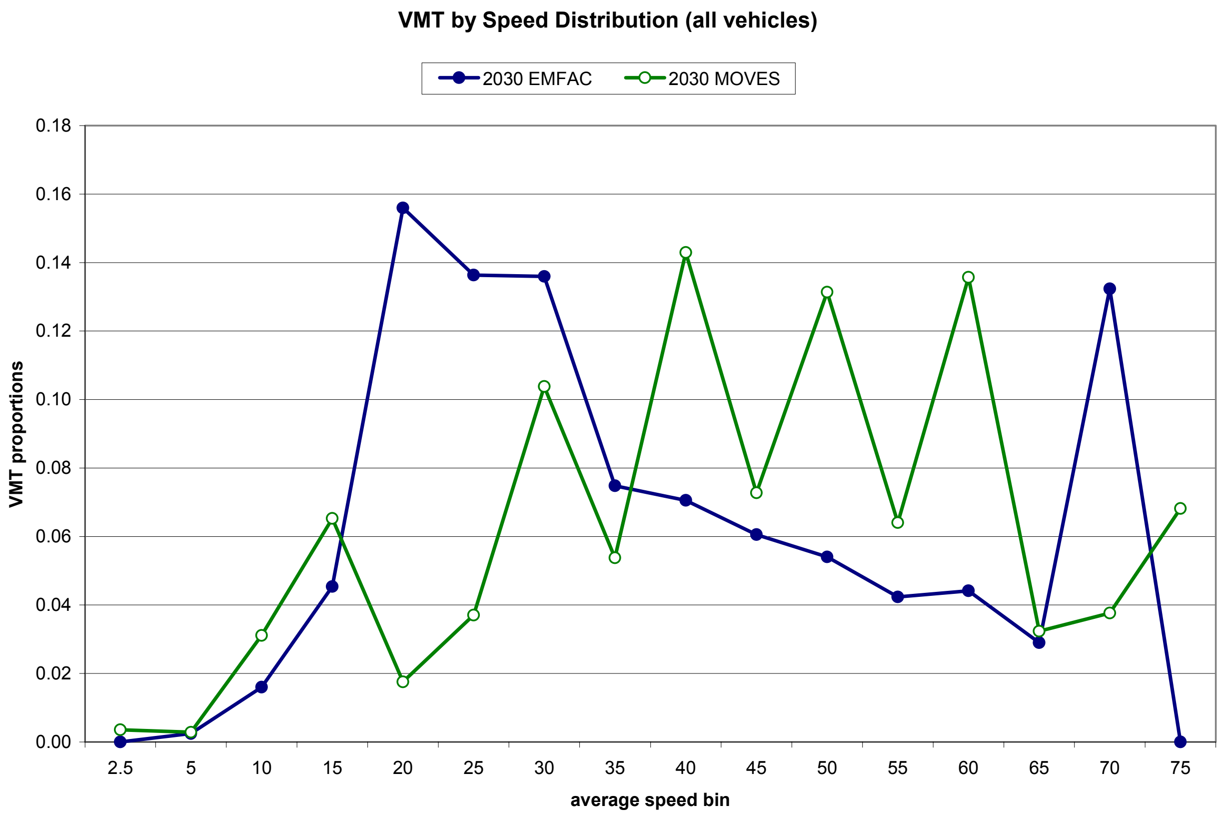


Figure 3.27. LA County VMT by speed, EMFAC vs. MOVES.

Note that both EMFAC and MOVES distribute VMT into speed bins based on link-based information. 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. Using detailed year 2030 LDA data in EMFAC as an example (see Figure 3.28a), we can find that, in Los Angeles County, congested traffic conditions result in more VMT within the 20 to 30 mph speed bins during day time; most nighttime travel (about 56% of VMT) is uncongested high-speed freeway activity. Therefore, EMFAC's VMT by speed distribution pattern reflects Los Angeles County's higher volume of freeway traffic and more congested driving conditions.

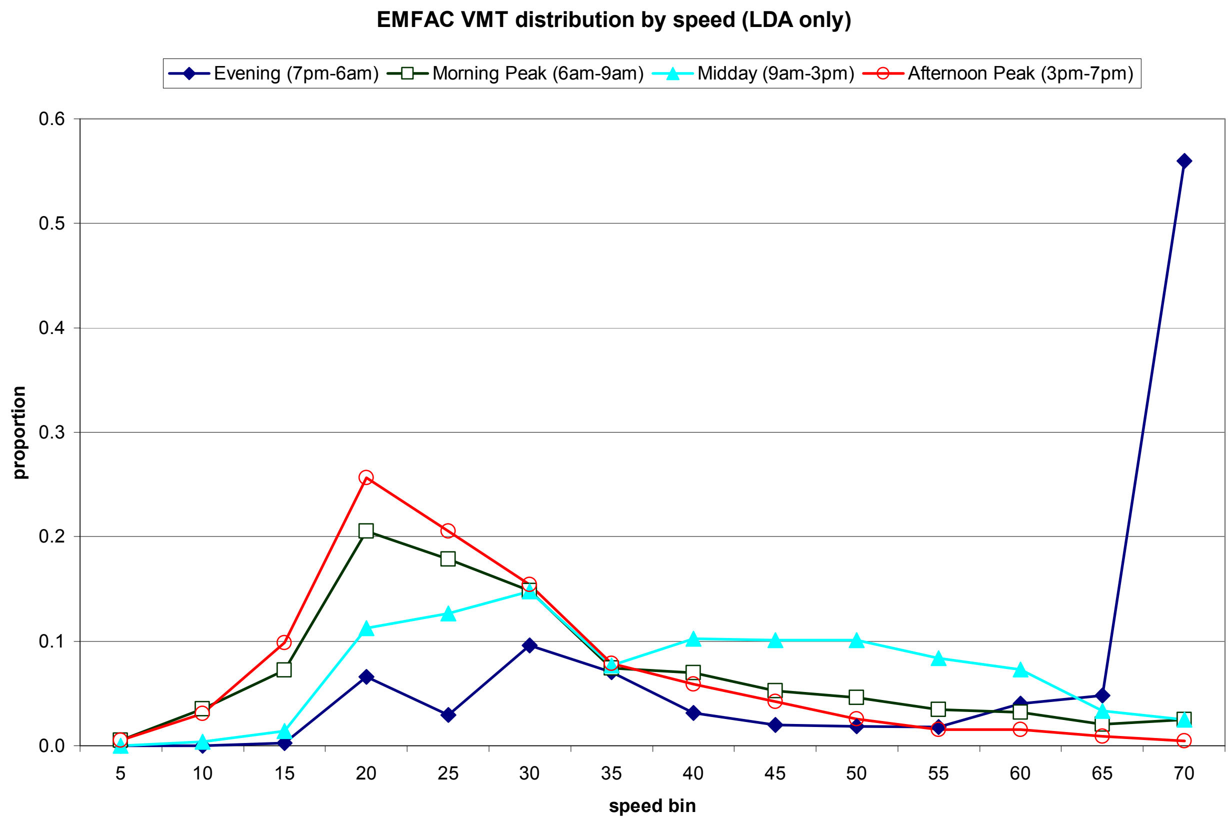


Figure 3.28a. LA County LDA VMT by speed distributions in EMFAC.

In contrast, MOVES disaggregates national data; it does not reflect the unique traffic characteristics of Los Angeles County. The VMT distribution pattern shown in Figure 3.27 is an aggregated result from four roadway types modeled in MOVES: urban freeways, urban arterials, rural freeways and rural arterials. As illustrated in Figure 3.28b, the fluctuations mainly reflect data from the urban freeway and arterial VMT distributions. In MOVES, urban driving values are based on MOBILE6 model defaults (EPA, 2004b). Looking at the MOBILE6 VMT by speed distribution for freeway links and arterial links by each hour of a day[8] (Figures 3.29a and 3.29b), we can observe a similar pattern as that shown in MOVES. The only difference is that there is a

[8] Note: these are specified in the "svmt" file of the MOBILE6 model database.

"bump" in the MOVES curve for the 15-mph bin for urban arterials; this bump represents local road VMT[9].

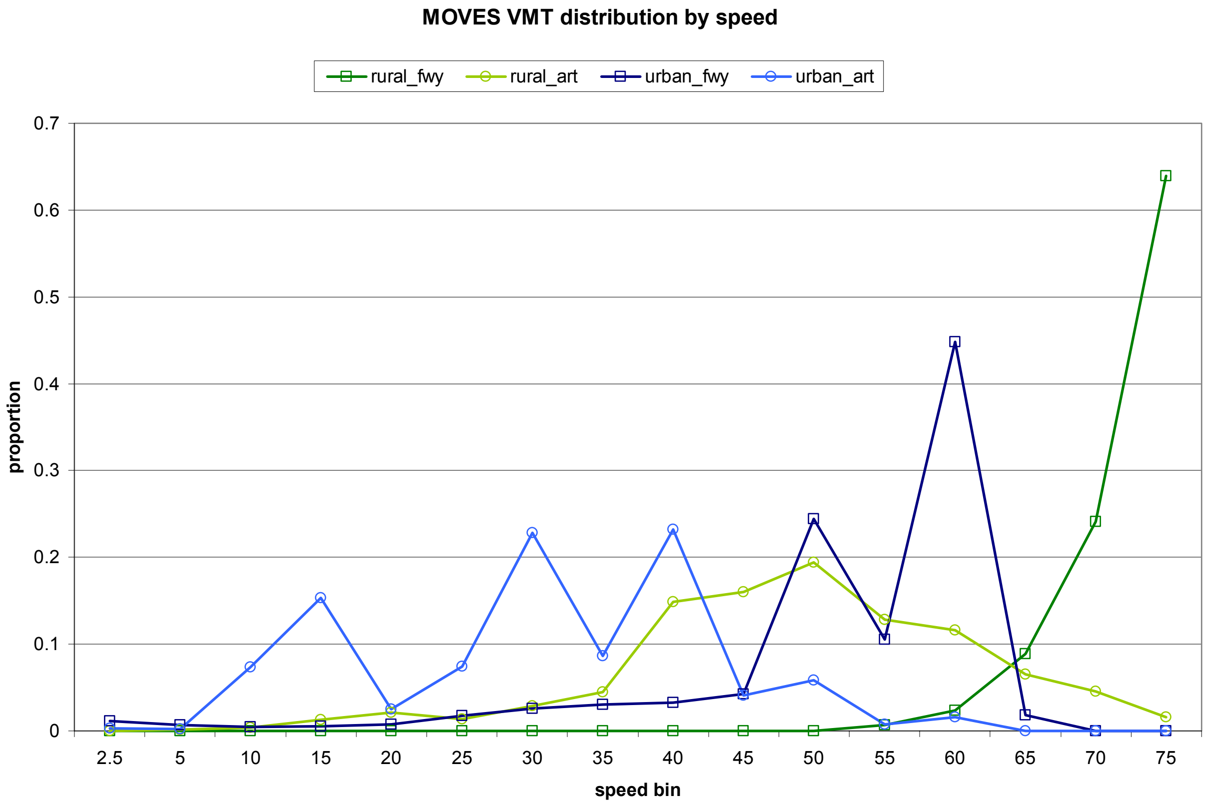


Figure 3.28b. VMT by speed distributions for different roadway types in MOVES.

[9] In MOBILE6, all local roads are assigned a speed of 12.9 mph, and they are classified into the 15-mph speed bin, separate from freeway and arterial/collector activity.

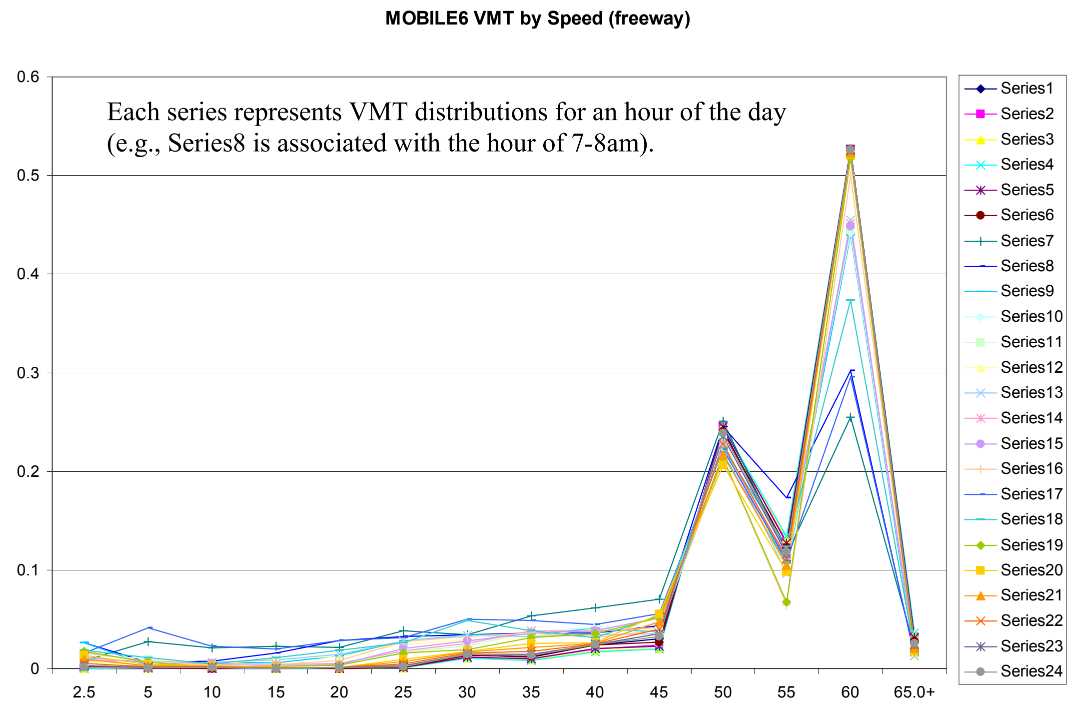


Figure 3.29a. Freeway VMT by speed distributions in MOBILE6.

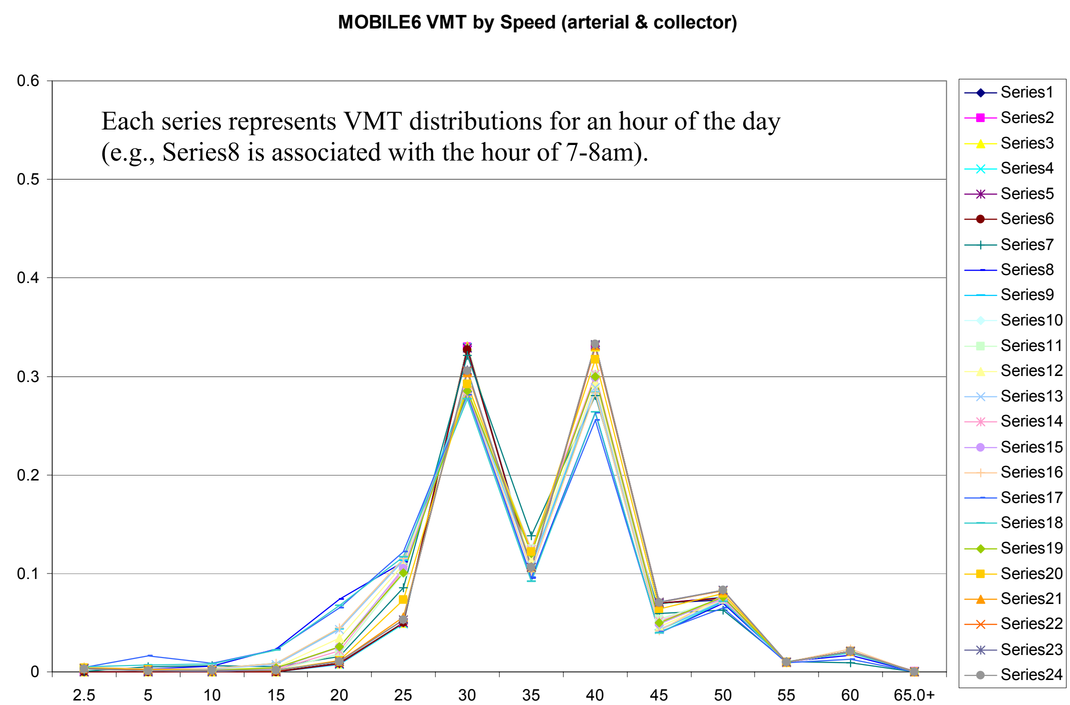


Figure 3.29b. Arterial/Collector VMT by speed distributions in MOBILE6.

Given the importance of the relationship between speeds and emissions, the distribution of VMT by speed bin is an important embedded assumption in both EMFAC and MOVES. As can be seen from this discussion (especially Figure 3.27), there are important differences that exist between EMFAC and MOVES. Although EMFAC incorporates local data, and MOVES incorporates national default assumptions, the VMT-speed distribution disparity between the two modeling tools merits further examination so that a clear understanding of the underlying basis for these differing distributions can be examined. In the recommended research discussion at the end of this study, we suggest continued examination of the VMT-speed distribution issue as MOVES development progresses.

3.5 Comparison of Greenhouse Gas Emission 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, base running emission rates in MOVES are in the unit of grams per hour for a VSP/speed bin. To compare emission factors on the same basis, Los Angeles County emissions and vehicle activity outcomes were post-processed. In the analysis presented below, CO_2 and CH_4 emission factors from both models are specified in grams per mile by speed bin, vehicle class, fuel type and model year.

It should be noted that, in MOVES, CO_2 and CH_4 are handled differently, and therefore the analysis results being presented here should be interpreted differently for these two pollutants. MOVES does not model CO_2 emissions directly; instead, it calculates "atmospheric CO_2"[10] based on the total energy consumed by vehicles. CO_2 estimates in MOVES therefore reflect fuel consumption and they include tailpipe emissions *plus* CO_2 produced secondarily in the atmosphere from gaseous carbon emitted from vehicles in the form of CO and HC. The Energy Consumption Calculator in the MOVES model estimates energy consumption using mean base

[10] In addition to atmospheric CO_2, MOVES can also provide CO_2–equivalent emissions, which are a combined measure of different greenhouse gases according to their global warming potential relative to CO_2. Specifically, MOVES calculates CO_2 equivalents based on three greenhouse gases: CO_2, CH_4, and N_2O, with global warning potentials relative to CO_2 of 1, 21, and 320, respectively (EPA, 2005c).

rates (by vehicle class, fuel type, model year and operating mode) with a range of adjustments (e.g., temperature, fuel, and air conditioning) and vehicle activities (source hours operating). After energy consumption estimates are developed, CO_2 emissions are derived based on the following equation:

Atmospheric CO_2 = total energy × oxidation fraction × carbon content × 44/12

where:

Total energy = total energy consumption by vehicles (in unit of Kilojoules)

Oxidation fraction = percent of carbon that winds up as CO_2 in the atmosphere

Carbon content = grams carbon per Kilojoules of energy consumption

and:

44 and 12 are molecular weights of carbon dioxide and carbon, respectively; therefore 44/12 is a ratio used to convert carbon mass to CO_2 mass.

Because the energy consumption rates in MOVES are VSP/speed bin-based, CO_2 estimates serve as a surrogate for how MOVES will later handle other pollutants (criteria pollutants, toxics). In contrast, CH_4 emissions numbers generated by MOVES-HVI Demo are still a function of the "old style" of generating emission rates from FTP bag data (as is done with EMFAC and MOBILE), rather than from VSP information. Thus, an assessment of the CH_4 estimates produced by MOVES, in comparison to comparable estimates produced by EMFAC, helps isolate the impact of how MOVES incorporates and handles activity data, including vehicle distributions. Technical details regarding CH_4 emission factors can be found in EPA documentation (EPA, 2004d).

3.5.1 CO_2 running emission factors

Average CO_2 emission factors for gasoline- and diesel-powered vehicles are presented in Figures 3.30 to 3.33. The comparison of CO_2 emission factors suggests small variations between EMFAC and MOVES in most cases. Specifically, MOVES has similar CO_2 emission factors as those produced by EMFAC for the majority of the vehicle fleet – the 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.

However, there are important differences in CO_2 emission factors for subsets of the vehicle fleet – diesel LDT and gasoline-powered M&HDT. The main observations include:

- MOVES tends to estimate 60-75% higher CO_2 emissions per vehicle mile driven by diesel LDT in 2002 and 2030 (note that EMFAC assumes no diesel powered light duty autos by 2030, resulting in zero total emissions from this vehicle category). (See Figure 3.33 for a comparison of emission rates.)
- MOVES tends to estimate 30-50% more CO_2 per vehicle mile driven by gasoline M&HDT in 2002 and 2030. (See Figure 3.31.)
- Relative to year 2002, MOVES effectively forecasts increased CO_2 emission factors in year 2030 for diesel LDA (about 50%) and LDT (about 7%), as well as gasoline MDT and HDT (about 17%). (See contrasting data in Figures 3.32 and 3.33 for diesel-powered light-duty vehicles, and Figures 3.30 and 3.31 for gasoline-powered trucks.)

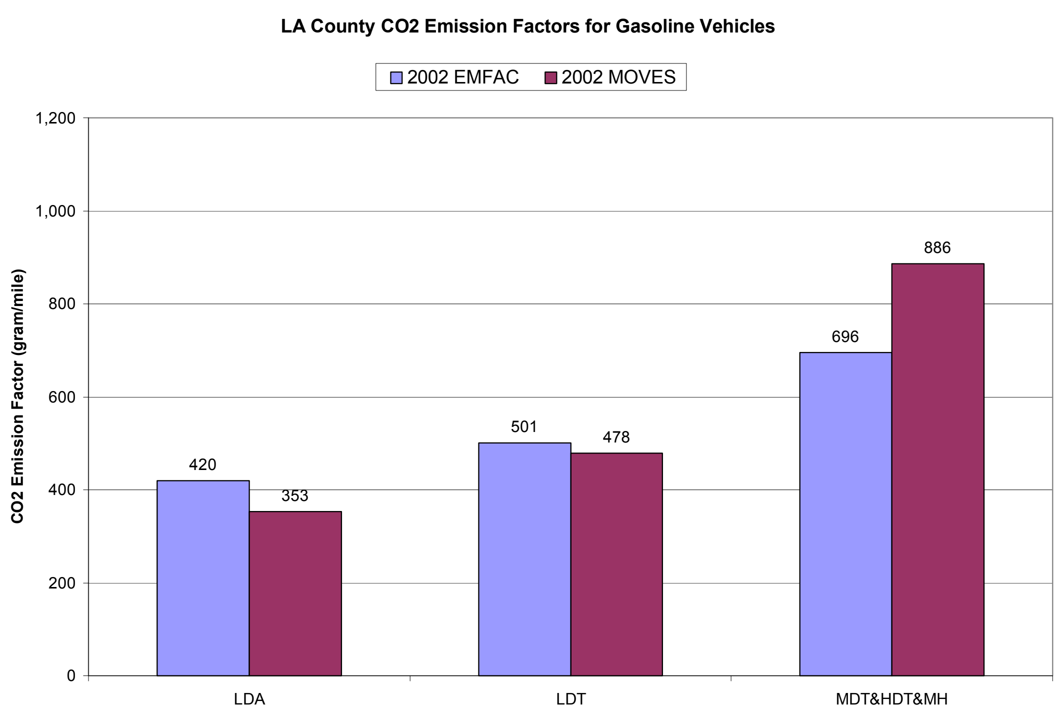


Figure 3.30. LA County 2002 CO_2 emission factors for gasoline vehicles.

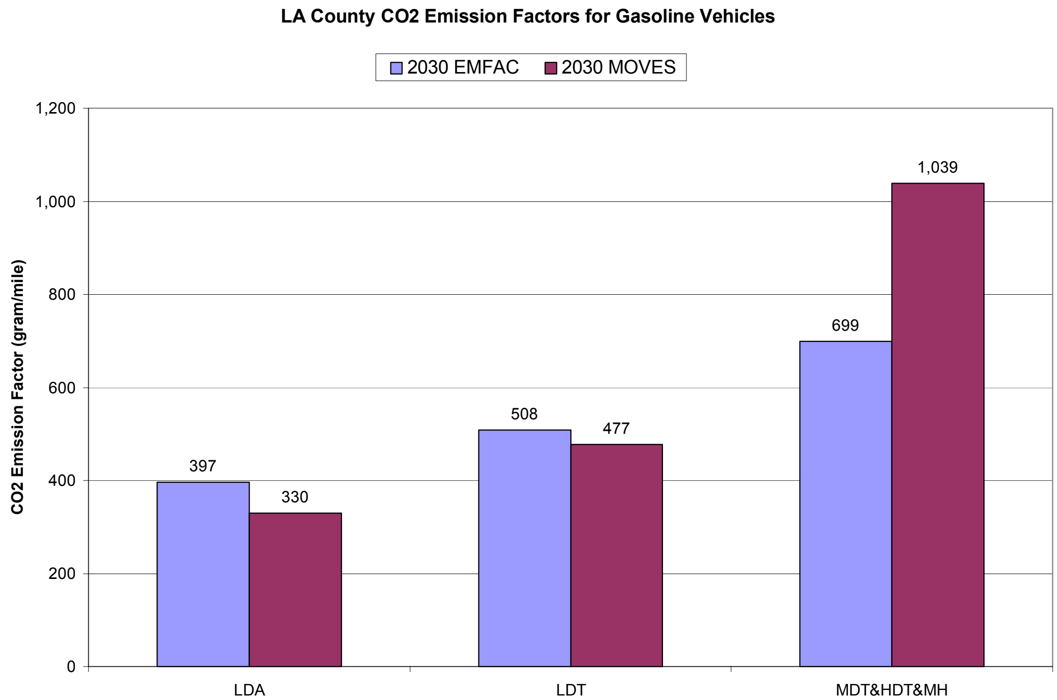


Figure 3.31. LA County 2030 CO_2 emission factors for gasoline vehicles.

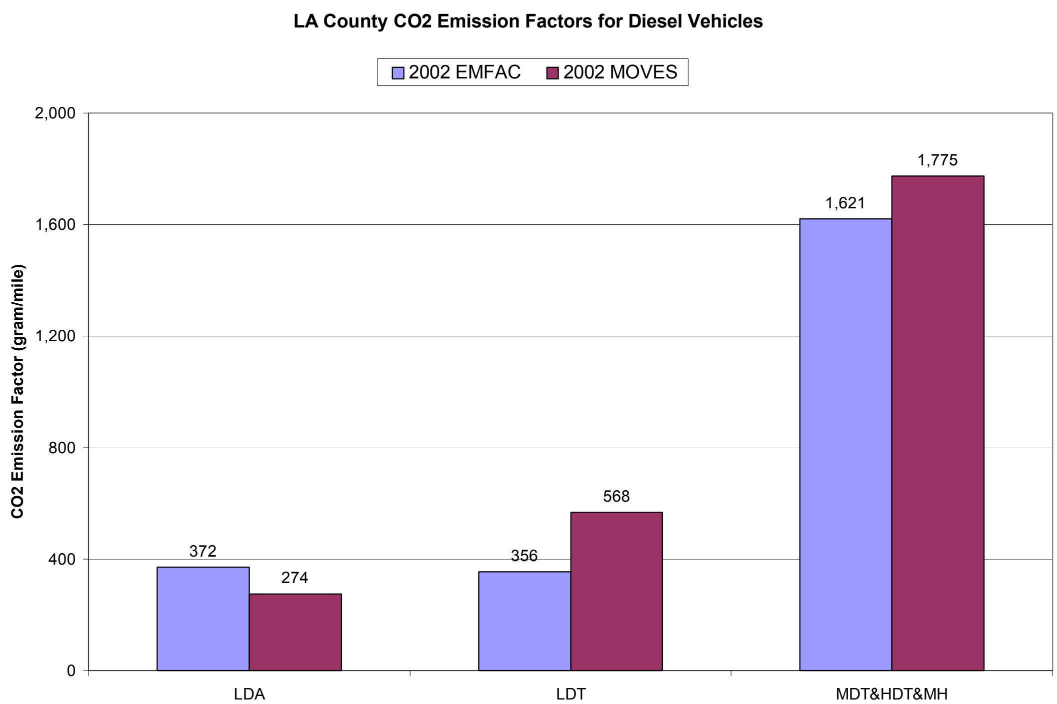
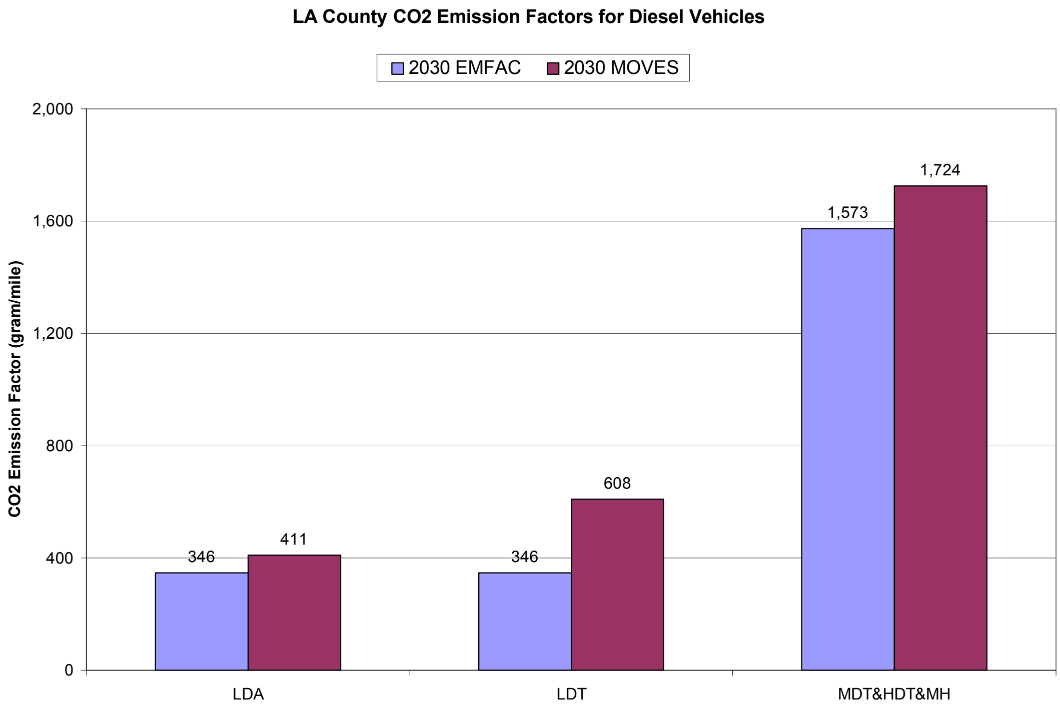


Figure 3.32. LA County 2002 CO_2 emission factors for diesel vehicles.



Note: EMFAC diesel-powered LDV CO_2 emission rates are uniform across all speeds for 2030. EMFAC varies medium and heavy-duty diesel vehicle emission rates by speed; the data presented here represent fleet averages. MOVES classifies passenger trucks and light commercial trucks by axle and wheel counts, rather than weight. In this comparison, these two categories are included in LDT and may include some diesel trucks that are classified as medium duty and above trucks in EMFAC. Therefore it partially explains the observation of higher average emission factors for diesel LDT in MOVES. Further investigation is needed to quantify the emission factors from each type of diesel vehicle.

Figure 3.33. LA County 2030 CO_2 emission factors for diesel vehicles.

3.5.2 CH_4 running emission factors

In MOVES, the base CH_4 emission rates are derived using the Federal Test Procedure (FTP) bag emissions data, instead of the VSP-bin modal emissions result. Thus, the CH_4 emission rates are analogous to those already included in the EMFAC and MOBILE6.2 models, rather than the VSP-based rates that MOVES will ultimately generate once the model is finished. Figures 3.34 to 3.37 illustrate Los Angeles County average CH_4 emission factors for gasoline and diesel vehicles. The comparison suggests that MOVES has much lower CH_4 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). As discussed earlier (see section 2.4), EPA's validation report for CH_4 emissions estimated in MOVES has stated that CH_4 emissions provided by MOVES were much lower than previous estimations of either the IPCC or the US EPA 1990-2001 Inventory of U.S. Greenhouse Gas Emissions and Sinks. It was believed that the new emission rates used in the MOVES model better represented the current vehicle fleet and technologies (EPA, 2004d; EPA, 2005b). For year 2030, MOVES projected slightly lower CH_4 emission factors than EMFAC for gasoline vehicles. EMFAC forecasts significant improvement in future CH_4 emissions and assumes no CH_4 emissions from diesel LDA and LDT by 2030. On the contrary, MOVES assumes improvements in future CH_4 emissions only for gasoline vehicles; for diesel powered vehicles, MOVES suggests no reduction of CH_4 emission factors from year 2002 to year 2030.

It should be noted that, to construct a consistent comparison between MOVES and EMFAC, this study presents findings and figures that focus on gasoline and diesel vehicles, since the EMFAC model does not include emissions information for advance-technology vehicles such as those fueled by compressed natural gas – CNG. One of the significant advantages of MOVES is that it provides emissions information for a range of advance-technology vehicles such as those fueled by CNG, liquid propane gas (LPG) and ethanol. In particular, in MOVES, the base CH_4 emission rates for CNG vehicles are much higher than other vehicle types. For Los Angeles County, MOVES estimates that alternative fueled vehicles contribute 1.2% and 8.4% to the total 2002 and 2030 CH_4 emissions, respectively, indicating an increased share of alternative fueled vehicles in the future fleet. More detailed discussions regarding the CH_4 emission rates of CNG vehicles in MOVES can be found in Sonntag and Gao (2007).

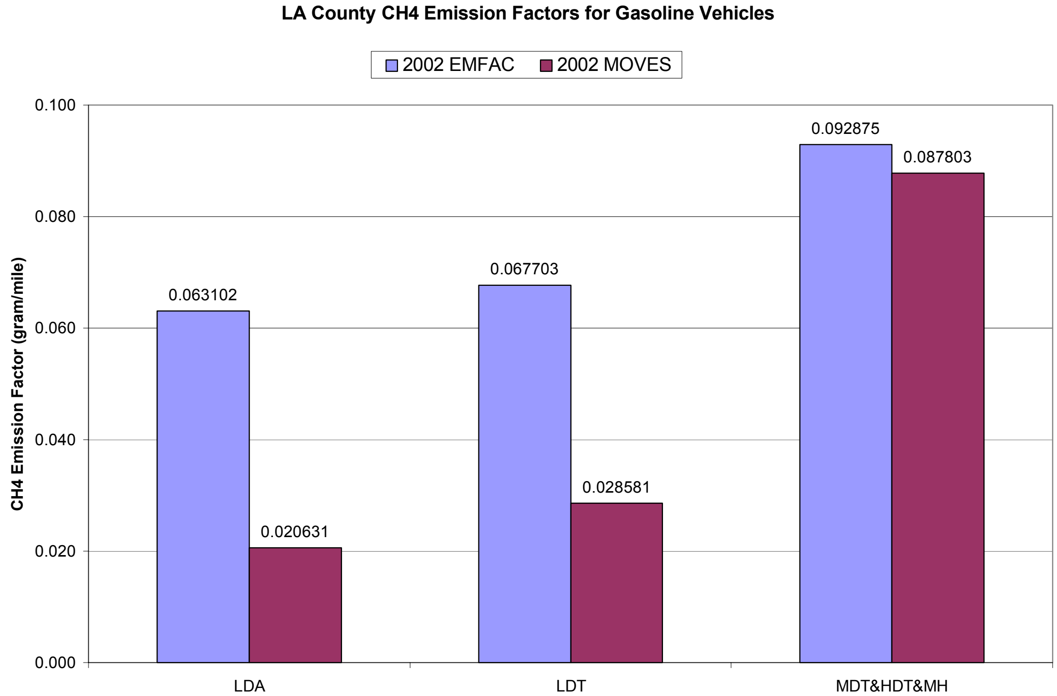


Figure 3.34. LA County 2002 CH_4 emission factors for gasoline vehicles.

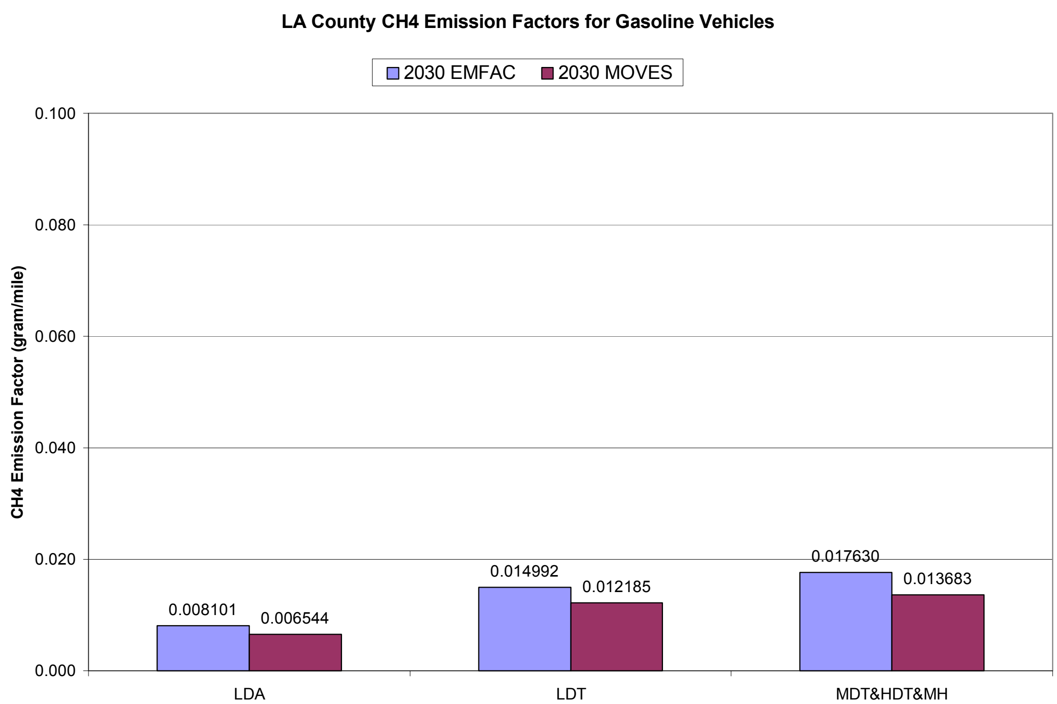


Figure 3.35. LA County 2030 CH_4 emission factors for gasoline vehicles.

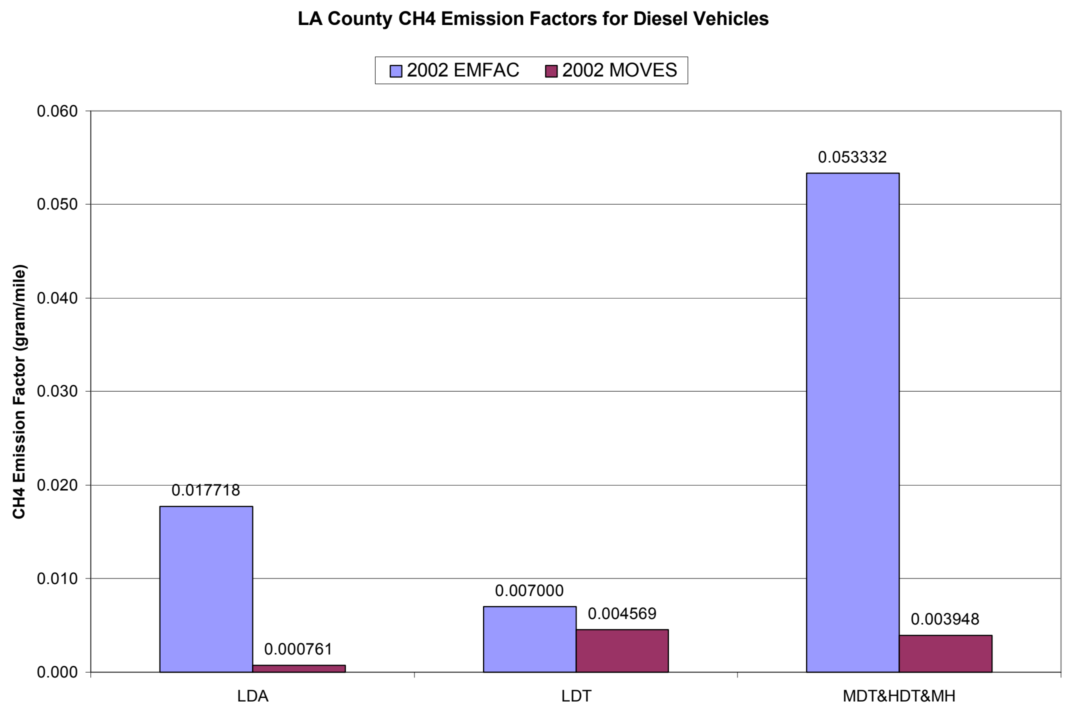
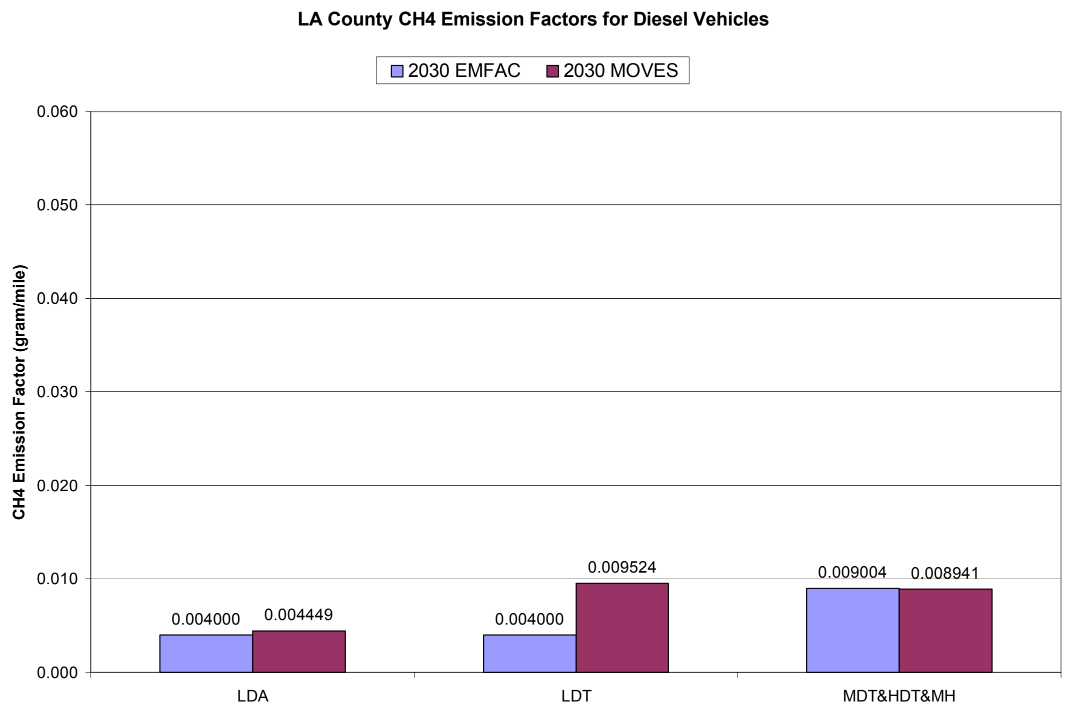


Figure 3.36. LA County 2002 CH_4 emission factors for diesel vehicles.



Note: EMFAC diesel-powered LDV CH_4 emission rates vary by speed, ranging from 0.002 to 0.009 g/mile; the data presented here represent fleet averages.

Figure 3.37. LA County 2030 CH_4 emission factors for diesel vehicles.

3.5.3 Running emission factors as a function of vehicle age

MOVES and EMFAC show different emission factors as a function of vehicle age, implying different assumptions regarding the effects of vehicle deterioration. As shown in Figures 3.38 and 3.39 for LDAs in the year 2002 fleet, MOVES has relatively higher deterioration rates than EMFAC in terms of CO_2 from vehicles older than 20 years. For CH_4, the reverse pattern is observed – vehicles in MOVES tend to have slower deterioration than those in EMFAC.

Figures 3.40 (for CO_2) and 3.41 (for CH_4) for the 2030 fleet indicate that emission factors in MOVES are flat against vehicle age. The current MOVES-HVI Demo model does not take deterioration or vehicle aging into account regarding energy consumption for model year 2001 and later vehicles (EPA, 2005b)[11]. For each vehicle class in the year 2030, MOVES assumes a constant (no deterioration) emission rate for CH_4 and for all model years between 2001 and 2050 (EPA, 2005c).

[11] Personal communication with EPA staff indicates that, in MOVES, emissions changes against vehicle age reflect the combination of a range factors, such as vehicle deterioration, technology improvement and trends in vehicle weights. Although MOVES-HVI Demo considers no deterioration when estimating energy use, CO_2 and CH_4, it reflects effect of vehicle technology changes (e.g., changing emission and fuel consumption standards) on emissions. Further investigation is needed to identify their specific impact on vehicle emissions trends.

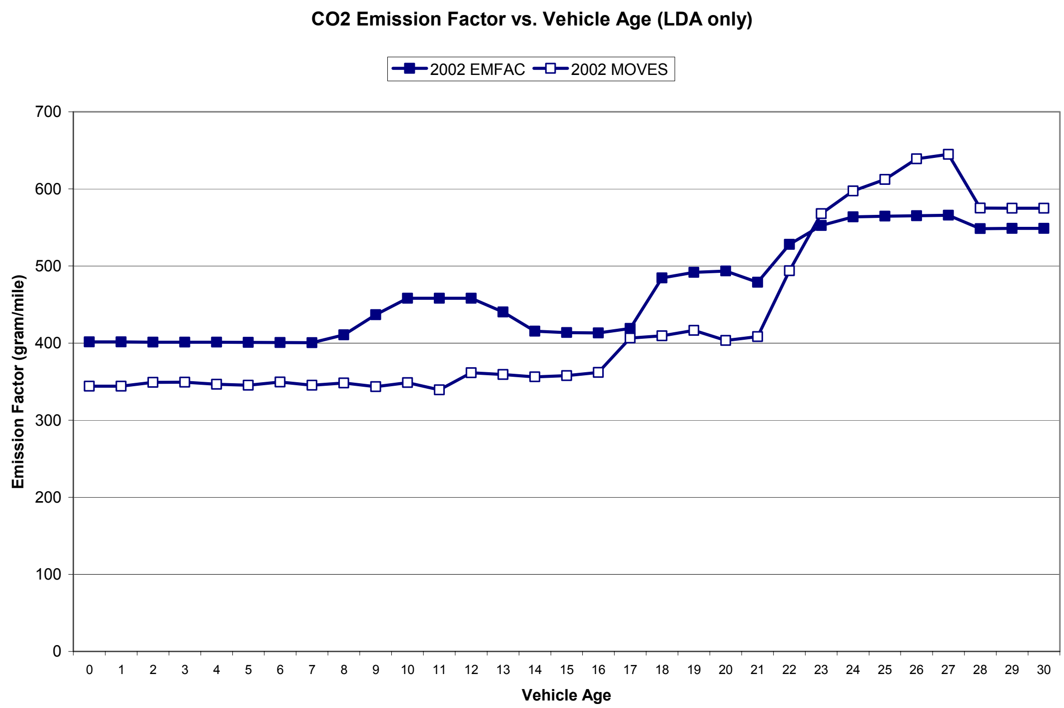


Figure 3.38. LA County 2002 LDA fleet average CO_2 emission factors by vehicle age.

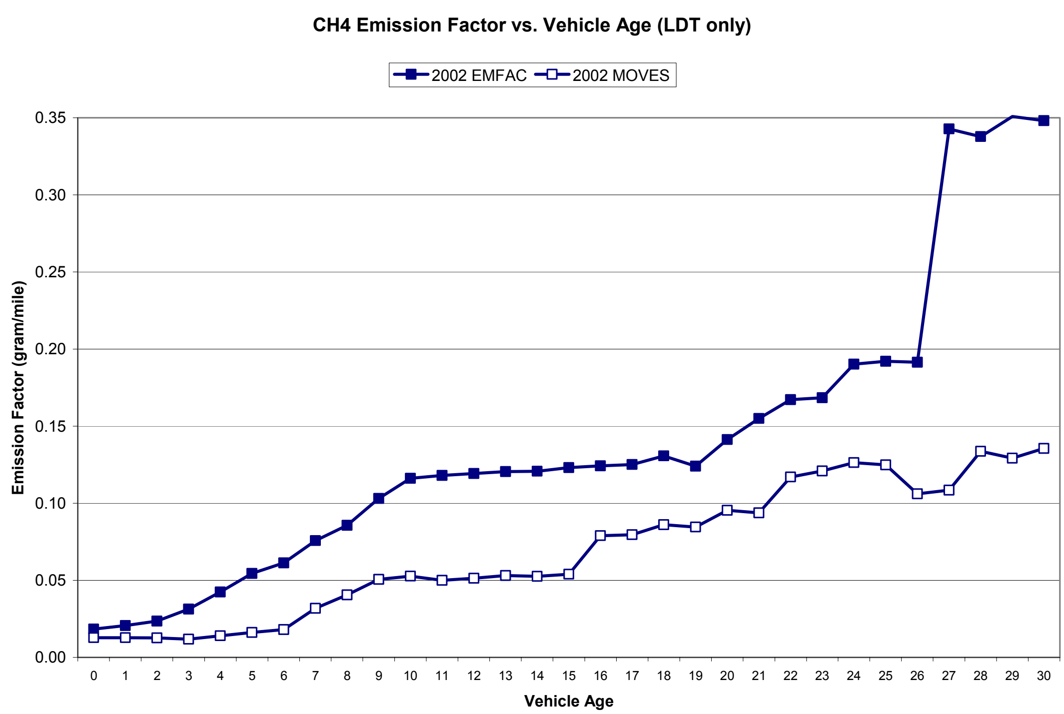


Figure 3.39. LA County 2002 LDA fleet average CH_4 emission factors by vehicle age.

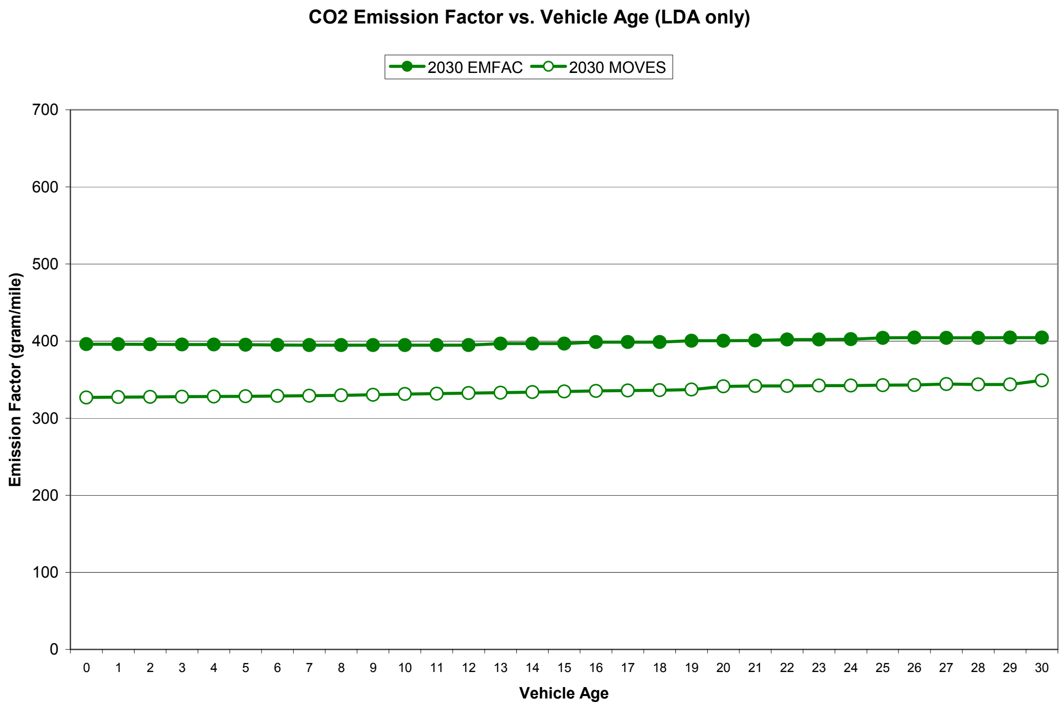


Figure 3.40. LA County 2030 LDA fleet average CO_2 emission factors by vehicle age.

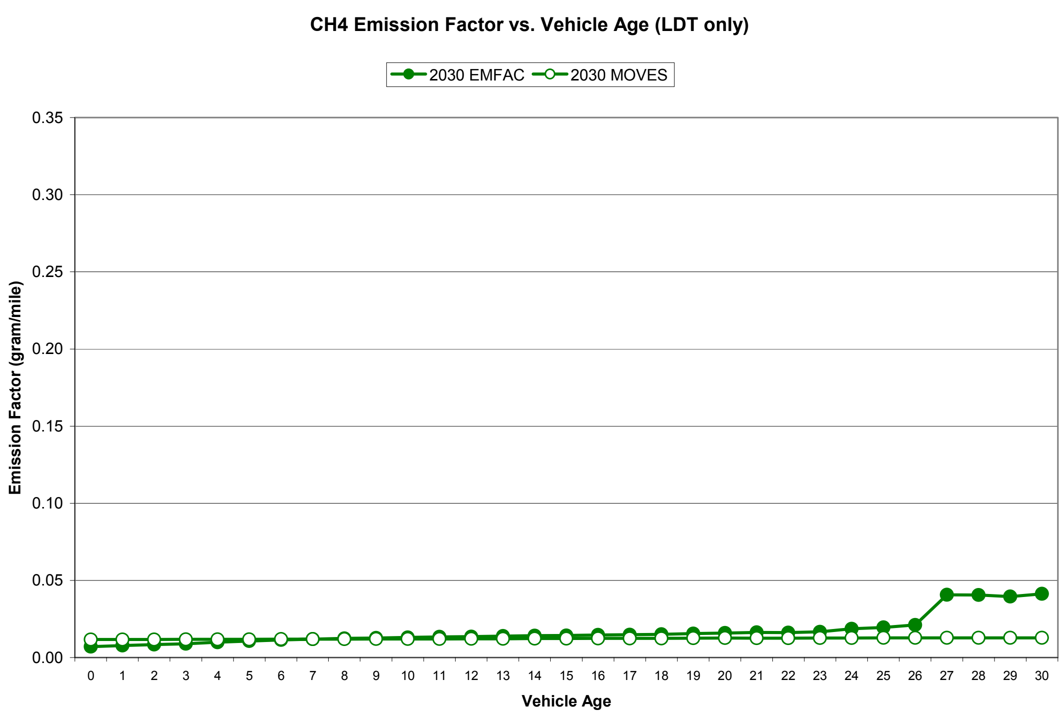


Figure 3.41. LA County 2030 LDA fleet average CH_4 emission factors by vehicle age.

3.5.4 Running emission factors as a function of speed bin

In EMFAC, emission factors vary by vehicle speed due to the application of speed correction factors (SCFs). Within MOVES there is no comparable speed-to-emissions adjustment factor. Instead, MOVES calculates emissions with respect to vehicle operating modes. In this analysis, average emission factors were compared to speed bins by post-processing MOVES emissions and activities data (i.e., total emissions divided by total VMT for each vehicle class and speed bin). Using LDAs in the 2030 vehicle fleet as an example, Figures 3.42 and 3.43 show that MOVES and EMFAC produce very close CO_2 and CH_4 emission factors associated with speeds ranging between 25 and 45 mph. Emission factors in MOVES are higher than those produced by EMFAC for lower speeds (5 mph and lower). However, for higher speeds (50 mph and higher), EMFAC emission factors are higher than those produced using MOVES data.[12]

Note that, in general, both CO_2 and CH_4 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. For example, assume a project that improves traffic flow and increases link-level speeds from 50 to 55 mph – MOVES and EMFAC may estimate absolute CO_2 and CH_4 emissions that are relatively similar in the project build and no-build scenarios. However, MOVES would show that building the project reduces emissions, while EMFAC would indicate that the project increases emissions. Although the absolute value of the estimates may be very close (and their differences may, in fact, be statistically insignificant), the results would be directionally opposite. In a project context where outcomes are assessed as being either negative or positive, the choice of which model to use to complete the analysis could have very different consequences for project approvals. In summary, based solely on the GHG analysis presented here and the macroscale

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[12] Personal communication with federal agency staff and other researchers indicates that EPA model development staff are aware of some limitations regarding the MOVES-HVI Demo interpretation of high-speed activity. For example, a potential explanation for the observed discrepancy between EMFAC and MOVES emission factors at higher speeds may be related to the size of the VSP bins associated with higher speeds; future model versions may disaggregate the high-VSP data into more VSP bins, with the result that future versions of MOVES may produce high-speed emissions more in line with the findings from EMFAC2007 (e.g., Gao, 2008).

version of MOVES currently available, MOVES will tend to favor speed improvements in terms of reducing emissions; emissions benefits estimated in EMFAC, however, will depend on how vehicle activities may change between different speed bins – speed improvements may not necessarily result in emissions reductions for certain transportation projects. It will be important to revisit this analysis once MOVES is finished and a microscale version of the model becomes available. Conceptually, MOVES should provide technically superior emission estimates for project-level analysis, since EMFAC is most appropriately applied at the regional scale. For the transportation planning community therefore, it will be important to examine whether the speed-emissions relationships discussed here continue to apply when modeling GHG, criteria pollutant, and air toxics emissions with future versions of MOVES that include a microscale function.

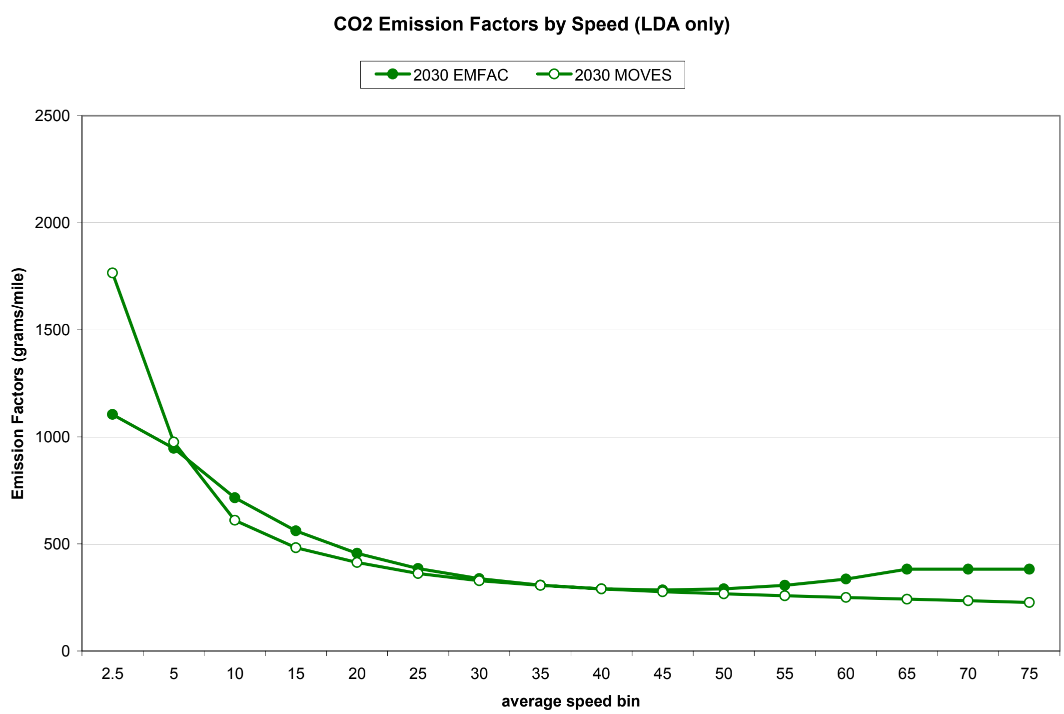

Figure 3.42. LA County average LDA CO_2 emission factors against speed bins.

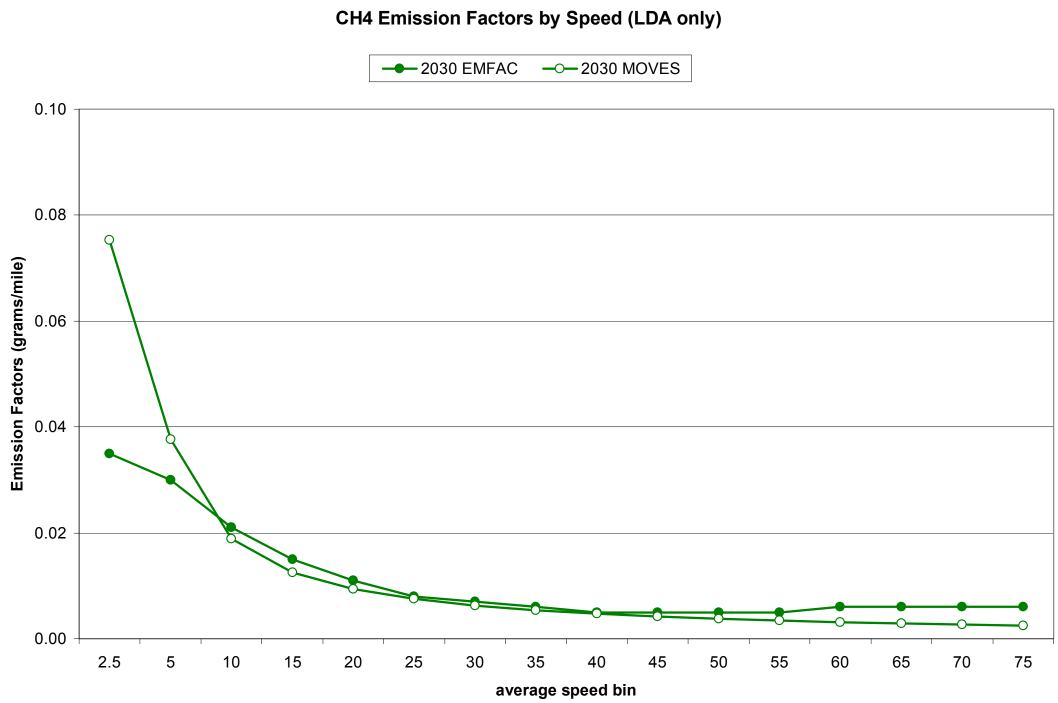

Figure 3.43. LA County average LDA CH_4 emission factors against speed bins.

3.5.5 Start emission factors

Average start emission factors for CO_2 and CH_4 were calculated based on Los Angeles County total daily vehicle starts (or trip starts) and start exhaust emissions[13]. As shown in Figures 3.44 and 3.45, in both year 2002 and 2030, average CO_2 start emission factors in MOVES are around three times larger than those estimated by EMFAC[14]. For CH_4, MOVES does not show much improvement in per start emission factors from year 2002 to year 2030 due to several reasons: 1) MOVES uses flat 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,

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[13] Total vehicle starts were calculated based on the MOVES database table "startsbyagehour"; start exhaust emissions were summarized from the MOVES emission output table; average start emission factor (grams per start) is equal to total start exhaust emissions divided total vehicle starts for Los Angeles County.

[14] Based on communication with EPA staff, calculations of start emissions for energy use and CO_2 emissions are being adjusted in the development of future versions of MOVES to account for soak time, which is expected to reduce start emissions; further investigation is needed to quantify its impact on average CO_2 start emission factors.

EMFAC assumes a significant reduction in per start emission rates over time (see Figure 3.46); by year 2030, average CH_4 emissions per vehicle start are only 10% of those estimated for year 2002. Note that, for CO_2, emissions are a function of energy consumption.

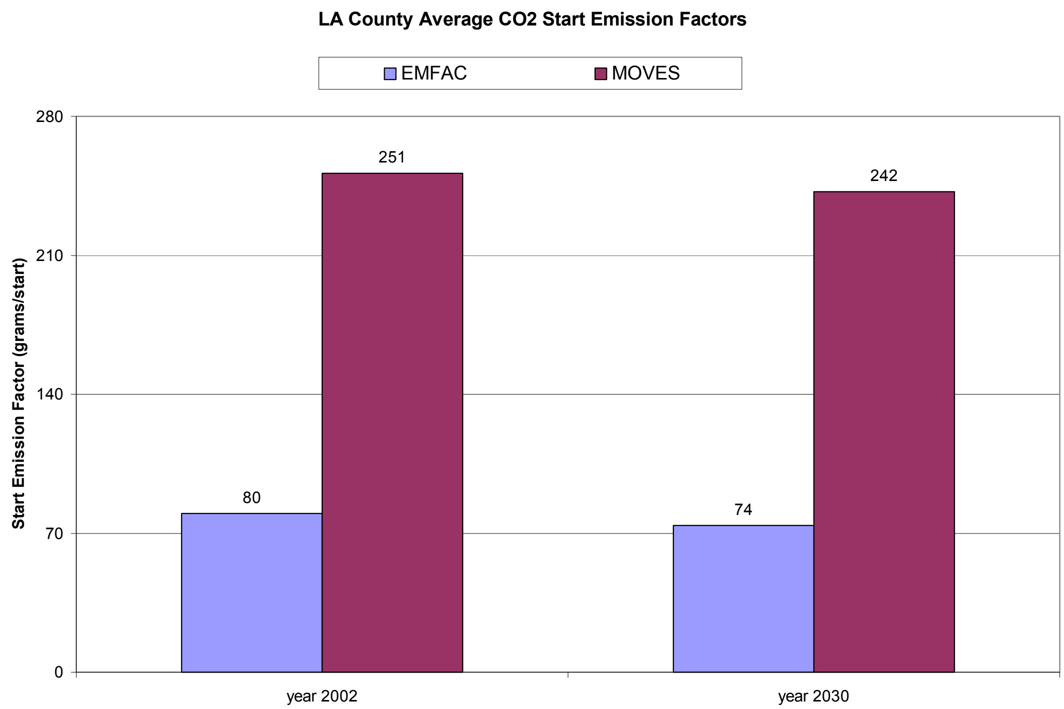

Figure 3.44. LA County average CO_2 start emission factors.

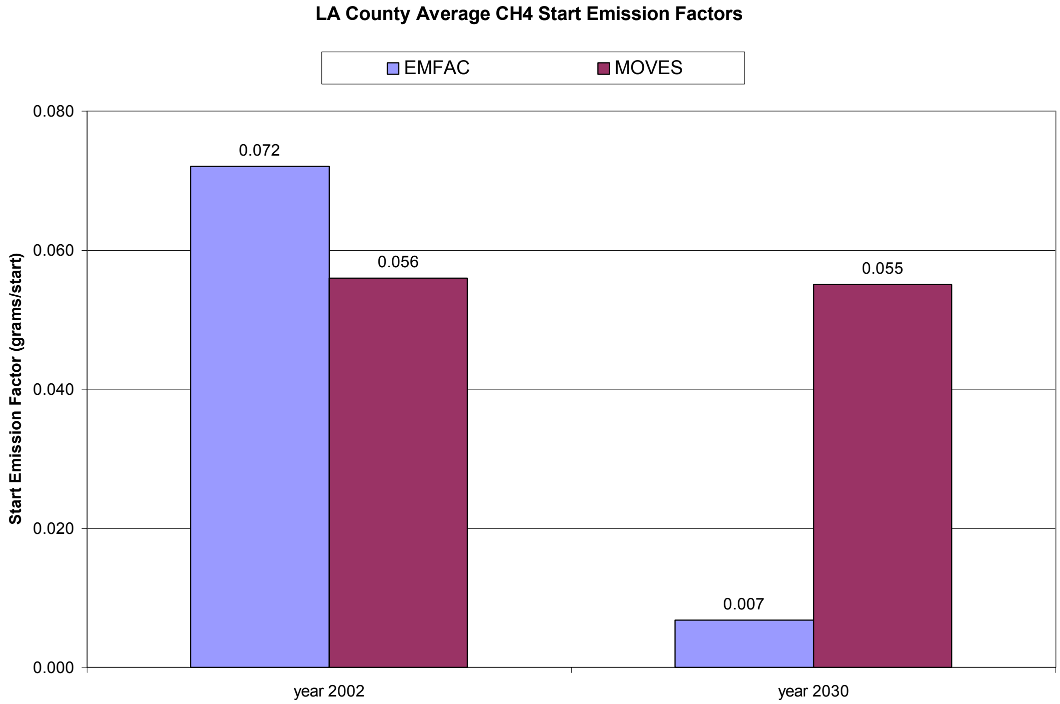

Figure 3.45. LA County average CH_4 start emission factors.

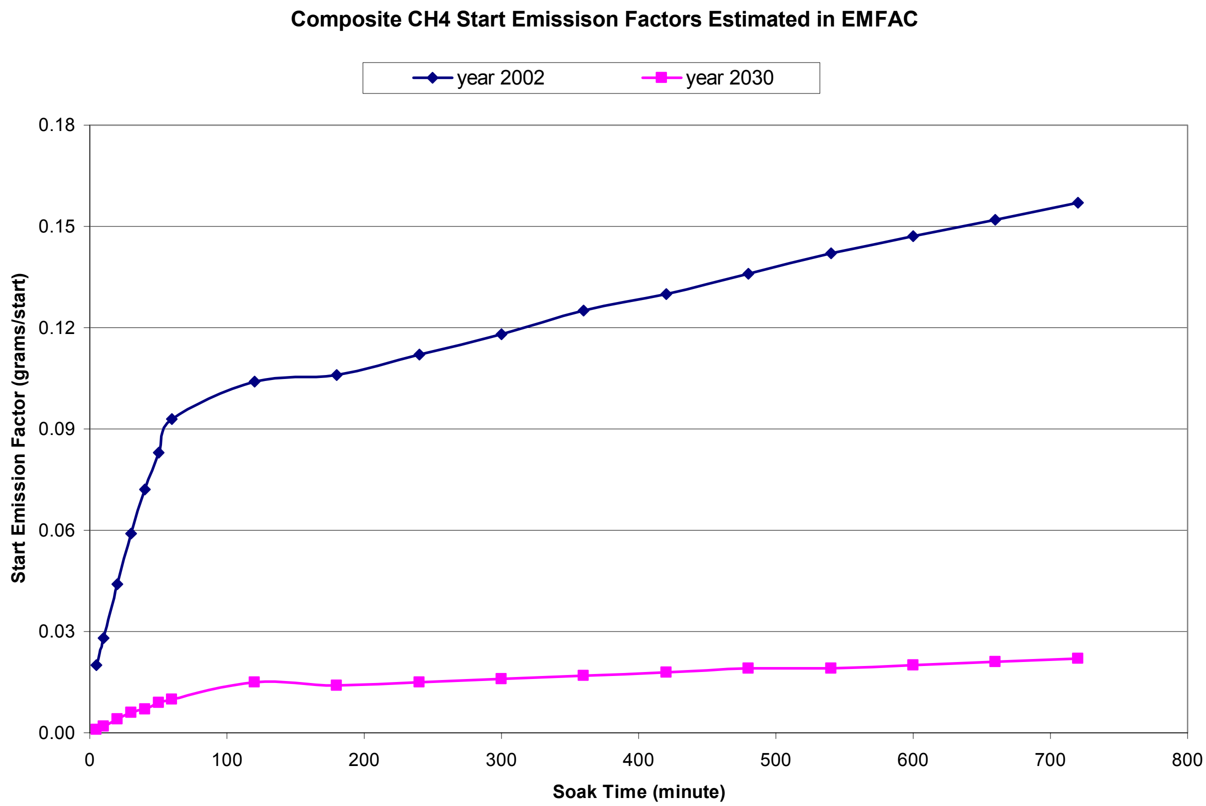

Figure 3.46. LA County composite CH_4 start emission factors in EMFAC.

3.6 Summary of Comparison Results: Activities and Emissions

MOVES and EMFAC use different modeling approaches in terms of specifying vehicle activities and measuring emission factors. The macroscale module in MOVES generates a "top-down" county-level *activity* inventory. MOVES employs national average default data to represent activity patterns, and then generates county-level activity data by applying spatial allocation factors to the national defaults. In contrast, MOVES creates "bottom-up" running exhaust *emission factors and energy consumption rates* based on VSP and instantaneous speed for a road type. EMFAC's emission factors 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 such as vehicle starts and stops.

Using Los Angeles County as a case study, we found that, for the 2002 base year, MOVES generated similar CO_2 emissions outcomes as EMFAC, and significantly lower CH_4 emissions. However, for year 2030, MOVES estimated higher CO_2 and CH_4 emissions than did EMFAC.

Comparing MOVES and EMFAC, the important factors leading to the observed emissions results include forecasted vehicle population and VMT, vehicle fleet composition, and base emission rates.

- Modeled CO_2 emissions differences appear to be a function of VMT estimation. Specifically, 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 emission factors for the base year vehicle fleet. However, MOVES assumes higher CH_4 start emission factors for the year 2030 vehicle fleet. Paired with MOVES's faster-growing future vehicle population, these start emission factors result in significantly higher CH_4 emissions from both LDAs and LDTs.

This analysis involved post-processing MOVES data to develop an effective gram per mile emission rate that could be compared to similar rates derived from EMFAC. Many factors likely contributed to observed differences between the output generated by the two models. The bullet points above highlight those issues that appear to contribute substantially to the differences observed in this study. However, other possible factors include:

- <u>The way in which MOVES distributes activity data into VSP/speed bins</u>. For example, suppose that MOVES accurately characterizes gram per hour emissions for a given vehicle category and VSP/speed bin – it may still produce inaccurate overall emission estimates if it does not apportion hourly vehicle use into VSP/speed bins in a way that appropriately matches a particular geographic area or a specific road type. As part of this study we did not investigate the basis for how MOVES apportions activity into VSP/speed bins; however, given that the apportionment is based on national defaults, further investigation is needed to examine those defaults and to understand whether those defaults need to be (or can be) adjusted to represent individual metropolitan areas[15].

- The gram per hour emission factors generated using the VSP-based method. For example, EPA has acknowledged that the underlying emission data for trucks is relatively sparse[16] as of this writing – that means that MOVES may inaccurately generate gram per hour emission rates for a particular vehicle class.
- EMFAC emission factors and/or embedded activity data. Independent of the emissions estimation methodology employed by MOVES, there could be problems inherent in the emission rates and/or activity information embedded in EMFAC.

Further comparisons between EMFAC and MOVES will be possible once a version of MOVES becomes available that allows for easier substitution of national default activity data with local data. Such comparisons will better assist in understanding how much of the differences between the two models originate from differing activity assumptions compared with differing emissions assumptions.

[15] Communication with EPA staff indicates that there will be two ways to allocate activities to VSP/Speed bins to represent a specific modeling area (e.g., a metropolitan region): one is to input customized average speed distributions specified in MOVES "AvgSpeedDistribution" table; another way is to use the "Domain Importer" to be included in future versions of MOVES to input VSP distributions directly.

[16] Data are sparse especially for heavy-duty trucks; for example, EPA has indicated that available heavy-truck emission data was limited to approximately 60,000 lbs, very limited data are available on extended idle energy consumption rates for heavy-duty trucks, and no in-use data were available for the heaviest trucks (EPA, 2005c).

4. IMPLICATIONS FOR MODELING PRACTICE

One of the goals of MOVES development is to provide a transparent modeling tool with more flexibility for local modeling practice. This chapter briefly addresses how MOVES may be adapted to complete emissions modeling analyses for a local area or a transportation project. Neither the mesoscale nor the microscale functions in MOVES were available at the time of this work (2007). Therefore, the focus of this section is to discuss activity data issues regarding local and project-level analyses, and some considerations regarding use of MOVES in California.

4.1 Data Issues Regarding MOVES Implementation at the Local and Project Level

Since MOVES incorporates a complete set of national default data, national, state or county-level emissions inventories can be developed without additional data input. However, link level emission analyses using the MOVES mesoscale or microscale modules (in future model versions) will need project-specific activity input. Notwithstanding the default information included in MOVES, EPA has recognized that, to obtain more accurate results, the national defaults will need to be replaced by local data whenever available (EPA, 2003; EPA, 2007b). In fact, EPA has noted that, "When a final version of MOVES is available, we will require SIP and conformity modelers to replace the national default data with local data, replacing the 'national' domain with one or more 'local' domains."[17] Consequently, MOVES users are interested in better understanding which national default information is important to replace, as well as how to replace default information with corresponding local data.

As of this writing, no detailed studies have been published evaluating how sensitive MOVES emissions estimates are with respect to default input data (or variables). A general sense is that vehicle activity data are important and need to be as localized as possible. As modeling scales change from macro to meso or micro levels, the need for locality-specific data will increase accordingly. In a presentation for a Federal Advisory Committee Act (FACA) workshop, EPA emphasized that data describing the following vehicle activities should be locally prepared (Beardsley, 2003): total VMT and VMT growth, VMT allocations by time and location, average

[17] See: http://www.epa.gov/otaq/models/ngm/movesdemo/movesintro.htm.

speeds (for different facilities), vehicle age distribution, and alternative fueled vehicle fractions. Peer reviews during the MOVES development process also suggested that EPA

- provide more information regarding how to supply local travel activities and road grade information, and how to translate local data to a useable form into MOVES (EPA, 2003a);
- address potential bias in VMT estimates derived from local HPMS data (EPA, 2003b);
- encourage local regions to collect better speed data by facility and parking inventories (SwRI, 2003); and
- encourage states to submit local VMT, vehicle mix and speed data (NESCAUM, 2005).

The data needs identified above are related to specific relational tables in the MOVES default database. In Table 4.1, we briefly describe these relational tables and summarize which input variables are likely to necessitate the use of local data when running the MOVES model. It should be noted, however, that the activity data summary presented in Table 4.1 does not reflect EPA's conclusions. EPA is planning to address data issues in the development of technical guidance for the use of future versions of MOVES, including thoroughly assessing the availability and quality of local data and the sensitivity of emissions estimates to changes in model inputs.

Table 4.1. Priority MOVES default activity data to replace with local data.

Data	Table name in MOVES database	Variables	Modeling description	Example data sources for localization
Vehicle population	SourceTypeYear	• Sales growth factor • Migration factor	Measuring new growth of vehicle population	Local vehicle sales data; local registration data; vehicle population forecast
	SourceTypeAge	• Vehicle survival rate by age • Vehicle relative accrual rate by age	Measuring vehicle population and annual accumulated mileage	Local vehicle fleet data; local registration data
	SourceTypeAgeDistribution	• Vehicle age distribution	Measuring vehicle age distribution	Local vehicle fleet data; local registration data
Vehicle miles traveled	HPMSVtypeYear	• Base year VMT in HPMS system • VMT growth factor	Specifying annual VMT based on HPMS system	Local HPMS data; VMT forecast from travel demand models or other local sources
	HourVMTFraction	• Hourly VMT fractions	Specifying hourly VMT	Local HPMS data; VMT data from travel demand models; local traffic count data
Vehicle driving pattern	AvgSpeedDistribution	• Distribution of time spent in average speed bins by vehicle class, facility type and time	Measuring average speed of facilities for different vehicle classes	Travel demand models; traffic simulation models; local traffic count data and roadside observations
	DriveScheduleSecond	• Second-by-second speed for each driving schedule	Measuring vehicle instantaneous speed within predefined driving cycles	Traffic simulation models; local-specific driving cycles; roadside observations
Vehicle starts	StartsPerVehicle	• Starts per vehicle by vehicle class (based on a predefined sample vehicle trip table)	Measuring vehicle starts for computing start exhaust emissions	Travel demand models; local travel survey data
Vehicle operating modes	OpModeDistribution	• Operating mode fractions	Measuring vehicle operating mode fractions by vehicle class, facility type and time	Traffic simulation models; analysis of local-specific driving cycles; roadside observations

4.2 Replacing national default data with local data: some California considerations

Future MOVES users will, ideally, be able to easily replace default information with local data. As of this writing, MOVES was still under development; the version assessed here (MOVES-HVI Demo) did not yet include the capability to allow easy substitution of national default data. Given that MOVES-HVI Demo is only an interim product, and that EPA's next version of MOVES will likely be restructured to enable easier data substitution, this discussion only briefly outlines issues associated with substituting local data for MOVES default data.

California has relied on EMFAC for both regional- and project-level analyses. Theoretically, MOVES will be more appropriate for modeling emissions from transportation projects, given its modal-based methodology and (in future models) its option to complete micro-scale (link-level) assessments. EMFAC, in contrast, outputs emission factors more appropriate for regional-scale use. However, to complete project-level analyses with MOVES, users will need to replace MOVES default data with data applicable to the project being evaluated. Table 4.2 summarizes local data needs to complete project-level analyses with MOVES.

Nominally, MOVES appears to be a superior tool to complete project-level assessments, since it links modal-based emission rates with traffic activity that can be scaled from large regions down to single links. However, as illustrated in Table 4.2, a wide range of local data is needed to take full advantage of this modeling resource – unfortunately, providing much of this data is beyond the ability of travel demand models in current practice. It may be possible to use advanced traffic simulation models or roadside observations to generate the local data needed to populate the MOVES model; however, these efforts are likely to be labor intensive or costly and will therefore take time to implement.

In addition, California analysts could, in concept, use MOVES to produce regional-scale on-road inventories. To do so could, for example, involve using local activity data and fleet information already included in EMFAC. However, significant efforts are needed to transfer to or link EMFAC data with the MOVES model. Some local data in EMFAC may be transferred to MOVES in a straightforward way. For example, activities for passenger cars may be transferred relatively easily to MOVES, because both EMFAC and MOVES treat passenger cars as an individual vehicle class. Other data, however, have to be carefully processed before being loaded into MOVES. For example, it will be difficult to map EMFAC vehicle age distributions to the MOVES data structure, given that the two models use different vehicle type classifications.

Table 4.2. Local data needs to complete project-level emissions assessments with MOVES.

Scope	Module Options	Method highlight	Local data needed	Primary local data source
Mesoscale	Basic option	Generate emissions at roadway link and zone level (counties, traffic analysis zones, or user-defined sub-zones), based on cycle-based average emission factors.	Link level and zone level vehicle activities; county-specific fleet, meteorology and control program information.	Travel demand models.
	Modal option	Generate emissions considering project-specific vehicle operating modes and road grade.	In addition to above, link level vehicle operating mode distributions; road grade.	Travel demand models, advanced traffic simulation models, or roadside observations.
	Advanced option	Generate emissions considering modal activity and fleet with finer spatial scales.	In addition to above, improved GIS-based activity data with higher spatial resolutions.	In addition to above, GIS models, census and land use data.
Microscale	N/A	Combine modal emission rates with activities specified for a corridor or an intersection.	Project-specific vehicle activities, fleet, operating modes and road grade.	Advanced traffic simulation models or roadside observations.

Source: summarized from EPA, 2001.

Given the many options that will be available to users in terms of replacing national default data with local data, and given the wide range in data availability, ease of substitution, and cost for data acquisition, users will need a roadmap to prioritize which local data to acquire. Future work is needed, once MOVES nears completion, 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.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of MOVES Assessment

This report provided an assessment of the modeling features and methods of MOVES, the new mobile source emission model. The assessment was preliminary; MOVES is still under development and future model versions are expected to be substantially different in terms of capabilities and structure, as well as pollutants covered. 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 more appropriate project-level analysis tool – one that is more responsive to variations in link-level travel vehicle speeds and roadway congestion levels.

This study compared MOVES-HVI Demo and EMFAC2007 using a Los Angeles County, California example application, and two greenhouse gases: CO_2 and CH_4. The case study identified important differences regarding both the magnitude and distribution of embedded activity data (e.g., vehicle population, fleet composition and VMT) across vehicle classes, travel speeds, and other factors. The default vehicle activities in MOVES suggest a significant departure from EMFAC local data, especially for the future light-duty truck fleet. Differences between MOVES and EMFAC for CO_2 emissions in the case study appear to be mainly affected by the magnitude of forecasted vehicle miles traveled; while for CH_4 emissions, the inventory results tend to hinge on the base emission rates.

The case study findings have important implications with respect to emissions modeling practices:

- MOVES incorporates more features and functions than both EMFAC and MOBILE. Its modal emissions approach allows MOVES 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 as of this writing 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, however, EPA has made clear that the medium- and heavy-duty truck portions of the MOVES dataset are less populated than those applicable to the light-duty fleet.
- 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. Considerable effort will 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.
- A potential source for local (regional-scale) California activity data is the EMFAC model, since EMFAC is already populated with activity data generated and quality-assured by metropolitan planning organizations and the state Air Resources Board. However, it may be difficult to map EMFAC's activity data to the MOVES model. The two models use different approaches to bin data – an important example being the use of different vehicle class definitions.
- Post-processing of MOVES output enables preparation of speed-to-emissions relationships; these facilitate comparisons to EMFAC's speed correction factors. The post-processed MOVES data suggest that fleet-average gram per mile vehicle

emissions for CO_2 and CH_4 decline as average vehicle speeds increase – this finding is in contrast to output derived from EMFAC, which indicates rising gram per mile emission rates as vehicle speeds exceed about 50 mph. An important caveat is that this pattern was observed based solely on CO_2 and CH_4 emissions in the Los Angeles County case study. Further investigation is needed for criteria pollutants, air toxics, applications in other geographic areas, and assessments at spatial scales applicable to individual transportation projects. In addition, MOVES continues to undergo revision; future model versions may not produce the same findings as those presented here. However, if the results illustrated here remain applicable in future model versions, they suggest that at the project-level, there are important distinctions between MOVES and EMFAC: MOVES estimates reduced emissions as per-vehicle speeds increase, while EMFAC indicates an opposite outcome.

5.2 Major Technical Findings: MOVES Compared to EMFAC

<u>Modeling Features:</u>

- MOVES and EMFAC apply different modeling approaches in terms of specifying vehicle activities and measuring emission factors (see Table 3.1).
- MOVES has multiple modeling scales and finer temporal resolutions than EMFAC (see Tables 1.1 and 3.1).
- MOVES and EMFAC have different vehicle classifications (see Table 3.3). MOVES identifies vehicle classes as a subset of the classes used in the federal Highway Performance Monitoring System (HPMS).

<u>L.A. County Emissions:</u>

- MOVES and EMFAC seem to have similar CO_2 emissions overall, once adjusted by VMT (see Table 3.4, Figures 3.1 and 3.2). In absolute terms, EMFAC and MOVES generated similar 2002 CO_2 emissions; for 2030 MOVES generated 40% higher CO_2 emissions.

- MOVES produces higher (by a factor of three) start emissions of CO_2 than EMFAC in both of the analysis years examined (2002, 2030), once adjusted by vehicle starts (see Figures 3.4 and 3.5).
- MOVES generates significantly lower (less than half) CH_4 emissions than EMFAC for the base year 2002 (see Table 3.4 and Figure 3.3). This outcome is due in large part to the fact that MOVES incorporates more recent dynamometer test data results than EMFAC; these test data indicate reduced gram per mile CH_4 emissions. Since the CH_4 emission factors in MOVES are based on MOBILE-like FTP derived emissions information, the differences between MOVES and EMFAC are not related to the new MOVES VSP/speed bin modeling approach.
- MOVES projects similar running exhaust CH_4 emissions, but substantially higher (by a factor of nine) start exhaust CH_4 emissions, for year 2030 (see Figure 3.9). The high start emissions mainly result from larger per vehicle start emission rates embedded in MOVES. The result is that, for the year 2030, overall CH_4 emissions produced by MOVES are nearly double the estimates provided by EMFAC.

L.A. County Vehicle Activities:

- MOVES assumes a younger vehicle fleet overall. Given that both EMFAC and MOVES assume that more recent model year vehicles accrue more miles per year, the fleet age distribution differences may contribute to the VMT differences between the two models (see Figures 3.14 and 3.15).
- MOVES assumes more light-duty truck (LDT) VMT (see Figure 3.24) – a result of (compared to EMFAC) a larger population, younger fleet and higher mileage accrual rate for personal trucks and light commercial trucks (see Figures 3.12, 3.16, 3.20 and 3.23). MOVES assumes a higher fleet growth rate of LDTs than that of other vehicles.
- The differences between MOVES and EMFAC default LDT activity data contribute to different apportionments of CO_2 emissions by vehicle type (see Figures 3.7 and 3.11). MOVES apportions more of its CO_2 emissions to LDTs.

- VMT by speed distributions are very different between the two models. MOVES VMT distributions are consistent with MOBILE's default and includes more travel activity in the 30-50 mph range than does EMFAC. This difference is important for emissions, since the low and high-speed ends of the curve (where more of EMFAC's activity is concentrated) traditionally mean greater per-mile emission rates (see Figures 3.27, 3.28 and 3.29).

L.A. County Emission Factors:

- Once MOVES data is post-processed, MOVES and EMFAC have similar CO_2 fleet-average gram per mile emission factors; however, MOVES has higher emission factors for a small subset of the 2030 vehicle fleet: diesel powered light-duty trucks, as well as gasoline powered medium or heavy-duty trucks (see Figures 3.31 and 3.33). There are various underlying factors that contribute to the observed differences between the effective gram per mile MOVES and EMFAC emission factors, including VSP/speed-bin distributions and vehicle fleet mix assumptions embedded in MOVES.
- MOVES has lower CH_4 emission factors than EMFAC for gasoline vehicles, especially for the year 2002 fleet (see Figures 3.34 and 3.35). This is a function of the incorporation of more recent vehicle test data as noted above under the "Emissions" discussion.
- For both CO_2 and for CH_4, MOVES does not take deterioration or vehicle aging into account for vehicles of model year 2001 and later (see Figures 3.40 and 3.41)[18]. For CH_4, for each vehicle class, MOVES assumes constant CH_4 running and start emission rates for model year 2001 and later vehicles.
- MOVES shows declining gram per mile CO_2 emission rates when plotted against travel speeds; EMFAC, in contrast, shows increasing CO_2 at higher speeds – these differences will be important if they apply at the project level (see Figures 3.42 and 3.43) (further assessment is needed once the microscale feature of MOVES becomes available, and once MOVES models a broader array of pollutants).

[18] With respect to emission changes against vehicle age, MOVES considers changes in emissions and fuel consumption to reflect vehicle technology improvement; future research is needed to investigate their impact on vehicle emission factors.

- MOVES has much higher (by more than a factor of three) fleet-average CO_2 start emission factors than EMFAC for both the 2002 and 2030 vehicle fleet (see Figure 3.44).
- MOVES has lower fleet-average CH_4 start emission factors than EMFAC for the 2002 vehicle fleet, but has considerably higher CH_4 start emission factors for the 2030 vehicle fleet (see Figure 3.45). MOVES uses aggregated FTP bag data to develop start emission rates; model year 2001 and later vehicles have the same start emission rates.

5.3 Recommendations for Future Research

This section identifies opportunities for further research regarding MOVES. The discussion is broad, given the status of the model. As of this writing, 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. This schedule is likely to change, however, based on past model development experience. Given that MOVES remains under development, future model versions will be substantially different in structure and content than the model version assessed as part of this study. Considerations for further assessment work include:

- Replacing default fleet and activity data: MOVES currently relies on the embedded Total Activity Generator (TAG) to define vehicle fleet and activity data for a given application. For example, for each vehicle class, the TAG grows 1999 base year nationwide VMT to a target year. The model then allocates the VMT to counties in later steps. Therefore, replacing MOVES default county VMT by local data is not straightforward; instead, it requires processing both the base year and the target year local VMT, and applying local growth factors and spatial allocation factors to match the MOVES activity growth structure. As a result, users of the MOVES-HVI Demo model must apply rough scaling ("back-of-the-envelope") methods to partially account for local data.[19] Future versions of MOVES are expected to better facilitate the input of local activity data. As the MOVES model moves closer to its final structure, further work will be needed to examine and illustrate how to replace national defaults.

- Examining the VMT-speed distribution assumptions embedded in MOVES: As shown earlier (Figure 3.27), there are important VMT-speed differences between EMFAC and MOVES. The VMT-speed distribution disparity between the two modeling tools merits further examination given the importance of the relationships among speed, VSP, and emissions (e.g., see Figure 2.2).

- Prioritizing the replacement of default data with local data, and providing guidance to accomplish priority data replacement: Important research needs include identifying, for future model versions, the most important national default data that needs to be replaced, and identifying how, at the local level, agencies can best complete data collection and integration into MOVES. Such work is especially important given that most widely used travel demand models will not readily generate activity data with the spatial and temporal precision needed to populate the MOVES database.

- Completion of uncertainty analyses: MOVES includes the ability to estimate the uncertainty associated with its emissions estimates. The uncertainty function is limited to emission factor-related information; it does not address uncertainty associated with vehicle activity data. Further work is needed to illustrate how to use and interpret the uncertainty information generated by MOVES.

- MOVES, EMFAC, MOBILE model comparisons: As the final version of MOVES takes shape, further analyses will be needed to compare MOVES,

[19] For example, a late-2007 federally-sponsored MOVES orientation session illustrated that an interim way to at least partially account for local VMT was to simply scale MOVES emissions output by the ratio of national default VMT to local VMT. (Source: FHWA workshop given December 5, 2007: "MOVES-HVI Demo, Basic Orientation. J. Byun and J. Houk, Carson City, Nevada." Note that the workshop was only an overview of MOVES, and was not official training or guidance in the use of 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 SIP and transportation conformity implications of the model output differences. In addition, specific anomalies identified in this study should be further investigated once a new version of MOVES becomes available – a notable example is the effective mileage accrual rates embedded in MOVES. As discussed in Section 3.4.3, for portions of the vehicle fleet, MOVES effectively includes mileage accrual rates that decline over time (2002-2030), a finding that runs counter to expectations.

In summary, further work should explore the underlying causes contributing to the emissions differences modeled using EMFAC and MOVES. Such work will be easier to complete once a version of MOVES appears that allows for easier replacement of default activity data with local data. Future work can then focus more closely on isolating the impact of key input variables on model results.

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