Air Pollution Emissions from Highway Vehicles: What MOVES Tells Us

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ABSTRACT

The U.S. Environmental Protection Agency is developing the Motor Vehicle Emission Simulator (MOVES) to estimate air pollution emissions from cars, trucks and other mobile sources. When complete, MOVES will replace EPA's MOBILE and NONROAD models. The EPA has created a draft version of MOVES that incorporates extensive new data and advanced algorithms to better estimate highway vehicle emissions of greenhouse gases, criteria pollutants and selected air toxics. This paper summarizes how MOVES differs from MOBILE6 in terms of capabilities, inputs, and preliminary results.

INTRODUCTION

Since 1978, the U.S. Environmental Protection Agency has used computer models to estimate emissions from cars, trucks and other mobile sources. The initial MOBILE model was expanded many times over the years to incorporate new data on vehicle emissions, new vehicle emission standards and to better address new policy questions,[1] but the basic structure of the model has remained constant. MOBILE uses average gram per mile emission rates and a series of correction factors to estimate emissions over a wide range of driving conditions.

MOBILE6.2[2], finalized in 2004, is EPA's current official model for highway vehicle emissions. It is used for EPA internal policy analyses and is required for use (outside California) in the evaluation of State Implementation Plans (SIPs) and transportation conformity determinations.[3]

A number of analysts have critiqued the MOBILE series of models.[4] In 2000, the National Research Council prepared an evaluation that recommended a number of design changes for MOBILE.[5] They suggested that EPA develop a modeling "toolkit" that would better serve the range of uses for highway vehicle modeling, including consistent modeling at the aggregate scale, mesoscale, and microscale analysis. The model should integrate the modeling of criteria pollutants, air toxics, greenhouse gases and fuel consumption.

In response to these and other concerns, EPA has developed the Motor Vehicle Emissions Simulator (MOVES). MOVES incorporates extensive new data and advanced

algorithms to better estimate highway vehicle emissions of greenhouse gases, criteria pollutants and selected air toxics at the national, regional and project level. A draft version of MOVES is planned for release in spring 2009. A final version for highway vehicles is planned for release in December 2009.

MOVES CAPABILITIES

MOVES greatly extends the capabilities of MOBILE6, allowing significantly greater flexibility in modeling choices and offering a variety of tools designed to ease the use of the model in a variety of use cases. Draft MOVES2009 calculates highway vehicle emissions of greenhouse gases, criteria pollutants and selected air toxics. It also calculates energy consumption. Emissions are calculated for all the significant vehicle emission processes: running emissions, start emissions, evaporative emissions, extended idle emissions, crankcase emissions, tirewear and brakewear.

In response to criticisms of MOBILE, MOVES was designed to allow easier incorporation of large amounts of in-use data from a variety of sources. MOBILE was written in Fortran, and many data elements were hard-coded, making them difficult to update. MOVES is written in Java and MYSQL, and data elements are stored in database tables.

Like MOBILE6, MOVES adjusts emissions to account for changes in vehicle mix, fuel properties, temperatures, and speeds. Unlike MOBILE6, MOVES is designed to estimate emissions at multiple geographic scales. MOBILE6 emissions rates were based on regional-scale trip pattern, while MOVES emissions are based on operating modes, and thus can be customized to the unique driving patterns in a particular region or project area.

MOVES has a menu-driven interface to guide users as they set up and execute MOVES runs. The interface includes graphical display to help users define their desired model run and a variety of data importers to help users create appropriate input files. MOVES also includes a command-line interface to facilitate batch runs. MOVES can be run on a single computer, or set up in a "master/worker" configuration, allowing distributed processing. Users can model the impacts of particular policy options using built-in tools. Current policy tools include vehicle inspection/maintenance (I/M) programs, retrofits of vehicle equipment, and the phase-in of alternative fuels and advanced technology vehicles.

MOVES allows users to output emissions either in MOBILE6-like gram-per-mile emission factors or in total mass for a given area and time. Users can select the desired level of output detail through the user interface, and can apply database processing tools to further customize reports.

MOVES INPUTS

In MOBILE6, emissions were calculated from default information in block data, supplemented with information provided by the user in input text files. In MOVES, default information is contained in a default input database. Hypothetically, users can run MOVES using all default data, all new data, or anything in-between. In reality, the inputs that users bring to the model will depend on the situation being modeled and the purpose of the modeling. EPA is preparing detailed technical guidance on the requirements for users running the model to prepare SIP inventories and conformity determinations.

Generally, users are not expected to modify the default MOVES emission rates. The default rates were developed by assessing millions of vehicles. For Light Duty Vehicles, emission rates for hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NOx) from existing vehicles were derived from ten years of second-by-second data from Arizona's Inspection/Maintenance (I/M), with comparisons to other I/M programs and remote sensing data. Particulate Matter (PM) emissions were derived from a major new EPA study in Kansas City[6]. Heavy Duty emissions were derived from more than 300 in-use vehicles in a number of detailed studies.

Many of user inputs expected by MOVES are similar to those previously used in MOBILE6. For example, information on age distributions, local fuels and local temperatures are essential inputs for any accurate estimate of emissions. MOVES differs however, in that the categories for these inputs have changed. For example, MOBILE6 has 28 vehicle categories, generally based on vehicle weight ratings, while MOVES has only 13 categories, based on observable characteristics (e.g. combination vs. single unit trucks) and typical use (e.g. long haul vs. short haul). The EPA is developing converters to allow users to automatically convert MOBILE6 inputs into MOVES formats.

MOVES new capabilities also require new inputs. In particular, because MOVES can calculate inventories as well as gram per mile emission rates, MOVES relies on input of Vehicle Miles Travelled (VMT). The MOVES design also recognizes that vehicle starts and evaporative activity may not be well correlated with VMT, and thus relies on vehicle population estimates to calculate these emissions.

In another example of how new capabilities require new inputs, MOBILE6 allowed users to enter a speed distribution or an average speed for a run. MOVES also allows input of a speed distribution, but it can also accept specific driving cycles or operating mode distributions, allowing the user to model emissions resulting from changes in driving behavior.

MOVES can work with inputs at the national level, with allocation to specific counties if desired; or MOVES can work at the county or project level, with inputs specific to that time and place.

PRELIMINARY RESULTS

MOVES updated data and advanced capabilities enhance our understanding of vehicle emissions. To begin to understand how MOVES emissions differ from MOBILE6 emissions, we ran some simple comparisons with a preliminary draft version of MOVES. Comparing MOVES and MOBILE6 is better done for specific local areas, as it is easier to align the inputs for the two models on a smaller scale, and because national default inputs in MOVES would not fully capture the individual variation between nonattainment areas.

To best characterize the comparison most relevant for U.S. nonattainment areas, we ran the preliminary draft version of MOVES for three sample cities: a medium-sized city in the western U.S., a large city in the north central U.S., and a large city in the Southeast. For these preliminary runs, we used local data submitted to the U.S. EPA as part of the National Emission Inventory effort. This data included local information on the age distribution of the fleet, the fraction of light-duty and heavy-duty VMT, local fuel characteristics, and temperature data. This allowed us to match the activity and other inputs between MOVES and MOBILE and to simulate local data that would be used in a SIP. However, the inputs were simplified and may not be completely consistent with data that the state would actually use in preparing a SIP for the city.

For 2008, 2015 and 2020, we ran this data through the MOBILE6.2 model (using the National Mobile Inventory Model (NMIM)) and through MOVES, adjusting inputs as necessary to fit MOVES data categories. Our results were generally consistent between the three cities, with decreases or little change in hydrocarbon (HC) emissions, moderate increases in nitrogen oxides (NOx) and significant increases in particulate matter (PM). Figures 1-3 illustrate these trends for the northern city in our sample.

Figure 1. Hydrocarbon emissions in example northern city

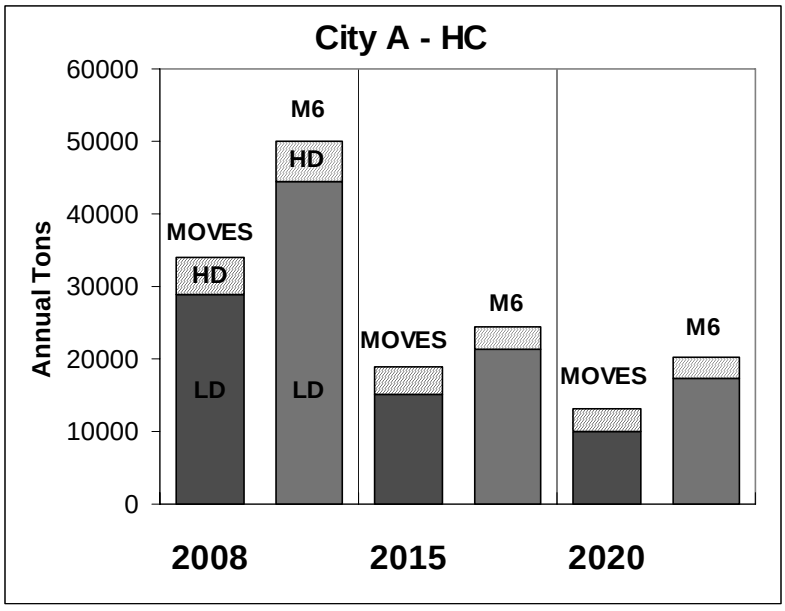


Figure 2. Nitrogen Oxide emissions in example northern city

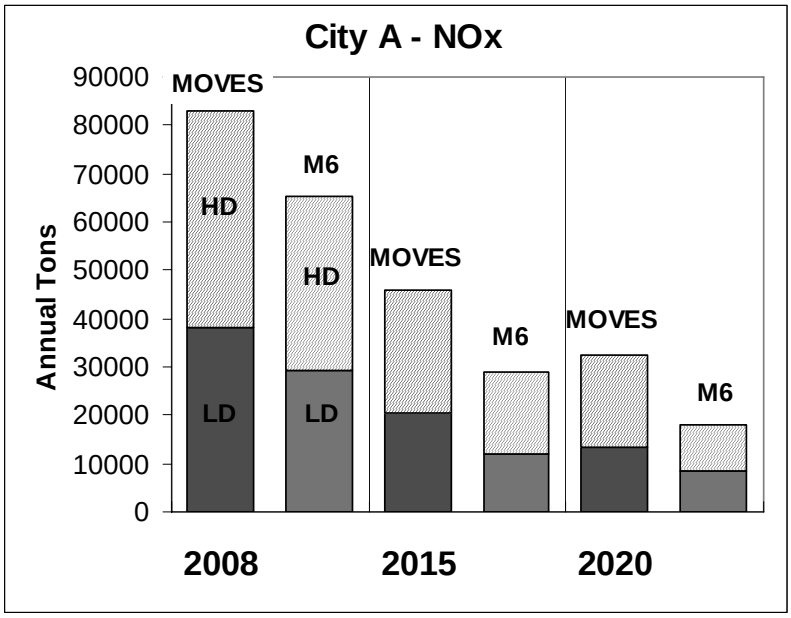
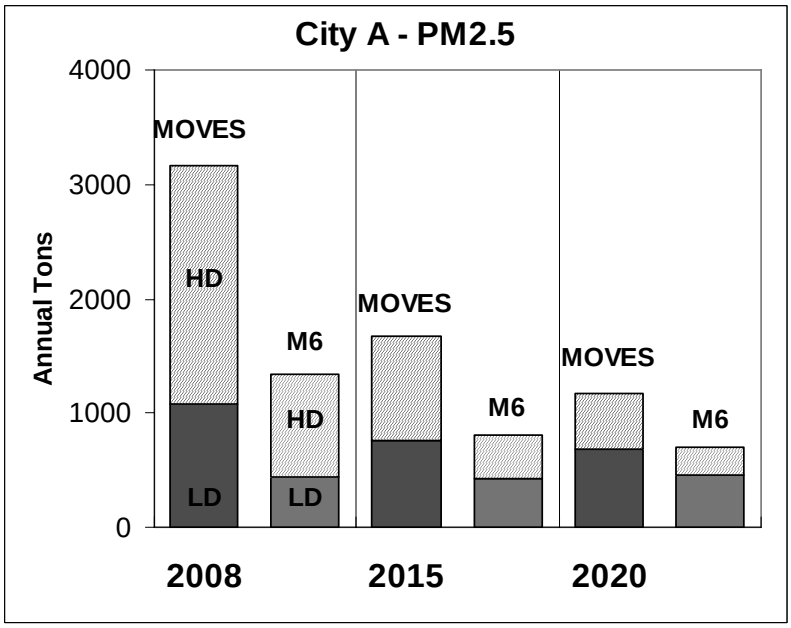


Figure 3. Particulate Matter emissions in example northern city



CONCLUSIONS

The results of our preliminary comparisons were consistent with our understanding of the changes in underlying emission rates. In MOVES, light duty cars and trucks tend to have similar or lower HC emissions than in MOBILE6. This is because new exhaust and evaporative emissions test data has demonstrated that MOBILE6 was overly pessimistic in estimating how emissions from mid-1990s and later

vehicles would increase with age. Light duty trucks tend to have higher NOx emissions than forecast by MOBILE6, and heavy duty trucks tend to have higher NOx than estimated from the engine certification tests used in the MOBILE6 analysis – in part due to higher brake-specific emissions from in-use trucks, and in part due to the differences between real-world operation and the certification test. Extended idle NOx emissions were also given a much more careful treatment in MOVES than in MOBILE6; given default assumptions about extended idle activity and the projected lack of control from NOx aftertreatment devices during extended idle operation, they are projected to form a large portion of the future-year heavy duty NOx inventory. The growth in light-duty PM emissions from MOBILE6 to MOVES reflects the higher emissions and strong temperature dependence that we saw in the Kansas City study.[7,8] The growth in heavy-duty PM reflects new information on in-use vehicles[9] and new analysis of emission deterioration. MOVES also adjusts PM emissions for speed, which MOBILE6 did not do, which leads to a very large difference in emissions between the two models at lower speeds typical of congested urban operation.

The implications of the changes in emission estimates for SIPs will depend on local conditions and regulatory requirements. Higher NOx and PM emissions from mobile sources will impact local air quality modeling and will increase the role of mobile source control measures in attainment demonstrations. However, it is important to note that for attainment analysis, a key measure is the percent reduction in emissions from the analysis base year. In our limited analysis, we saw a greater percent reduction for PM in MOVES than in MOBILE6, but a lower percent reduction for NOx.

Table 1. Percent Reduction in On-Road Emissions, 2008 to 2015

	City A		City B		City C	
	MOVES	**MOBILE6**	**MOVES**	**MOBILE6**	**MOVES**	**MOBILE6**
HC	50%	50%	39%	32%	38%	31%
NOx	54%	56%	40%	52%	36%	53%
PM2.5	57%	40%	52%	40%	38%	23%

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