Appendix C: GHG Emissions Model

1   METHOD OVERVIEW

The Maryland Statewide Transportation Model (MSTM) Emissions Model (EM) is a CUBE-based model that uses emission rates calculated by the MOVES2010 EPA model developed for conformity purposes in non-attainment areas. The MOVES model uses generalized national data such as vehicle fleet age distributions with localized county data such as average hourly temperatures and fuel mixtures to produce emission rates for every vehicle and mile traveled in the region. These rates are then applied to produce trip tables and loaded networks to calculate summary emissions output and link level (road segment) emissions in the network.

The EM model has four explicate steps that must be run to calculate total MSTM area emissions. They include the development of emission factors; preparation of MSTM and MOVES data; calculations of intrazonal VMT; and application of emission rates by total output tables and at the link level on a network.

Step 1, Develop emissions factors from MOVES2010: Emissions are categorized by speed bin, pollutant, and model year. Emissions are further classified by multipliers relating to Grams per mile (running emissions) and Grams per vehicle (non-running emissions). The EM reformats MOVES output emissions factors for input into MSTM model.
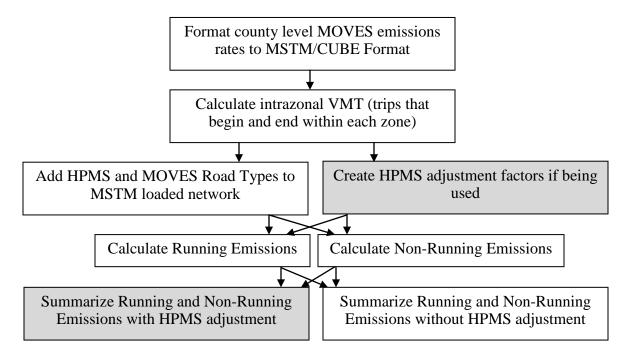
Step 2, Prepare MSTM DATA: This step categorizes congested speeds from the assigned network into HPMS and MOVES pre-defined speed bins through a link read phase. Vehicle miles traveled within the network are calculated for application to the running emission rates. This procedure also requires calculating intrazonal VMT, which in itself takes several steps. First, intrazonal VMT is calculated by assuming an intrazonal travel distance of one half the average distances between the nearest three zones by skimming the loaded MSTM network to get the congested travel time on each link. This VMT is then appended to

centroid connectors. Second, Intrazonal VMT is determined by multiplying the new intrazonal time matrix by the vehicle trip matrix. With the intrazonal trips calculated in the new trip matrix, the intrazonal VMT is appended to the network. The intrazonal VMT is pro-rated by the total VMT distribution between centroid connectors within the zone. The pro-rated VMT is appended to each centroid connector in the network. Finally, emissions factors are applied to the centroid connectors by five miles per hour speed bins. A 25 mph speed as applied to all centroid connectors to reflect a likely average speed along local roads that are not represented in the MSTM Network.

In the second part of step two, MOVES road types are matched and appended to the MSTM network based on facility type and area type. Additionally HPMS functional classification codes are appended to the MSTM network. It is important to account for intrazonal trips, as they are not directly captured in the MSTM loaded network, so emissions estimates without these trips have undercounts of total pollutants.

Step 3, Create HPMS Adjustment Factors: This step is an intermediate process to create HPMS Adjustment Factors. Link level VMT is aggregated by HPMS functional class. HPMS adjustment factors are then calculated using the ratio of HPMS VMT to model VMT. The new HPMS adjustment factors are applied to VMT estimates at the link-level by HPMS functional class

Step 4, Calculation emissions: This is the final step of the model. Running emissions are calculated by applying emissions factors per mile to model VMT for each link. Aggregate link-level emissions are also calculated by HPMS functional class and pollutant. Non-running emissions are calculated by applying emissions factors/vehicle to the pre-calculated vehicle population. Link level emission rates are appended to the MSTM network and running and non-running emissions by HPMS functional class by pollutant are summed.

Figure C-1 MSTM Emissions Model Flow Chart

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┌────────────────────────────────────────┐
│  Format county level MOVES emissions    │
│      rates to MSTM/CUBE Format          │
└────────────────────────────────────────┘
                     │
                     ▼
┌────────────────────────────────────────┐
│  Calculate intrazonal VMT (trips that   │
│    begin and end within each zone)      │
└────────────────────────────────────────┘
         │                      │
         ▼                      ▼
┌──────────────────────┐  ┌──────────────────────────┐
│ Add HPMS and MOVES   │  │ Create HPMS adjustment   │
│ Road Types to MSTM   │  │ factors if being used    │
│ loaded network       │  │                          │
└──────────────────────┘  └──────────────────────────┘
         │        ╲    ╱          │
         ▼         ╳             ▼
┌──────────────────────┐  ┌──────────────────────────┐
│ Calculate Running    │  │ Calculate Non-Running    │
│ Emissions            │  │ Emissions                │
└──────────────────────┘  └──────────────────────────┘
         │        ╲    ╱          │
         ▼         ╳             ▼
┌──────────────────────┐  ┌──────────────────────────┐
│ Summarize Running    │  │ Summarize Running and    │
│ and Non-Running      │  │ Non-Running Emissions    │
│ Emissions with HPMS  │  │ without HPMS adjustment  │
│ adjustment           │  │                          │
└──────────────────────┘  └──────────────────────────┘
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2   INPUTS

Timeframe - Emissions are modeled for all scenarios for year 2030. Each scenario will use a separate set of inputs to reflect changes in VMT and the underlying highway network.

Geographic Scale - The MSTM Emissions Model covers the same area as the MSTM which includes the entire states of Maryland, District of Colombia, Delaware and portions of southern Pennsylvania, northern Virginia and West Virginia.

2.1.3 Roads - Emissions are modeled for all roads included in the MSTM network which is composed of major collectors, arterials, highways and interstates. Emissions for intrazonal trips using centroid connectors (local roads not in the MSTM network), that is, vehicle trips that do not leave a SMZ and therefore are not calculated in the model's vehicle trip table are calculated using a special procedure (described in Step 2 in Section 1) so that even emissions from minor trips are calculated.

2.1.4 Vehicles - The MSTM emissions model captures all vehicle trips within the region based on the vehicle trip table produced by the MSTM transportation model. Emission rates are calculated for a variety of EPA defined vehicles based fleet compositions of MSTM constituent counties, for specific model years. Vehicles considered in this model are described in section 2.2.2.

2.2.1 Meteorology – Temperatures at which vehicles are started and operated are an important factor in estimating the level of emissions produced by motor vehicles. Temperature can have a substantial impact on the emission level of several important pollutants. Another factor considered in the meteorology of emissions is humidity which has an impact on the level of nitrogen oxides (US EPA 2010). MOVES uses meteorology data gathered by month and hour for each county in the study area. For purposes of modeling emissions in the MSTM, the temperatures and humidity of July are used in MOVES to represent a worst case scenario during the peak of the regional ozone season.
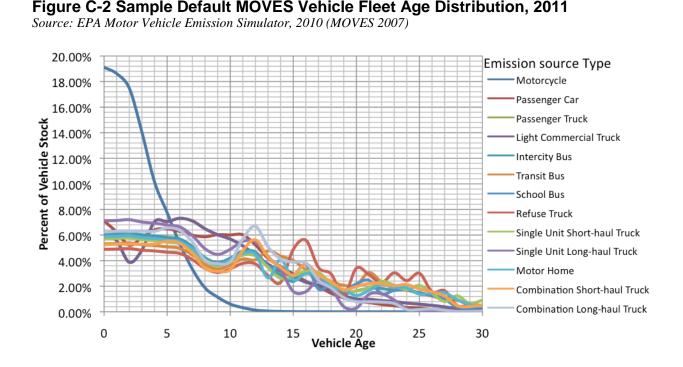
2.2.2 Source Type – Part of the MOVES output is emission rates by source type (vehicle type). MOVES calculates emissions for vehicles categorized into 13 source types (Table D-1), which are subsets of six HPMS vehicle types in MOVES. "MOVES produces emission rates for start and non-running evaporative emissions by source type in terms of grams per vehicle. Total start and non-running evaporative emissions are then calculated outside of MOVES by multiplying the emission rates by the vehicle populations for each source type" (US EPA 2010).

Table C-1 MOVES Source Types and HPMS Vehicle Types

MOVES Vehicle Specification		HPMS Vehicle Specification	
Source Type ID	Source Types	Vehicle Type ID	Vehicle Type
11	Motorcycle	10	Motorcycles
21	Passenger Car	20	Passenger Cars
31	Passenger Truck	30	Other 2 axle-4 tire vehicles
32	Light Commercial Truck	30	Other 2 axle-4 tire vehicles
41	Intercity Bus	40	Buses
42	Transit Bus	40	Buses
43	School Bus	40	Buses
51	Refuse Truck	50	Single Unit Trucks
52	Single Unit Short-haul Truck	50	Single Unit Trucks
53	Single Unit Long-haul Truck	50	Single Unit Trucks
54	Motor Home	50	Single Unit Trucks
61	Combination Short-haul Truck	60	Combination Trucks
62	Combination Long-haul Truck	60	Combination Trucks

Source: EPA Motor Vehicle Emission Simulator, 2010 (MOVES 2007)

2.2.3 Age distribution - The age of vehicle fleets have an impact on the level of calculated emissions in a given area. In order to accurately model emissions, a fleet with a variety of vehicle ages must be included. For each model year, MOVES covers a fleet of vehicles with a mix of ages up to 31 years, with vehicles greater than 30 year old grouped in the last category (US EPA 2010). The EPA recommends developing local data for conformity purposes, but offers yearly default distributions for all other purposes. Due to the significant data requirements that would be needed to use local MSTM data; the default age distribution is used. It is assumed that given the very large MSTM sample area, vehicle age distributions trend towards the national population. "The default age distributions in MOVES are specific for each calendar year and include assumptions about changes in age distributions over time" (US EPA 2010). A sample age distribution for the year 2011 is provided in Figure C-2.

Figure C-2 Sample Default MOVES Vehicle Fleet Age Distribution, 2011
Source: EPA Motor Vehicle Emission Simulator, 2010 (MOVES 2007)

2.2.4 Average speed distribution - "Vehicle power, speed, and acceleration have a significant effect on vehicle emissions. MOVES models those emission effects by assigning activity to specific drive cycles or operating mode distributions" (EPA Data).

The EM takes congested roadway speeds developed in the traffic assignment portion of the transportation model and sorts the speed for each link into EPA defined speed bins and appends the bin to the highway link. Using these pre-defined speed bins running emission rates are calculated for each link. Table C-2 provides a listing of the EPA defined speed bins.

Table C-2 MOVES Defined Speed Bins

Speed Bin ID	Average Bin Speed	Speed Bin Range
1	2.5	speed < 2.5mph
2	5	2.5mph <= speed < 7.5mph
3	10	7.5mph <= speed < 12.5mph
4	15	12.5mph <= speed < 17.5mph
5	20	17.5mph <= speed <22.5mph
6	25	22.5mph <= speed < 27.5mph
7	30	27.5mph <= speed < 32.5mph
8	35	32.5mph <= speed < 37.5mph
9	40	37.5mph <= speed < 42.5mph
10	45	42.5mph <= speed < 47.5mph
11	50	47.5mph <= speed < 52.5mph
12	55	52.5mph <= speed < 57.5mph
13	60	57.5mph <= speed < 62.5mph
14	65	62.5mph <= speed < 67.5mph
15	70	67.5mph <= speed < 72.5mph
16	75	72.5mph <= speed

Source: EPA Motor Vehicle Emission Simulator, 2010 (MOVES 2007)

2.2.5 Road type distribution: The amount of vehicle miles traveled (VMT) on varied road types can have a significant effect on overall emissions from on-road mobile emission sources. MOVES accounts for this differentiation in roads by cross-classifying emission rates by five road types:

Off-Network (roadtype 1) – all locations where the predominant activity is vehicle starts, parking and idling (parking lots, truck stops, rest areas, freight or bus terminals)

Rural Restricted Access (2) – rural highways that can only be accessed by an on-ramp

Rural Unrestricted Access (3) – all other rural roads (arterials, connectors, and local streets)

Urban Restricted Access (4) – urban highways that can only be accessed by an on-ramp

Urban Unrestricted Access (5) – all other urban roads (arterials, connectors, and local streets) (US EPA 2010). The EM categorizes each of the MSTM network links into these MOVES defined road types so that emission rates at the link level reflect the unique parameters of area and facility type.

2.2.6 Fuel formulation and supply: Fuel formulation and supply have an impact on the amount and type of pollutants produced by vehicle fleets. MOVES models these differences in fuel formulation and fuel supply at the county level for the area being modeled. The fuel formulation attributions table defines the chemical composition of local fuel (such as RVP, sulfur level, ethanol volume, etc.); while the fuel supply attribution table identifies the fuel formulations used in an area and each formulation's respective market share. MOVES calculates fuel composition based on the attributes defined in the fuel formulation table. MOVES then uses the market shares from the fuel supply attribution table to create weighted fuel adjustment factors to determine total pollutant emission rates. "MOVES has default gasoline and diesel fuel formulation and supply information for every county-year-month combination that can be selected. The default fuels in each county were developed from two sources: 1) the NMIM County Database (NCD), which incorporates data from local, regional (refinery-level), and RFG fuel surveys, for years up to 2005; and 2) the Energy Information Administration's Annual Energy Outlook 2007, which projected fuel usage for 2012 (all later years are identical to 2012). Values for some fuel properties were interpolated in the gap between 2005 and 2012 to generate a consistent trend." (US EPA 2010)

The EM models emissions for two fuel formulations, gasoline and diesel. The EPA describes the chemical composition of each fuel and its impact on emission in each county as follows:

"Gasoline: The Tier 2 gasoline sulfur rule established a national average of 30 ppm sulfur (S) and a cap of 80 ppm S, which was fully implemented in 2006 (except for the Geographic Phase-In Area, see 65 FR 6755, February 10, 2000). This means that some areas will have sulfur levels above 30 ppm S and users creating a new formulation should not assume 30 ppm S gasoline. Areas where the MOVES default gasoline sulfur level is above 30 should use this value unless local data on

sulfur content are available. MOVES2010 does not provide additional benefits or reductions for sulfur levels below 30 ppm S.

Diesel: Between 2006 and 2010, the Ultra-Low Sulfur rule requires at least 80% of the highway diesel fuel sold to meet the 15 ppm S standard; the remaining 20% must meet the Low Sulfur Diesel standard of 500 ppm S. In the Regulatory Impact Analysis for the Non-road Diesel rule (RIA: EPA420-R-04-007, Rule: 69 FR 38957, June 29, 2004), a weighted average of the sulfur level in diesel fuel was estimated as 43 ppm S and in many areas, the MOVES default sulfur level value is 43 ppm S for these years because the singular value from the NCD was used to generate the fuel properties in MOVES. The default weighted value is acceptable if users do not have local data in this instance because the diesel sulfur value impacts the fuel adjustment in a linear fashion for all emission calculations. However, users can also enter two diesel fuel formulations, with sulfur level of 11 and 331 and market shares of 0.9 and 0.1, respectively, which would yield an average sulfur level of 43 ppm S and be more representative of actual fuel usage. If users have volumetric data for diesel fuel sulfur levels in the area being modeled, this information can be entered in the "sulfurLevel" and "marketShare" fields of the "fuelformulation" and "fuelsupply" tables, respectively" (US EPA 2010).

3   OUTPUTS

2.3.2 Pollutants Considered: The MSTM Emissions Model uses the MOVES Emissions Rate (Factor) Model to measure emissions across the entire network. The emission rates (emissions per unit of distance for running emissions or per vehicle for starts, extended idle and resting evaporative emissions) are created in a look-up table format which is then applied to the appropriate figures from the loaded MSTM network. Emissions rates are output from MOVES only and input into MSTM as part of the emissions model.

Two categories of emissions and five compounds are modeled with MOVES and input into the MSTM Emissions Model.

2.3.2a Emissions related to Ozone formation

Oxides of Nitrogen – Primarily concerned with the formation of nitrogen dioxide. Oxides of nitrogen are a group of highly reactive gasses which includes such pollutants as Nitrogen dioxide (NO2), nitrous acid and nitric acid. "While EPA's National Ambient Air Quality Standard covers this entire group of NOx, NO2 is the component of greatest interest and the indicator for the larger group of nitrogen oxides. NO2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO2 is linked with a number of adverse effects on the respiratory system." (3)

Volatile Organic Compounds – Volatile organic compounds (VOC) are compounds composed primarily of carbon that exclude more stable pollutants like carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, that participate in "atmospheric photochemical reactions. A VOC is thus a compound that reacts with light and nitrogen oxides to for ozone. (4)

2.3.2b Emissions related to Greenhouse Gas (GHG) formation

Carbon Dioxide Equivalents – Carbon dioxide equivalents is a measure of a compound's equivalent to carbon dioxide's global warming potential (GWP). "Carbon dioxide equivalents are commonly expressed as 'million metric tons of carbon dioxide equivalents (MMTCO2Eq).' The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP. The use of carbon equivalents (MMTCE) is declining.

MMTCO2Eq = (million metric tons of a gas) * (GWP of the gas)" Carbon dioxide (5)

Methane – "Methane (CH4) is a greenhouse gas that remains in the atmosphere for approximately 9-15 years. Methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide (CO2) over a 100-year period and is emitted from a variety of natural and human-influenced sources. Human-influenced sources include landfills, natural gas and petroleum systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial process." (6)

Nitrous Oxide – "Nitrous oxide (N2O) is a greenhouse gas with an atmospheric lifetime of approximately 120 years. Nitrous oxide is about 310 times more effective in trapping heat in the atmosphere than CO2 over a 100-year period. The primary sources of human-influenced emissions of nitrous oxide are agricultural soil management, animal manure management, sewage treatment, mobile and stationary fuel combustion, adipic acid production, and nitric acid production. Nitrous oxide is also emitted naturally from a wide variety of biological sources." (7)

Final Model Outputs - MOVES and EM account for several forms of emissions. Within the two broad categories of running and non-running emissions six sources of emissions are considered. For running (when vehicle is in motion) tailpipe exhaust, crankcase (engine) and evaporative emissions are calculated. For non-running (when vehicle is stationary) start exhaust, refueling and evaporative emissions are calculated.

4   REFERENCES

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