Appendix A: CSNA Emissions Inventory and Modeling Documentation

Introduction

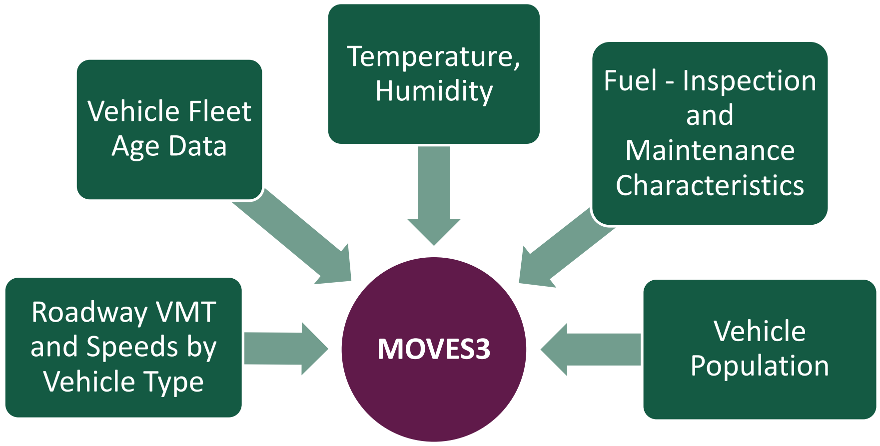
This technical analysis report documents the methodology and assumptions used to produce the greenhouse gas (GHG) inventory for Maryland's on-road portion of the transportation sector. Statewide emissions have been estimated for the 2031 Standards and Current Vehicle Miles Traveled (VMT) Growth (SCVG) and 2031 Metropolitan Planning Organization (MPO) Plans & Programs (P/P) scenarios based on the most recent traffic trends. The inventory was calculated by estimating emissions for carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). Those emissions were then converted to carbon dioxide equivalents (CO2e) that are measured in the units of million metric tons (mmt). CO2 represents about 97% of the transportation sector's GHG emissions.

The on-road portion of the inventory was developed using the U.S. Environmental Protection Agency's (EPA) emissions model Motor Vehicle Emissions Simulator (MOVES3) released in November 2020. The MOVES3 model incorporates the latest data on vehicle populations, travel activity and emission rates as well as updated fuel data at the county level. The model used (version 3.1) includes updated on-road emission rates for heavy-duty GHG Phase 2 rule and the effects of the Safer Affordable Fuel-Efficient (SAFE) rule on light-duty fuel economy as compared to its predecessor, MOVES2014b. MOVES3 calculates GHG emissions from vehicle energy consumption rates, which varies by vehicle operating characteristics including speed, engine size and vehicle age.

On-Road Analysis Process

The data, tools and methodologies employed to conduct the on-road vehicle GHG emissions inventory were developed in close consultation with the Maryland Department of the Environment (MDE) and are consistent with the *MOVES3 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity, US EPA Office of Transportation and Air Quality, EPA-420-B-20-052, November 2020*. MOVES3 incorporates all existing corporate average fuel economy (CAFE) standards in place in 2017 plus: a) medium-/heavy-duty GHG standards Phase 1 for model years 2014-2018, b) medium-/heavy-duty GHG standards Phase 2 for model years 2018 and beyond c) light-duty GHG standards Phase 2 for model years 2017-2020, d) SAFE Vehicle Rule for model years 2021-2026 light-duty vehicles and e) Tier 3 fuel and vehicle standards for model years 2017-2025. As illustrated in **Figure 1**, the MOVES3 model has been integrated with local traffic, vehicle fleet, environmental, fuel and control strategy data to estimate statewide emissions.

Figure 1: Emission Calculation Data Process



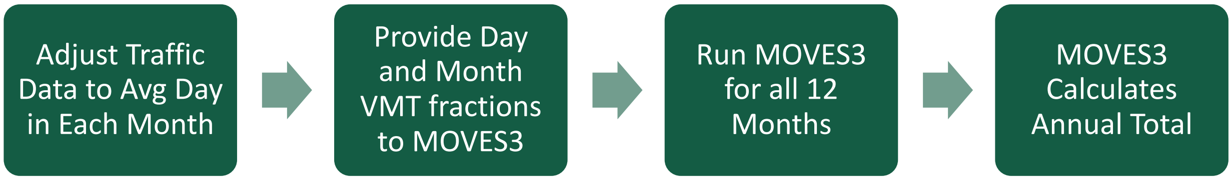
The modeling assumptions and data sources were developed in coordination with MDE and are consistent with other State Implementation Plan-related inventory efforts. The process represents a "bottom-up" approach to estimating statewide GHG emissions based on available roadway and traffic data. A "bottom-up" approach provides several advantages over simplified "top-down" calculations using statewide fuel consumption. These include:

- Addresses potential issues related to the location of purchased fuel. Vehicle trips with trip ends outside of the state (e.g. including "thru" traffic) create complications in estimating GHG emissions. For example, commuters living in Maryland may purchase fuel there but may spend much of their traveling in Washington D.C. The opposite case may include commuters from Pennsylvania working in Maryland. With a "bottom-up" approach, emissions are calculated for all vehicles using the transportation system.

- Allows for a more robust forecasting process based on historic trends of VMT or regional population and employment forecasts and their relationship to future travel. For example, traffic data can be forecasted using growth assumptions determined by the MPO through their analytics (travel model) and interagency consultation processes.

GHG emission values are reported as annual numbers for the 2031 SCVG scenario. The annual values were calculated based on annual MOVES3 runs as summarized in Figure 2. Each annual run used traffic volumes and speeds that represent an annual average daily traffic (AADT) condition, temperatures and fuel input parameters representing an average day in each month.

Figure 2: Calculation of Annual Emissions



For the 2031 SCVG and P/P scenarios emissions inventories, the traffic data was based on roadway segment data obtained from the State Highway Administration (SHA). This data does not contain information on congested speeds and the hourly detail needed by MOVES3. As a result, post-processing software (PPSUITE) was used to calculate hourly-congested speeds for each roadway link, apply vehicle type fractions, aggregate VMT and vehicle hours traveled, and prepare MOVES3 traffic-related input files. The PPSUITE software and process methodologies are consistent with what is used for state inventories and transportation conformity analyses throughout Maryland. Other key inputs including vehicle population, temperatures, fuel characteristics and vehicle age were obtained from and/or prepared in close coordination with MDE staff. The following sections summarize the key input data assumptions used for the inventory runs.

Summary of Data Sources

A summary of key input data sources and assumptions were developed in consultation with MDE and are consistent with the *MOVES3 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity, US EPA Office of Transportation and Air Quality, EPA-420-B-20-052, November 2020* and are provided in **Table 1**. Many of these data inputs are consistent with those used for State Implementation Plan inventories and conformity analyses. Several data items require additional notes:

- Traffic volumes and VMT are forecasted for the 2031 SCVG scenario analysis. A discussion of forecasted traffic volumes and VMT is discussed in more detail in the following section.

- Vehicle population is a key input that has an important impact on start and evaporative emissions. The MOVES3 model requires the population of vehicles by the 13 source type categories. For light-duty vehicles, vehicle population inputs were prepared and provided by MDE for the base year (2020). For the analysis year 2031, the vehicle population was forecasted based on projected household and population growth obtained from state and MPO sources and VMT growth. For heavy-duty trucks, vehicle population was calculated from VMT using MOVES3 default estimates for the typical miles per vehicle by source type (e.g. vehicle type). The PPSUITE post processor automatically prepares the vehicle population file under this method.

- The vehicle mixes are another important file that is used to disaggregate total vehicle volumes and VMT to the 13 MOVES3 source types. The vehicle mix was calculated based on 2020 SHA vehicle type pattern percentages by functional class, which disaggregates volumes into four vehicle types: light-duty vehicles, heavy-duty vehicles, buses and motorcycles. As illustrated in **Figure 3**, from these four vehicle groups, MOVES3 default Maryland county VMT distributions by source type were used to divide the four groups into each of the MOVES3 13 source types.

Figure 3: Defining Vehicle Types

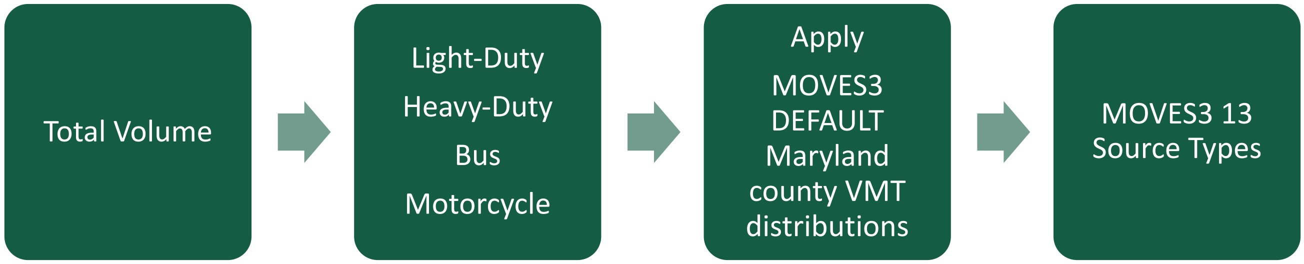


Table 1: Summary of Key Data Sources

Data Item	Source	Description
Roadway Characteristics	2020 Maryland Department of Transportation (MDOT) SHA Universal Database	Includes lanes, segment distance, facility type, speed limit
Traffic Volumes	2020 MDOT SHA Universal Database	AADT
Seasonal Adjustments	SHA 2020 Factors to Convert Volume to AADT report from the MDOT SHA website	Used to develop day and month VMT fractions as inputs to MOVES3 to disaggregate annual VMT to daily and monthly VMT
VMT	Highway Performance Monitoring System (HPMS) 2020	Used to adjust VMT to the reported 2020 HPMS totals by county and functional Class
Hourly Patterns	MDOT SHA 2020 24-hour traffic count data	Used to disaggregate volumes and VMT to each hour of the day
Vehicle Type Mix	2020 MDOT SHA Vehicle Classification by Functional Class and TMS & hourly distribution from SHA traffic count data	Used to split traffic volumes to the 13 MOVES3 vehicle source types
Vehicle Ages	2020 Maryland Registration data; MOVES3 national default age distribution data	Provides the percentage of vehicles by each model year age
Hourly Speeds	Calculated by PPSUITE Post Processor	Hourly speed distribution file used by MOVES3 to estimate emission factors
Inspection and Maintenance Data	Vehicle Emissions Inspection Program Reinvention Program provided by MDE	Based on the current Inspection and Maintenance program
Fuel Characteristics	MOVES3 inputs provided by MDE	Fuel characteristics vary by year
Temperatures	2020 inputs provided by MDE	Average monthly temperature sets
Vehicle Population	Light-duty vehicles: used 2020 vehicle population data provided by MDE and applied growth rates to forecast population to 2031 Heavy-duty trucks (source type 52, 53, 61 & 62): Calculated by PPSUITE Post Processor; MOVES3 Default Miles/Vehicle Population Data	Number of vehicles by MOVES3 source type that impact forecasted start and evaporative emissions

Traffic Volume and VMT Forecasts

The traffic volumes and VMT within the SHA traffic database were forecast to estimate future year emissions. Several alternatives are available to determine forecast growth rates, ranging from historical VMT trends to the use of MPO-based travel models that include forecast demographics for distinct areas in each county. For the 2031 SCVG scenario, the forecasts were determined based on historic trends of 2000-2019 highway performance monitoring system (HPMS) VMT growth. Using 2022 HPMS VMT as the base, the average statewide annualized growth rate through 2031 for this scenario is 2.0%. The 2031 VMT for the rollback of the SAFE rule scenario uses the same forecasted VMT as the 2031 SCVG scenario.

The P/P scenario is from the implementation of the most recently adopted MPO fiscally constrained long-range transportation plans and cooperative land use. The VMT projections of implementing the plans and programs that include MPO planned projects (highway and transit) and future regional demographic projections developed by the jurisdictions in cooperation with the Maryland Department of Planning (MDP), show an expected decrease of 4,725 billion VMT in 2031 relative to the SCVG scenario VMT forecast. The average statewide annualized VMT growth rate through 2031 for the P/P scenario is 1.1%. Annual VMT growth rates as forecast by the Baltimore Metropolitan Council (BMC), Metro Washington Council of Governments (MWCOG), Hagerstown/Eastern Panhandle Metropolitan Planning Organization (HEPMPO) and Cecil County within their modeling areas have been used for modeling purposes. Outside of these MPO counties, SHA-developed HPMS VMT growth rates from 2000 to 2019 are used. **Table 2** summarizes the growth rates by county for the 2031 SCVG and the 2031 P/P scenarios.

Table 2: 2022-2031 VMT Annual Growth Rates for the 2031 Standards and Current VMT Growth and MPO Plans & Programs Scenarios

County	2031 Standards and Current VMT Growth (Based on 2000-2019 HPMS)	2031 MPO Plans & Programs
Allegany	0.5%	0.5%
Anne Arundel	2.2%	1.6%
Baltimore	2.0%	1.3%
Calvert	1.7%	0.0%
Caroline	1.5%	1.5%
Carroll	1.2%	1.2%
Cecil	1.2%	1.4%
Charles	2.8%	0.6%
Dorchester	0.3%	0.3%
Frederick	2.6%	2.0%
Garrett	0.1%	0.1%
Harford	2.0%	1.8%
Howard	2.9%	2.0%
Kent	0.4%	0.4%
Montgomery	1.8%	0.5%
Prince George's	2.3%	0.0%
Queen Anne's	1.4%	1.4%
Saint Mary's	2.4%	0.0%
Somerset	0.1%	0.1%
Talbot	1.5%	1.5%
Washington	1.3%	1.0%
Wicomico	1.1%	1.1%
Worcester	4.5%	4.5%
Baltimore City	0.9%	1.3%
Statewide	**2.0%**	**1.1%**

Table 3 summarizes the total 2031 forecast VMT by vehicle type for the 2031 SCVG and P/P scenarios.

Table 3: 2031 Standards and Current VMT Growth and MPO Plans and Programs Scenarios – VMT by Vehicle Type

Annual VMT (millions)	2031 SCVG	2031 P/P
Light-Duty	62,281	57,891
Medium-/Heavy-Duty Truck & Bus	5,312	4,977
TOTAL VMT (in millions)	67,593	62,868

The analysis process (e.g. using PPSUITE post-processor) re-calculates roadway speeds based on the forecast volumes. As a result, future year emissions are sensitive to the impact of increasing traffic growth on regional congestion.

Vehicle Technology Adjustments

The MOVES3 emission model includes the effects of the following post-2017 vehicle programs on future vehicle emission factors:

- **Maryland Clean Car Program (Model Year 2011)** – Implements California's Low-Emission Vehicle (LEV) standards to vehicles purchased in Maryland. The California LEV program also includes a Zero Emissions Vehicle (ZEV) mandate (adopted in 2007). These programs were included in the modeling process following the guidelines provided in the MOVES3 Technical Guidance.

- **National Program Phase 2 (Model Years 2017-2020)** – The light-duty vehicle fuel economy for model years between 2017 and 2020 is based on the October 15, 2012 Rule "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards" (EPA-HQ-OAR-2010-0799 and No. NHTSA-2010-0131)[1]. These standards were projected through the model year 2025 but were replaced by the SAFE Vehicle Rule.

- **Safer Affordable Fuel-Efficient (SAFE) Vehicle Rule (Model Years (2021-2026)** – The light-duty fuel economy standards for model years 2021-2026. SAFE replaces the Phase 2 National Fuel Economy Program. Under SAFE, the rollback to standards equates to estimated miles per gallon efficiency of 40.4 mpg compared to the previous rule that would have achieved 54.5 mpg (published April 2020).

- **Phase 1 National Medium- and Heavy-Duty Vehicle Standards (Model Years 2014-2018)** – The medium- and heavy-duty vehicle fuel economy for model years between 2014-2018 are based on the September 15, 2011, Rule "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles." The rulemaking has adopted standards for three main regulatory categories: combination tractors, heavy-duty pickups and vans, and vocational vehicles. For combination

[1] http://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf

tractors, the final standard will achieve a 9 to 23% reduction in CO2 emissions and fuel consumption by the 2017 model year compared to the 2010 baseline. For heavy-duty pickup trucks and vans, separate standards have been established for gasoline and diesel trucks, which will achieve up to a 10% reduction for gasoline vehicles and a 15% reduction for diesel vehicles by the 2018 model year (12 and 17% respectively if accounting for air conditioning leakage). Lastly, for vocational vehicles, the final standards would achieve CO2 emission reductions from 6 to 9% by the 2018 model year.

- **Phase 2 National Medium- and Heavy-Duty Vehicle Standards (2018 and Beyond)** – The Phase 2 fuel efficiency and GHG standards for medium- and heavy-duty vehicles for the model year 2018 and beyond. The standards apply to four categories of medium- and heavy-duty vehicles: combination tractors, heavy-duty pickups and vans, vocational vehicles, and trailers to reduce GHG emissions and improve fuel efficiency. The standards phase in between model years 2021 and 2027 for engines and vehicles, and between model years 2018 and 2027 for trailers (published October 2016).

SAFE Vehicle Rule Rollback

On December 30, 2021, the EPA revised the light-duty fuel economy standards for model years 2023-2026. The EPA established significantly more stringent GHG emissions standards for model years 2023-2026 compared to the standards established by the SAFE rule. With the revised fuel standards, the projected industry fleet-wide CO2 target is 161 grams/mile in 2026, which equates to an average fuel economy of 55 mpg.

Since MOVES3 incorporates the effects of the SAFE Rule on light-duty fuel economy, the rollback of the SAFE Rule scenario adjusts the GHG emission rates for the light-duty vehicles to represent the revised light-duty fuel economy standards in EPA's December 2021 rulemaking for model years 2023-2026. **Table 4** presents the estimates of the CO2 targets for the revised fuel economy standards.

Table 5 summarizes the GHG emission rate adjustment factors (calculated based on **Table 4**) that are used to apply to the GHG emission factors by model years from the 2031 SCVG scenario. The GHG emissions for the light-duty vehicles for the Rollback of SAFE Rule scenario are then adjusted/ based on the adjustment factors in

Table 5 to reflect the more stringent fuel economy standards in the December 2021 rule.

Table 4: Projected Industry Fleet-wide CO2 Compliance Targets (CO2 grams/mile)

Model Year	Cars	Trucks	Combined Fleet
2022 (SAFE Reference)	181	261	224
2023	166	234	202
2024	158	222	192
2025	149	207	179
2026 and Later	132	187	161

Table 5: GHG Emission Rate Adjustment Factors for Rollback of SAFE Rule Scenario

Model Year	Cars	Trucks	Combined Fleet
2022	1.0000	1.0000	1.0000
2023	0.9171	0.8966	0.9018
2024	0.8729	0.8506	0.8571
2025	0.8232	0.7931	0.7991
2026 and Later	0.7293	0.7165	0.7188

Emission Results

The 2031 SCVG scenario emission results for the Maryland statewide GHG inventories are provided in **Table 6**. In **Table 7**, the 2031 rollback of the SAFE Rule is considered as another scenario and these emission results are shown. Finally, the emission results for the Maryland statewide GHG inventories are provided in
Table 8 for the P/P scenario (accounting for the rollback of the SAFE rule). Within each table, emissions are also provided by fuel type and vehicle type.

Table 6: 2031 Standards and Current VMT Growth Annual-On Road GHG Emissions (mmt)

	VMT (Millions)	CO_2	CH_4	N_2O	CO_2e
		By Fuel Type			
Gasoline	61,190	18.929	0.000470	0.000286	19.026
Diesel	5,191	6.081	0.000131	0.000016	6.088
CNG	63.6	0.082	0.001103	0.000010	0.113
E-85	98.3	0.032	0.000002	0.000000	0.032
Electricity	1,051	-	-	-	-
		By MOVES Vehicle Type			
Motorcycle	300	0.109	0.000029	0.000001	0.110
Passenger Car	26,555	6.611	0.000183	0.000100	6.645
Passenger Truck	31,886	10.737	0.000231	0.000159	10.790
Light Commercial Truck	3,540	1.232	0.000024	0.000018	1.238
Intercity Bus	123	0.186	0.000165	0.000001	0.190
Transit Bus	97.6	0.141	0.000125	0.000001	0.144
School Bus	271	0.289	0.000072	0.000001	0.291
Refuse Truck	26.1	0.039	0.000117	0.000001	0.042
Single Unit Short-haul Truck	1,789	1.569	0.000399	0.000022	1.586
Single Unit Long-haul Truck	118	0.099	0.000022	0.000001	0.099
Motor Home	51.1	0.059	0.000002	0.000000	0.059
Combination Short-haul Truck	540	0.778	0.000297	0.000003	0.786
Combination Long-haul Truck	2,296	3.276	0.000041	0.000005	3.279

Table 7: 2031 Rollback of SAFE Rule Scenario Annual On-Road GHG Emissions (mmt)

	VMT (Millions)	CO_2	CH_4	N_2O	CO_2e
		By Fuel Type			
Gasoline	61,190	16.791	0.000422	0.000254	16.877
Diesel	5,191	6.057	0.000129	0.000016	6.065
CNG	63.6	0.082	0.001103	0.000010	0.113
E-85	98.3	0.028	0.000002	0.000000	0.028
Electricity	1,051	-	-	-	-
		By MOVES Vehicle Type			
Motorcycle	300	0.109	0.000029	0.000001	0.110
Passenger Car	26,555	5.967	0.000165	0.000090	5.998
Passenger Truck	31,886	9.411	0.000202	0.000139	9.457
Light Commercial Truck	3,540	1.035	0.000020	0.000015	1.040
Intercity Bus	123	0.186	0.000165	0.000001	0.190
Transit Bus	97.6	0.141	0.000125	0.000001	0.144
School Bus	271	0.289	0.000072	0.000001	0.291
Refuse Truck	26.1	0.039	0.000117	0.000001	0.042
Single Unit Short-haul Truck	1,789	1.569	0.000399	0.000022	1.586
Single Unit Long-haul Truck	118	0.099	0.000022	0.000001	0.099
Motor Home	51.1	0.059	0.000002	0.000000	0.059
Combination Short-haul Truck	540	0.778	0.000297	0.000003	0.786
Combination Long-haul Truck	2,296	3.276	0.000041	0.000005	3.279

Table 8: 2031 Plans and Programs Scenario Annual On-Road GHG Emissions (mmt) (Accounting for the Rollback of SAFE Rule)

	VMT (Millions)	CO_2	CH_4	N_2O	CO_2e
		By Fuel Type			
Gasoline	56,879	15.660	0.000404	0.000248	15.744
Diesel	4,864	5.674	0.000122	0.000015	5.681
CNG	59.8	0.077	0.001035	0.000010	0.106
E-85	91.6	0.026	0.000002	0.000000	0.026
Electricity	973	-	-	-	-
		By MOVES Vehicle Type			
Motorcycle	280	0.102	0.000027	0.000001	0.103
Passenger Car	24,576	5.541	0.000159	0.000088	5.571
Passenger Truck	29,728	8.796	0.000195	0.000136	8.842
Light Commercial Truck	3,307	0.969	0.000019	0.000015	0.974
Intercity Bus	116	0.175	0.000156	0.000001	0.179
Transit Bus	90.4	0.131	0.000115	0.000001	0.134
School Bus	250	0.267	0.000066	0.000001	0.269
Refuse Truck	26.0	0.039	0.000117	0.000001	0.042
Single Unit Short-haul Truck	1,673	1.467	0.000372	0.000021	1.482
Single Unit Long-haul Truck	111	0.092	0.000021	0.000000	0.093
Motor Home	50.8	0.058	0.000002	0.000000	0.058
Combination Short-haul Truck	506	0.729	0.000277	0.000003	0.737
Combination Long-haul Truck	2,153	3.071	0.000039	0.000005	3.073