# CMAQ Emissions Calculator Toolkit

## Documentation of Emissions Data for the Transit Bus Service and Fleet Expansion Tool

This document serves as a supplement to the documentation for the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit) Transit Bus Service and Fleet Expansion Tool. It discusses the primary data sources and how the emissions datasets for these calculators were derived. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses.

This document details the emissions data used from the US Environmental Protection Agency (EPA) Motor Vehicle Emissions Simulator (MOVES)[1] and the Argonne National Laboratory Alternative Fuel Lifecycle Environmental and Economic Transportation (AFLEET) Tool.[2] The MOVES Methodology cites specific inputs/outputs and post-processing that were used to generate the national-scale emission rates used within the tool. The AFLEET Methodology describes how alternative fuel adjustment factors were accessed to estimate emissions for alternative fuel vehicle data not included in MOVES. The user-supplied emission rates section provides instruction on how users may import their own emission rates into the tool.

## Contents

**MOVES METHODOLOGY** ..... 1

**AFLEET METHODOLOGY** ..... 5

**USER-SUPPLIED EMISSION RATES** ..... 6

## MOVES METHODOLOGY

The emission reductions calculators for the Transit Bus Service and Fleet Expansion Tool rely primarily on running, start, and crankcase exhaust emission rates[3] as well as national-scale activity rates within MOVES. Data for evaporative emissions were not included in this tool. The transit bus and passenger vehicle emission rates were obtained with a set of MOVES runs in which all evaluation years were combined into a single MOVES run, and were generated on the national scale. MOVES3 (version 3.0.2 from September 2021)[4] was used to obtain the rates used in the tool.

[1] US Environmental Protection Agency, Office of Transportation and Air Quality, https://www.epa.gov/moves
[2] US Department of Energy, Argonne National Laboratory, https://greet.es.anl.gov/afleet_tool
[3] As a simplification, brakewear and tirewear have been included in the running particulate matter (PM) emissions.
[4] EPA, https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves

## National-Scale Run

Table 1 shows the national-scale run used to obtain transit bus emission rates.

*Table 1 National-scale transit bus run parameters*

| Category | Variable | Input |
|---|---|---|
| **Description** | ----- | <blank> |
| **Scale** | Model | Onroad |
| | Domain/Scale | National |
| | Calculation Type | Inventory |
| **Time Spans** | Time Aggregation Level | Year |
| | Years | [2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040] |
| | Months | All Selected |
| | Days | All Selected |
| | Hours | All Selected |
| **Geographic Bounds** | ----- | Nation |
| **Vehicles/Equipment** | On-Road Vehicle Equipment | Gasoline, Diesel, and CNG Transit Buses |
| **Road Type** | Road Types | All Selected |
| **Pollutants and Processes (selected)** | Total Gaseous Hydrocarbons | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust, Refueling Displacement Vapor Loss[5], Refueling Spillage Loss[5] |
| | Non-methane Hydrocarbons | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust, Refueling Displacement Vapor Loss[5], Refueling Spillage Loss[5] |
| | Volatile Organic Compounds | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust, Refueling Displacement Vapor Loss[5], Refueling Spillage Loss[5] |
| | Carbon Monoxide (CO) | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Oxides of Nitrogen (NOx) | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Primary Exhaust PM2.5 – Total | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Primary PM2.5 – Brakewear Particulate | Brakewear |

[5] Refueling emissions only available for gasoline transit buses.

| Category | Variable | Input |
|---|---|---|
| | Primary PM2.5 – Tirewear Particulate | Tirewear |
| | Primary Exhaust PM10 – Total | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Primary PM10 – Brakewear Particulate | Brakewear |
| | Primary PM10 – Tirewear Particulate | Tirewear |
| **Manage Input Data Series** | ----- | <blank> |
| **Strategies** | Rate of Progress | <blank> |
| **General Output** | Units | Mass: kilograms, Energy: Million BTU, Distance: miles |
| | Activity | Distance Traveled, Population, Starts |
| **Output Emissions Detail** | Always | Year, Nation |
| | On Road/Off Road | Road Type, Source Use Type |
| | For All Vehicle/Equipment Combinations | Model Year, Fuel Type, Emission Process |
| **Advanced Performance Features** | ----- | <blank> |

Similarly, the national-scale run used to obtain passenger vehicle emission rates was set up with the following parameters:

*Table 2 National-scale passenger vehicle run parameters*

| Category | Variable | Input |
|---|---|---|
| **Description** | ----- | <blank> |
| **Scale** | Model | Onroad |
| | Domain/Scale | National |
| | Calculation Type | Inventory |
| **Time Spans** | Time Aggregation Level | Year |
| | Years | [2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040] |
| | Months | All Selected |
| | Days | All Selected |
| | Hours | All Selected |
| **Geographic Bounds** | ----- | Nation |
| **Vehicles/Equipment** | On-Road Vehicle Equipment | Gasoline, Diesel, and E85 Passenger Cars; Gasoline, Diesel, and E85 Passenger Trucks |
| **Road Type** | Road Types | All Selected |
| **Pollutants and Processes (selected)** | Total Gaseous Hydrocarbons | Running Exhaust, Start Exhaust |
| | Non-Methane Hydrocarbons | Running Exhaust, Start Exhaust |

| Category | Variable | Input |
|---|---|---|
| | Volatile Organic Compounds | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Carbon Monoxide (CO) | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Oxides of Nitrogen (NOx) | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Primary Exhaust PM2.5 – Total | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Primary PM2.5 – Brakewear Particulate | Brakewear |
| | Primary PM2.5 – Tirewear Particulate | Tirewear |
| | Primary Exhaust PM10 – Total | Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust |
| | Primary PM10 – Brakewear Particulate | Brakewear |
| | Primary PM10 – Tirewear Particulate | Tirewear |
| **Manage Input Data Series** | ----- | <blank> |
| **Strategies** | Rate of Progress | <blank> |
| **General Output** | Units | Mass: kilograms, Energy: Million BTU, Distance: miles |
| | Activity | Distance Traveled, Population, Starts |
| **Output Emissions Detail** | Always | Year, Nation |
| | On Road/Off Road | None selected |
| | For All Vehicle/Equipment Combinations | Emission Process |
| **Advanced Performance Features** | ----- | <blank> |

### Post-MOVES Run Data Processing:

Results from the national-scale MOVES run were used to obtain different categories of data for use in this Transit Bus Service and Fleet Expansion Tool. The following descriptions are of the MOVES emissions inventory and activity data used to create the emission rates in the tool:

1. **Activity data –** MOVES national default activity data was used to produce estimates of vehicle miles traveled for transit buses and passenger vehicles.
2. **Emissions data –** Emission rates were generated on a per-mile basis for transit buses (sourceTypeID 42). For passenger vehicles, a combination of passenger cars (sourceTypeID 21)

and passenger trucks (sourceTypeID 31), emission rates were calculated on a per mile basis for running emission processes and on a per start basis for start emissions processes. This required joining emission inventories from the movesoutput table and activity from the movesactivityoutput table. The emission rates of transit buses were developed over an aggregation of running and start operations. For passenger vehicles, rates were developed separately for running and start operations.

For transit buses, emission rates are based on evaluation year, pollutant, model year, fuel type, and road type. These rates are aggregated over all running, start, crankcase running and crankcase start processes, in order to apply the alternative fuel factors from AFLEET. As discussed in the tool's user documentation, the tool allows for modeling of transit buses powered by conventional fuels, namely gasoline and diesel, as well as compressed natural gas (CNG), battery electric hybrid-electric, and other alternative fuels.

For passenger vehicles, emission rates are based on evaluation year, running or start emissions processes, and pollutant only. Emission rates are aggregated over emission processes specific to running activity and also over processes specific to start activity. Emission rates are aggregated over other parameters such as model year, fuel type, and road type. Those interested in customizing the distributions of these parameters for passenger vehicles can generate and import their own local emission rates, as described in the last section of this document.

## AFLEET METHODOLOGY

The Alternative Fuel Emission Factor Multipliers from AFLEET 2020's Background Data tab were simply copied and pasted into this CMAQ tool. Where alternative fuel emission rates were not available in MOVES, alternative fuel factors from AFLEET 2020[6] were applied to default conventional fuel emission rates depending on the fuel type and pollutant. In this tool, AFLEET alternative fuel factors for transit buses are applied to the MOVES diesel transit bus rates for emission estimates. As described in the tool's user guide, Table 3 below presents a list of data sources of transit bus fuel types (gasoline, diesel, CNG, or alternative fuels) and indicates whether the emissions data for each fuel has come from MOVES directly or from AFLEET-adjusted conventional fuel emission rates. Combinations without emissions data are left out from the table (see footnote 7 for more detail).

[6] DOE, https://greet.es.anl.gov/index.php?content=registration&from=afleet

*Table 3 Alternative fuels available in this tool for transit buses*[7]

| Replacement Fuel | Data Source |
|---|---|
| Gasoline | M |
| Diesel Fuel | M |
| Compressed Natural Gas (CNG) | M |
| Biodiesel (B100) | A |
| Biodiesel (B20) | A |
| Hybrid Electric (HEV) | A |
| Hydraulic Hybrid (HHV) | A |
| Liquefied Natural Gas (LNG) | A |
| Dual Fuel (Natural Gas/Diesel, LNG/D) | A |
| Battery Electric (BEV) | A |
| Hydrogen Fuel Cell (FCV) | A |
| **M =** MOVES emission rates, **A = A**FLEET factors combined with conventional fuel emission rates | |

The updated version of the CMAQ Transit Service & Fleet Expansion tool includes outputs for $CO_2$, $CO_2$ equivalents reductions as well as Total Energy Consumption reductions. AFLEET does not include emissions factors for these emissions quantities. Therefore, estimates of these benefits are only available for fuel types that are output by MOVES, namely for gasoline, diesel, and CNG transit buses. If the alternative fuels that use AFLEET factors are selected (before or after project), the tool will not output estimates for these pollutants.

## USER-SUPPLIED EMISSION RATES

The tool's emission rates are based on national-scale MOVES runs. Some users may be interested in incorporating local data into the tool, and this section provides instructions on how to import local emission rates into the Transit Bus Service and Fleet Expansion Tool. For those unfamiliar with developing local MOVES runs, please refer to EPA's mobile-source emissions modeling guidance and documentation for transit buses and light-duty vehicles.[8]

### Importing Local Transit Bus Emissions Data:

Users may take the following steps to replace transit bus emission rates in the Transit Bus Service and Fleet Expansion Tool:

1. Using the national-scale MOVES run parameters listed in the table above, develop local emission rates. The CMAQ Toolkit is not prescriptive about which MOVES inputs are derived from local data. Users only must specify the same output parameters and details as the national-scale run. Complete any local MOVES runs for the selected calendar years and any other parameters listed in the table above.

[7] There is not sufficient test data to estimate emissions of propane (LPG) or ethanol (E85) transit buses, so these fuel types were not included in this tool.

[8] EPA, https://www.epa.gov/moves/tools-develop-or-convert-moves-inputs

2. The MOVES output data needs to be reformatted so that it can be used in the tool. The details on post processing this output are described below:

    - Unhide the 'TransitBusEmissionsData' tab in Excel and ensure that MOVES output has the six parameters yearID, modelYearID, sourceTypeID, fuelTypeID, roadTypeID, and pollutantID.
    - For calculating the transit bus emission rates, extract emissions by disaggregating the "movesoutput" table by the above six output parameters. Include only the transit bus source type (sourceTypeID 42) in the post-processed data and ensure that results consist of the running and start (along with the crankcase running and crankcase start where available) emission processes.
    - Extract vehicle miles traveled (VMT) from the "movesactivityoutput" table (activityTypeID 1), differentiating only by unique combinations of yearID, sourceTypeID, fuelTypeID, modelYearID, and roadTypeID.
    - Merge the emission estimates from the movesoutput table and the VMT estimates from the movesactivityoutput table using yearID, sourceTypeID, fuelTypeID, modelYearID, and roadTypeID.
    - Divide the emission estimates in kilograms by the VMT to compute the emission rates per mile in a new column and create three fields for massUnits (kg), distanceUnits (mi), and rateUnits (kg/mi).

    The local MOVES output data should now be formatted in exactly the same way as the national default output data initially used in the tool. Export the final table of local transit bus emission rates in .csv or .xlsx file format.

3. Delete any data (keep the title of the columns the same) in the 'TransitBusEmissionsData' tab in the Transit Bus Service and Fleet Expansion tool and then copy and paste your exported local transit bus emission rate data into the existing worksheet with the same table format. Save a new version of the tool under a different name and verify that it produces expected results with local emission rates.

## Importing Local Passenger Vehicle Emissions Data:

Users may take the following steps to replace the passenger vehicle emission rates in the Transit Bus Service and Fleet Expansion Tool:

1. Using the national-scale MOVES run parameters listed in the table above, develop local emission rates. The CMAQ Toolkit is not prescriptive about which MOVES inputs are derived from local data. Users only must specify the same output parameters and details as the national-scale run. Complete any local MOVES runs for the selected calendar years and any other parameters listed in the table above.

2. The MOVES output data needs to be reformatted so that it can be used in the tool. The details on post processing this output are described below:
    - Unhide the 'PassengerVehEmissionRates' tab in Excel and ensure that MOVES output has the following two parameters: yearID and pollutantID. Post-processed data should include only passenger cars (sourceTypeID 21) and passenger trucks (sourceTypeID 31).

- From a local MOVES run, aggregate the emission quantities in the movesoutput table by year, running and start specific processes, and pollutant.
    i. Running process ids include running exhaust, crankcase running exhaust, brakeware and tireware (processid 1, 15, 9, and 10)
    ii. Start process ids include start exhaust and crankcase start exhaust (processids 2 and 16)
- Incorporate brakewear and tirewear PM emissions in total running PM emissions. For PM10 emissions, change pollutantIDs 106 and 107 to 100. For PM2.5, change pollutantIDs 116 and 117 to 110.
- After these pollutantIDs have been changed, sum the emission quantities again to ensure a unique combination of fields exist in the post-processed data.
- Extract vehicle miles traveled (VMT) and starts from the movesactivityoutput table (activitytypeID 1 and 2 respectively) by yearID.
- Merge the emission estimates from the movesoutput table and the VMT estimates from the movesactivityoutput table using yearID and the appropriate equivalent processIDs and activitytypeIDs.
- Include a column in the post-processed data for emission rate. Emission rate is calculated by dividing emission quantity by VMT for each unique combination of year and pollutant.
- Be sure to define unit columns where appropriate, namely massUnits (kg), activityUnits (mi or start, depending on activity type), and rateUnits (kg/mi or kg/start, depending on activity type).

The local MOVES output data should now be structured and labeled in exactly the same way as the national default output data initially used in the tool. Export the post-processed local emission rates in .csv or .xlsx file format.

3. Delete any data (keep the title of the columns the same) in the 'PassengerVehEmissionsData' tab in the Transit Bus Service and Fleet Expansion Tool and then copy and paste the exported local passenger vehicle emission rates data into the existing worksheet with the same table format. Save a new version of the tool under a different name and verify that it produces expected results with local emission rates.