CMAQ Emissions Calculator Toolkit

Documentation of Emissions Data for the Freight Modal Shift Tool

This document supplements the User Guide for the Freight Modal Shift tool in the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit). It discusses the primary data sources and how the emission datasets for the Freight Modal Shift tool were derived. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses.

The document details the emissions data obtained from the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator (MOVES)[1] for on-road heavy-duty vehicles and from the EPA's Ports Emissions Inventory Guidance document[2] for locomotives and marine vessels as well as emission rate adjustment factors from the U.S. Department of Energy's Alternative Fuel Lifecycle Environmental and Economic Transportation (AFLEET 2020) Tool[3] for on-road alternative fuel and vehicle type combinations not included in MOVES. The MOVES Methodology section describes the specific inputs and outputs, pre-processing, and post-processing that were used to generate the national-scale emission rates used within the tool.

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[1] U.S. Environmental Protection Agency (EPA), https://www.epa.gov/moves.
[2] EPA, 2022, *Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-B-22-011. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.
[3] U.S. Department of Energy (DOE), Argonne National Laboratory, https://greet.es.anl.gov/afleet_tool.

U.S. Department of Transportation
Federal Highway Administration

EMISSION RATE DATA SUMMARY

Emission rates for the Freight Modal Shift tool were acquired from three main sources:

1. EPA's MOtor Vehicle Emissions Simulator (MOVES)
2. EPA's *Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*
3. Emission rate adjustment factors from DOE's AFLEET Tool[4] applied to diesel MOVES data for on-road alternative fuel and vehicle type combinations not included in MOVES.

EPA's MOtor Vehicle Emissions Simulator (MOVES) does not include emission rates for locomotive or commercial marine applications. This tool uses EPA's published emission factors as estimates of emission rates for locomotives and marine vessels. Additionally, conversion factors were identified from several other sources in order to convert user input for annual activity in ton-miles or vehicle miles traveled (VMT) for use with the emission factors available in the EPA Ports Guidance and MOVES. Refer to Table A1 in Appendix A for details. Table 1 details the emission rate source by mode and choice of vessel or vehicle offered by the tool.

Table 1. Emission rate source by mode

Mode (Mode Choices)	Emission Rate Source
Rail (Linehaul Locomotive)	EPA Ports Emissions Inventory Guidance
Marine (Barge)	EPA Ports Emissions Inventory Guidance
Highway (Short-Haul or Long-Haul Truck)	MOVES3 Runs
Other Battery Electric/Self-Powered	None (assumed to be 0)[5]

MOVES METHODOLOGY

National-Scale Run

A national-scale run used to obtain emission rates for long-haul and short-haul combination trucks was set up with the parameters displayed in Table 2 below. MOVES3.0.4 (released August 2022) was used for the runs.[6]

Table 2. National-scale run parameters

Category	Variable	Input
Description	-----	<blank>
Scale (1/3)	Model	ONROAD
Scale (2/3)	Domain/Scale	Default
Scale (3/3)	Calculation Type	Inventory
Time Spans (1/4)	Years	[2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040]

[4] DOE, https://greet.es.anl.gov/afleet_tool.
[5] All emissions associated with battery electric powered equipment, including trucks, are assumed to be zero (or close to zero), including particulate matter (PM) associated with brakewear and tirewear for the purposes of this tool. Upstream emissions are not included.
[6] EPA, https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

Category	Variable	Input
Time Spans (2/4)	Months	All Selected
Time Spans (3/4)	Days	All Selected
Time Spans (4/4)	Hours	All Selected
Geographic Bounds	-----	No Selection Needed
Vehicles/Equipment	On-Road Vehicle Equipment	All Selected
Road Type	Road Types	All Selected
Pollutants and Processes (selected) (1/17)	Total Gaseous Hydrocarbons	All Selected
Pollutants and Processes (selected) (2/17)	Non-methane Hydrocarbons	All Selected
Pollutants and Processes (selected) (3/17)	Volatile Organic Compounds	All Selected
Pollutants and Processes (selected) (4/17)	Carbon Monoxide (CO)	All Selected
Pollutants and Processes (selected) (5/17)	Oxides of Nitrogen (NOx)	All Selected
Pollutants and Processes (selected) (6/17)	Primary Exhaust PM2.5 – Total	All Selected
Pollutants and Processes (selected) (7/17)	Primary Exhaust PM2.5 – Species	Running Exhaust, Start Exhaust, Extended Idle Exhaust, Auxiliary Power Exhaust
Pollutants and Processes (selected) (8/17)	Primary PM2.5 – Brakewear Particulate	All Selected
Pollutants and Processes (selected) (9/17)	Primary PM2.5 – Tirewear Particulate	All Selected
Pollutants and Processes (selected) (10/17)	Primary Exhaust PM10 – Total	All Selected
Pollutants and Processes (selected) (11/17)	Primary Exhaust PM10 – Species	All Selected
Pollutants and Processes (selected) (12/17)	Primary PM10 – Brakewear Particulate	All Selected
Pollutants and Processes (selected) (13/17)	Primary PM10 – Tirewear Particulate	All Selected
Pollutants and Processes (selected) (14/17)	Carbon Dioxide Equivalent (CO_2e)	All Selected
Pollutants and Processes (selected) (15/17)	Total Energy Consumption (TEC)	All Selected
Pollutants and Processes (selected) (16/17)	Atmospheric CO_2	All Selected
Pollutants and Processes (selected) (17/17)	Select Prerequisites	All Selected
General Output (1/2)	Units	Mass: Kilograms, Energy: Million BTU, Distance: Miles
General Output (2/2)	Activity	All Selected
Output Emissions Detail (1/3)	Output Aggregation	Year, Nation

Category	Variable	Input
Output Emissions Detail (2/3)	On Road	Road Type, Source Use Type
Output Emissions Detail (3/3)	For All Vehicle/Equipment Combinations	Model Year, Fuel Type, Emission Processes
Advanced Features (1/2)	Time Aggregation	Hour
Advanced Features (2/2)	Region Aggregation	Nation

Post-MOVES Run Data Processing

Results from the national-scale MOVES run were utilized to obtain emission rates in kilograms (kg) per mile, or kg/mile, for use in the Freight Modal Shift tool. Emission rates for emissions that are generated on a per-mile basis (namely, running exhaust, tirewear, brakewear, and crankcase running exhaust) were obtained by joining the emission inventories from the movesoutput table and activity from the movesactivityoutput table. Emission rates are based on evaluation year, model year, fuel type, and pollutant. Those provided in the tool were aggregated over other processes and model parameters, such as road type. Users interested in controlling those parameters can generate and import their own local emission rates, as described in the last section of this document.

Freight modal shift projects can reduce overall VMT by heavy-duty diesel vehicles in the affected area. Therefore, off-network idling activity is also projected to decrease, in addition to emissions from evaporative processes while vehicles are operating on-network. As part of freight modal shift projects, vehicles are expected to spend less time refueling as a result of reduced VMT, thus reducing refueling evaporative emissions. This tool includes emissions per mile driven from off-network idling vehicle activity, as well as evaporative emissions from certain MOVES process types on certain road types (Table 3).

Table 3. Evaporative processes and associated road types

ProcessIDs	RoadTypeIDs
11 (Evaporative Permeation) 12 (Evaporative Fuel Vapor Venting) 13 (Evaporative Fuel Leaks)	3 (Rural Unrestricted Access) 5 (Urban Unrestricted Access)
18 (Refueling Displacement Vapor Loss) 19 (Refueling Spillage Loss)	All Road Types

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 emission rates were not available in MOVES, alternative fuel factors from AFLEET 2020[7] were applied to default conventional fuel emission rates depending on vehicle source type and pollutant. AFLEET alternative fuel factors for heavy-duty vehicles were based on diesel emission rates. As included in the tool's User Guide, Table 4 details the alternative fuel types and vehicle source types available in the tool and indicates whether the emissions data for each combination originated from MOVES or from AFLEET-adjusted conventional fuel emission rates. Combinations without emissions data are denoted as 'N/A'.

[7] DOE, https://greet.es.anl.gov/afleet.

Table 4. Vehicle source type- fuel type combinations in tool

Vehicle Source Type	Gasoline	Diesel	CNG	BEV
Combination Short-haul Truck	N/A	M	M: MY < 2009 A: MY > 2008	A
Combination Long-haul Truck	N/A	M	A	A

M = MOVES emission rates, A = AFLEET factors applied to MOVES conventional fuel emission rates, CNG = compressed natural gas, BEV = battery electric vehicle

Note that MOVES has data for gasoline combination short-haul trucks for model years 1988, 1989, 1992, 1993, 1995, 1997, 1999, 2001, 2002, 2003, and 2008. However, since AFLEET does not provide conversion factors for gasoline to fill in these data gaps, gasoline is excluded from the tool.

TOOL METHODOLOGY

The following sections provide a detailed description of emission rates and equations, conversion factors, and default input parameters for the Freight Modal Shift tool by mode: highway, locomotive, and marine. Note that battery electric/self-powered emissions are assumed to be zero. Table A1 of Appendix A summarizes the conversion factors and their respective sources. Tables A2 and A3 provide the emissions factors for locomotives and marine vessels, respectively. Note that emissions rates can also be accessed within the tool by right-clicking the tab bar at the bottom of the spreadsheet tool and selecting 'Unhide' for the appropriate tab ('HighwayEmissionsRates', 'RailEmissionsRates', or 'MarineEmissionsRates').

Highway

Emission rates for highway (short- or long-haul trucks) are post-processed from MOVES in kilograms per mile (kg/mile) for all pollutants and million British thermal units (Btu) per mile (MMBtu/mile) for total energy consumption (TEC). The user has the choice of entering annual activity for highway mode options as either VMT or ton-miles. When annual activity (A) is entered as VMT, emissions before or after project implementation ($E_{pre_{m,n}}$ or $E_{post_{m,n}}$) for each segment with a highway mode (e.g., long-haul or short-haul truck) can be calculated for all pollutants, including carbon dioxide (CO_2), carbon dioxide equivalents (CO_2e), and TEC as given by Equation 1:

$$E\left(\frac{kg}{day}\right) = e\left(\frac{kg}{veh\ mile}\right) * A(veh \cdot mile) * \left(\frac{1\ yr}{365\ day}\right) \quad (1)$$

where for diesel trucks,

$$e = e_{MOVES} \quad (2)$$

and where for compressed natural gas (CNG) long-haul trucks and CNG short-haul trucks with a model year greater than 2008,

$$e = e_{MOVES,diesel} * Alt \quad (3)$$

and where for battery electric trucks and all pollutants,[8]

$$e = 0 \quad (4)$$

such that,

e = emission rate for a given vehicle source type and model year in kg/mile

A = user input for activity for the given mode, segment, and pre- or post-project implementation in VMT

e_{MOVES} = emission rate for a given vehicle source type and model year from MOVES in kg/mile

$e_{MOVES,diesel}$ = diesel emission rate for a given vehicle source type and model year from MOVES in kg/mile

Alt = AFLEET factor for a specified alternative fuel, determined by vehicle source type and pollutant.

When annual activity is entered as ton-miles, the emissions calculation requires a few conversion factors in order to use the MOVES-generated emission factors in kg/mile: the density of the commodity (d), the length of the trailer (l) being transported by the long-haul or short-haul truck, and a deadhead mileage factor that incorporates an estimate of deadhead, or empty, truck miles into the annual activity entered by the user. Commodity density and trailer size are both user inputs. The emissions calculation for either before or after project implementation is described in Equation 5:

$$E\left(\frac{kg}{day}\right) = e\left(\frac{kg}{veh \cdot mile}\right) * A\ (ton \cdot mile) * \frac{1}{d}\left(\frac{ft^3}{ton}\right) * \frac{1}{l * CF_1}\left(\frac{veh}{ft^3}\right) * \left(\frac{1\ yr}{365\ day}\right) * (1 + DH) \quad (5)$$

where for diesel trucks,

$$e = e_{MOVES} \quad (6)$$

and where for CNG long-haul trucks and CNG short-haul trucks with a model year greater than 2008,

$$e = e_{MOVES,diesel} * Alt \quad (7)$$

and where for battery electric trucks and all pollutants,

$$e = 0 \quad (8)$$

such that:

d = commodity density for a given segment in ton/ft^3 (0.0095 or user input)

l = trailer size for a given segment in ft (28, 45, 48, or 53 ft, or custom user input)

CF_1 = 68, the cross-section of the trailer in ft^2

DH = 0.148, deadhead mileage factor

[8] While particulate matter (PM) emissions are estimated for trucks and other on-road vehicles from MOVES output in other CMAQ Toolkit tools, PM is omitted from this tool due to a lack of data for rail brakewear.

Note that the deadhead mileage factor is included since the activity input for trucks must be converted to VMT to calculate emissions using the kg/mile emissions factors output by MOVES. In using the commodity density and size of the trailer, the conversion assumes that freight tonnage is present in all trucks. However, the tool assumes that activity entered as VMT is derived from AADT and likely includes deadhead miles. A default percentage of 14.8 percent is added to user activity input as ton-miles to capture additional emissions from trucks that travel without freight. The default is based on the average percent of non-tanker carrier miles that were deadhead in 2022 according to the American Transportation Research Board.[9]

To ignore deadhead mileage entirely, the user can back out the deadhead percentage assumed in the tool by dividing their ton-mile activity estimate by 1.148 before entering the activity into the tool. See Table A1 of Appendix A for more information about the conversion factors.

Locomotive

For locomotives, the EPA emission factors (i.e., standards) are given in units of grams of pollutant per brake horsepower hour (g/bhp-hr). Brake horsepower is a measure of an engine's horsepower before the loss in power caused by the gearbox and drive train. It is measured at the crankshaft, just outside the engine, and is a function of engine torque and rotational speed. The locomotive application included in this tool is line-hauling.

EPA's hydrocarbon emission factors are provided in terms of total hydrocarbons (THC). For consistency with tool output and CMAQ reporting requirements, THC were converted to volatile organic compounds (VOC), using the following factor:[10]

$$\frac{VOC}{THC} = 1.053 \quad (9)$$

$PM_{2.5}$ emissions factors are assumed to be 97% of PM_{10} emissions factors.[11] The EPA emission rates for linehaul locomotives are displayed in Table A2 in Appendix A.

To calculate the grams of pollutant from annual ton-miles, a conversion factor of 20.8 bhp-hr/gal is applied to line-haul locomotives. This conversion factor was calculated by EPA based on the duty cycle of the two different locomotive applications.[12] This calculation also requires a fuel efficiency value derived from Surface Transportation Board data on total activity and total fuel use.[13] For more details on the derivation of the fuel efficiency value for locomotives, see Appendix B.

Emissions before or after project implementation for each segment with a locomotive mode (linehaul locomotive) can be calculated using the following equation for all pollutants except CO_2, CO_2e and TEC:

$$E\left(\frac{kg}{day}\right) = e_t\left(\frac{g}{bhp \cdot hr}\right) * A\,(ton \cdot mile) * CF_2\left(\frac{bhp \cdot hr}{gal}\right) * Eff_{Train}\left(\frac{gal}{ton \cdot mile}\right) * \left(\frac{1\,kg}{1000\,g}\right) * \left(\frac{1\,yr}{365\,day}\right) \quad (10)$$

[9] ATRI-Operational-Cost-of-Trucking-2022.pdf (truckingresearch.org)
[10] EPA, 2005, *Conversion Factors for Hydrocarbon Components,* EPA420-R-05-015. Available at: https://19january2017snapshot.epa.gov/www3/otaq/models/nonrdmdl/nonrdmdl2005/420r05015.pdf.
[11] EPA, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf.
[12] EPA, 2009, *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.
[13] Surface Transportation Board, Annual Report Financial Data, 2021, https://www.stb.gov/reports-data/economic-data/annual-report-financial-data/.

where:

e_t = linehaul locomotive emission rate for a given emissions tier in g/bhp-hr

A = user input for activity for the given mode and segment in ton-miles

CF_2 = 20.8, conversion factor in bhp-hr/gal

Eff_{Train}, fuel efficiency value in gal/ton-miles

CO_2 Calculation

CO_2 emissions are directly proportional to fuel consumption and are calculated using a carbon content factor given in grams of CO_2 per grams of fuel (g CO_2/g fuel) and a brake specific fuel consumption (BSFC) value given in grams per brake horsepower-hour (g/bhp-hr) specific to the type of locomotive. For the diesel used in locomotives, which is assumed to ultra-low sulfur diesel (ULSD), the carbon content value is 3.19 g CO_2/g fuel. For Class I linehaul locomotives, the BSFC is 154 g/bhp-hr.[14]

The following equation may be used to calculate CO_2 emissions for linehaul locomotives:

$$E_{CO_2}\left(\frac{kg}{day}\right) = e_{CO_2}\left(\frac{g\ CO_2}{g\ fuel}\right) * A\ (ton \cdot mile) * CF_2\left(\frac{bhp \cdot hr}{gal}\right) * Eff_{Train}\left(\frac{gal}{ton \cdot mile}\right) * BSFC\left(\frac{g\ fuel}{bhp \cdot hr}\right) * \left(\frac{1\ kg}{1000\ g}\right) * \left(\frac{1\ yr}{365\ day}\right) \quad (11)$$

where:

e_{CO2} = 3.19, carbon content of ULSD in g CO_2/g fuel

$BSFC$ = 154, brake specific fuel consumption in g fuel/bhp-hr

TEC Calculation

The total energy consumption (TEC) can be calculated using the energy content of ULSD as shown in the following equation:

$$TEC\left(\frac{MMBtu}{day}\right) = e_{TEC}\left(\frac{Btu}{gal}\right) * A\ (ton \cdot mile) * Eff_{Train}\left(\frac{gal}{ton \cdot mile}\right) * \left(\frac{1\ MMBtu}{1{,}000{,}000\ Btu}\right) * \left(\frac{1\ yr}{365\ day}\right) \quad (12)$$

where:

e_{TEC} = 138,490, energy content of ULSD in Btu/gal

Note that CO_2e emissions for linehaul locomotives consists of CO_2 emissions only as data on other greenhouse gases are not currently available.

Marine

The emissions rates for barges (C1 or C2 vessels), the only marine option available in this tool, are derived from the EPA's average harbor craft emission rates by emissions tier. Note that these average emission rates include barges as well as the vessels that push or pull them, such as towboats or tugboats. For the purposes of this tool, a barge may be either a self-propelled vessel or a tugboat-barge system. In a barge-tugboat system, emissions come from the tugboat providing the propulsion. The EPA emissions rates are given in units of grams per

[14] EPA, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf.

kilowatt hour (g/kWh). Similar to the emissions calculations for linehaul locomotives, the barge emission calculation must involve a fuel efficiency factor in gallons per ton-mile to convert user input in ton-miles to grams of pollutant. Currently, this tool only includes barge as an option for the marine mode due to lack of availability of fuel efficiency data for other types of marine vessels, such as larger ocean-going vessels (e.g., container ships).[15]

As for locomotives, EPA's harbor craft hydrocarbon emission factors were reported in terms of total hydrocarbons (THC). THC were converted to volatile organic compounds (VOC) for consistency with tool output and CMAQ reporting requirements, using the factor described in Equation 3.[16] $PM_{2.5}$ emissions factors are assumed to be 97% of PM_{10} emissions factors.[17] The EPA emission rates for harbor craft (including barges) are provided in Table A3 in Appendix A.

The emissions calculation for before or after project implementation for each segment for all pollutants besides CO_2, CO_2e, and TEC is given by Equation 7:

$$E\left(\frac{kg}{day}\right) = e_t\left(\frac{g}{kWh}\right) * A\ (ton \cdot mile) * e_{TEC}\left(\frac{Btu}{gal}\right) * Eff\left(\frac{gal}{ton \cdot mile}\right) * \left(\frac{1\ kWh}{3412\ Btu}\right) * \left(\frac{1\ kg}{1000\ g}\right) * \left(\frac{1\ yr}{365\ day}\right) \quad (13)$$

where:

e_t = average harbor craft emission rate for a given emissions tier in g/kWh

A = user input for activity for the given mode and segment in ton-miles

e_{TEC} = 138,490, energy content of ULSD in Btu/gal

Eff = fuel efficiency value in gal/ton-miles

Since emissions factors represent an average of all harbor craft, which includes tugboats, harbor ferries, towboats, fishing boats, and several others as well as barges, the barge-specific fuel efficiency value cannot be accurately applied to the previous equation to calculate barge-specific emissions. Thus, using the carbon content of the fuel and the EPA average harbor craft CO_2 emission rate, a scaled fuel efficiency factor may be calculated to scale the EPA emissions rates to be barge-specific, as provided in the next section's equations.

<u>CO_2 Calculation</u>

First, the CO_2 emissions are calculated using the diesel carbon content. The diesel used in barges (or the boats that propel them) is assumed to be ultra-low sulfur diesel (ULSD).

$$E_{CO_2}(g) = A\ (ton \cdot mile) * Eff_{Barge}\left(\frac{gal}{ton \cdot mile}\right) * e_{CO_2}\left(\frac{g\ CO_2}{g\ fuel}\right) * CF_3\left(\frac{g\ fuel}{gal}\right) \quad (14)$$

where:

[15] According to the Army Corps of Engineers Waterborne Commerce of the United States – Part 5, National Summaries 2020 report, barge traffic constitutes 87% of total domestic commerce. For more information, see https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center-2/WCSC-Waterborne-Commerce/.

[16] EPA, https://19january2017snapshot.epa.gov/www3/otaq/models/nonrdmdl/nonrdmdl2005/420r05015.pdf.

[17] EPA, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf.

e_{CO2} = 3.19, carbon content of ULSD in g CO_2/g fuel

Eff_{Barge} = 0.00154, barge-specific fuel efficiency value in gal/ton-miles

CF_3 = 3200, density of USLD in g fuel/gal

To use the EPA average harbor craft emission factors, CO_2 emissions from Equation 14 are used to calculate a scaled fuel efficiency that will scale the average emission factors to be barge-specific using the assumption that the CO_2 emissions calculated with the carbon content and the average harbor craft emission factor should produce the same value. The scaled fuel efficiency is calculated in the equation below using the average harbor craft emission rate for CO_2:

$$Eff_{Scaled}\left(\frac{gal}{ton \cdot mile}\right) = \frac{1}{E_{CO_2}}\left(\frac{1}{g\ CO_2}\right) * A\ (ton \cdot mile) * e_{CO_2,avg}\left(\frac{g\ CO_2}{kWh}\right) * \left(\frac{1\ kWh}{3412\ Btu}\right) * e_{TEC}\left(\frac{Btu}{gal}\right) \quad (15)$$

where:

Eff_{scaled} = scaled fuel efficiency factor in gal/ton-miles

E_{CO2} = barge CO_2 emissions calculated using Equation 14 in g CO_2

$e_{CO2,avg}$ = EPA average harbor craft emissions rate for CO_2 in g CO_2/kWh

e_{TEC} = 137,381, energy content of ULSD in Btu/gal

Emissions before or after project implementation for each segment with a marine mode (barge) can then be calculated using the following equation for all pollutants:

$$E\left(\frac{kg}{day}\right) = e_t\left(\frac{g}{kWh}\right) * A\ (ton \cdot mile) * e_{TEC}\left(\frac{Btu}{gal}\right) * Eff_{Scaled}\left(\frac{gal}{ton \cdot mile}\right) * \left(\frac{1\ kWh}{3412\ Btu}\right) * \left(\frac{1\ kg}{1000\ g}\right) * \left(\frac{1\ yr}{365\ day}\right) \quad (16)$$

where:

e_t = average harbor craft emission rate for a given emissions tier and pollutant in g/kWh

A = user input for activity for the given mode and segment in ton-miles

e_{TEC} = 137,381, energy content of ULSD in Btu/gal

Eff_{scaled} = scaled fuel efficiency value calculated in Equation 9 in gal/ton-miles

TEC Calculation

TEC on each segment for barges can be calculated with the following equation:

$$TEC\left(\frac{MMBtu}{day}\right) = e_{TEC}\left(\frac{Btu}{gal}\right) * A\ (ton \cdot mile) * Eff_{Scaled}\left(\frac{gal}{ton \cdot mile}\right) * \left(\frac{1\ MMBtu}{1{,}000{,}000\ Btu}\right) * \left(\frac{1\ yr}{365\ day}\right) \quad (17)$$

Note that CO_2e emissions for barges consists of CO_2 emissions only as data on other greenhouse gases are not available.

USER-SUPPLIED EMISSION RATES

Some users may be interested in incorporating local data for highway freight into the tool's emission rates, which are originally based on national-scale MOVES runs for short- or long-haul trucks. For those unfamiliar with developing local MOVES runs, please refer to EPA's mobile-source emissions modeling guidance and documentation for highway vehicles.[18] This section provides basic instructions on how to import local emission rates for short- or long-haul trucks into the Freight Modal Shift tool. Note that users may only supply their own emission rates for trucks, not linehaul locomotives or barges. Emission rates for linehaul locomotives and barges may be viewed in the tool by unhiding the 'RailEmissionRates' and 'MarineEmissionRates' tabs, respectively.

Develop Local Emissions Inventories in MOVES

Using the national-scale run parameters listed in Table 2, develop local emission rates. The CMAQ Emissions Calculator 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 Table 2.

Import Local Running Emissions Rates

Users may take the following steps to replace default highway emission rates with the local data prepared in MOVES:

1. The MOVES output needs to be reformatted for use in the tool, as described below:
    - Unhide the 'HighwayEmissionRates' tab in Excel and ensure that the local moves output has the following fields: yearID, pollutantID, processID, sourcetypeID, fueltypeID, roadTypeID, and modelyearID.
    - Users should join the 'movesoutput' and the 'movesactivityoutput' tables using the yearID, modelyearID, sourcetypeID, roadTypeID, and fueltypeID fields. Include columns for emission quantities, activitytypeID, and activity quantities.
    - Include emissions from single unit short-haul trucks, single unit long-haul trucks, combination short-haul trucks, and combination long-haul trucks buses (sourceTypeID 61 and 62) in the post-processed data.
    - Include the following pollutants in the post-processed data: CO, NOx, VOC, all particulate matter pollutants, CO_2, and CO_2 equivalents.
    - The following processes should be included in the post-processed data:
        i. All processID on roadTypeID 3 and 5
        ii. processID 1, 2, 9, 10, 11, 12, 13, 18, and 19 on roadTypeIDs 3 and 5.
    - Include PM from brakewear and tirewear in the total particulate matter emissions. For PM10, change pollutantID 106 and 107 to 100. For PM2.5, change pollutantID 116 and 117 to 110.
    - When joining the two MOVES output tables, include only distance traveled results (activitytypeID 1) in the post-processed data.
    - Be sure to sum emission quantities where values in the fields listed in the previous steps are the same, to ensure no repeated combinations exist in the post-processed data.
    - Include a column in the post processed data for emissionRate. Emission rates are calculated by dividing the emission quantity by the distance traveled in each entry.

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

- Be sure to include appropriate units columns in the post processed table.

2. The local MOVES running emissions data should now be structured in the same way as the national default data. Export the resulting local emission rates table in .csv or .xlsx file format.
3. Delete any data in the 'HighwayEmissionRates' tab in Excel and then copy and paste the running rates local data into the sheet. Make sure not to delete the existing table column headings, as the tool uses these labels as references in calculations. Save the Freight Modal Shift tool under a different file name and then run each module to ensure the new local running data produces different rates than the national defaults.

Appendix A. Conversion Factors & Emissions Rate Tables

Table A1. Summary of Conversion Factors and Sources

Variable	Description	Value	Unit	Source	Additional Notes
DH	Deadhead mileage factor	1.148	Unitless	American Transportation Research Institute	An estimated 14.8 percent of non-tanker truck miles were deadhead, or empty, miles in 2022.
CF_1	Cross-section of a freight trailer	68	ft^2	Intermodal Association of North America	The average trailer cross section is 8 feet by 8.5 feet: $8 * 8.5 = 68$
d	Commodity density	0.0095	ton/ft^3	EPA, Port Emissions Inventory Guidance	Density of mixed freight. For other commodity density values, see Table A1 in the appendix of the User Guide.
l	Default option for trailer length	40	ft	Intermodal Association of North America	International standard for trailer length.
l	Default option for trailer length	53	ft	Intermodal Association of North America	Most common domestic trailer length.
CF_2	Conversion factor for linehaul locomotives	20.8	bhp-hr/gal	EPA, Emission Factors for Locomotives	
Eff_{Train}	Fuel efficiency value for linehaul locomotives	475.26	ton-miles/gal	Surface Transportation Board	See Appendix B for derivation. Note that this value is 0.0021 gal/ton-miles $(1 \div 475.26)$ in Equations 4, 5, and 6.
e_{CO_2}	Carbon content of ULSD fuel	3.19	g CO_2/g fuel	EPA, Emission Factors for Locomotives	Note that this tool assumes linehaul locomotives and barges both use ULSD fuel.
$BSFC$	Brake specific fuel consumption	154	g/bhp-hr	EPA, Port Emissions Inventory Guidance	
e_{TEC}	Energy content of ULSD fuel	137,381	Btu/gal	U.S. Energy Information Association	
Eff_{Barge}	Fuel efficiency for barges	647.3	ton-miles/gal	Texas A&M & National Waterways Foundation	Note that this value is 0.00154 gal/ton-miles $(1 \div 647.3)$ in Equation 8.
CF_3	Conversion factor for ULSD	3,200	g fuel/gal	EPA, Emission Factors for Locomotives	

Table A2. Diesel (Line-haul) Locomotive Emission Factors[19]

Year of Manufacture	Tier	NO_X *(g/bhp-hr)*	PM *(g/bhp-hr)*	HC *(g/bhp-hr)*	CO *(g/bhp-hr)*
Pre-1973	Uncontrolled	13.00	0.32	0.48	1.28
1973-1992	Tier 0	8.60	0.32	0.48	1.28
1973-1992	Tier 0+	7.20	0.20	0.30	1.28
1993-2004	Tier 1	6.70	0.32	0.47	1.28
1993-2004	Tier 1+	6.70	0.20	0.29	1.28
2005-2011	Tier 2	4.95	0.18	0.26	1.28
2005-2011	Tier 2+	4.95	0.08	0.13	1.28
2012-2014	Tier 3	4.95	0.08	0.13	1.28
2015+	Tier 4	1.00	0.015	0.04	1.28

Tiers with '+' are applicable only to locomotives that were originally manufactured in the corresponding Year of Manufacture range and remanufactured in 2008 or later; EPA holds these remanufactured locomotives to a higher emissions standard.

Table A3. Diesel (as ultra low sulfur diesel; ULSD) Marine Vessel Emission Factors[20]

Vessel Category	Tier*	NO_X *(g/kWh)*	PM *(g/kWh)*	VOC *(g/kWh)*	CO *(g/kWh)*
C1 or C2	Tier 0	10.2	0.26	0.30	1.61
C1 or C2	Tier 1	9.6	0.26	0.30	1.61
C1 or C2	Tier 2	5.6	0.15	0.30	0.92
C1 or C2	Tier 3	4.7	0.08	0.12	0.92
C1 or C2	Tier 4	1.3	0.03	0.12	0.92

* Refer to Table A4 for assistance in determining the appropriate Tier for self-propelled barges or towboats (C1 and C2)

Table A4. Category 1 and 2 Marine Vessel Engine Tiers[21]

Cylinder Displacement Range (liters/cylinder)	Power Range (kilowatts)	Model Year Range	Engine Tier
All	0 < kW ≤ 19	Pre-2000	Uncontrolled (Tier 0)
All	19 < kW ≤ 37	Pre-1999	Uncontrolled (Tier 0)
Disp < 5	kW > 37	Pre-2004	Uncontrolled (Tier 0)
5 ≤ Disp < 30	All	Pre-2004	Uncontrolled (Tier 0)
All	0 < kW ≤ 19	2000-2004	Tier 1
All	19 < kW ≤ 37	1999-2003	Tier 1
Disp < 0.9	kW > 37	2004	Tier 1
2.5 ≤ Disp < 5	kW > 37	2004-2006	Tier 1
5 ≤ Disp < 30	All	2004-2006	Tier 1
All	0 < kW ≤ 19	2005-2008	Tier 2
All	19 < kW ≤ 37	2004-2008	

[19] EPA, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf.
[20] Ibid.
[21] Ibid.

Cylinder Displacement Range (liters/cylinder)	Power Range (kilowatts)	Model Year Range	Engine Tier
Disp < 0.9	37 < kW ≤ 75	2005-2008	Tier 2
Disp < 0.9	75 < kW ≤ 600	2005-2011	
0.9 ≤ Disp < 1.2	kW > 37	2004-2012	Tier 2
1.2 ≤ Disp < 2.5	kW > 37	2004-2013	
2.5 ≤ Disp < 3.5	kW > 37	2007-2012	Tier 2
3.5 ≤ Disp < 5	kW > 37	2007-2011	
5 ≤ Disp < 15	All	2007-2012	Tier 2
15 ≤ Disp < 30	All	2007-2013	
All	0 < kW ≤ 37	2009+	Tier 3
Disp < 0.9	37 < kW ≤ 75	2009+	Tier 3
Disp < 0.9	75 < kW ≤ 600	2012+	Tier 3
0.9 ≤ Disp < 1.2	kW ≤ 600	2013+	Tier 3
1.2 ≤ Disp < 2.5	kW ≤ 600	2014+	Tier 3
2.5 ≤ Disp < 3.5	kW ≤ 600	2013+	Tier 3
3.5 ≤ Disp < 7	kW ≤ 600	2012+	Tier 3
1.2 ≤ Disp < 2.5	600 < kW ≤ 1000	2014-2017	Tier 3
2.5 ≤ Disp < 3.5	600 < kW ≤ 1000	2013-2017	Tier 3
3.5 ≤ Disp < 7	600 < kW ≤ 1000	2012-2017	Tier 3
1.2 ≤ Disp < 2.5	1000 < kW ≤ 1400	2014-2016	Tier 3
2.5 ≤ Disp < 3.5	1000 < kW ≤ 1400	2013-2016	Tier 3
3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2012-2016	Tier 3
3.5 ≤ Disp < 7	kW > 1400	2012-2015	Tier 3
7 ≤ Disp < 15	kW ≤ 600	2013+	Tier 3
7 ≤ Disp < 15	600 < kW ≤ 1000	2013-2017	Tier 3
7 ≤ Disp < 15	1000 < kW ≤ 1400	2013-2016	Tier 3
7 ≤ Disp < 15	1400 < kW ≤ 2000	2013-2015	Tier 3
15 ≤ Disp < 30	1400 < kW ≤ 2000	2014-2015	Tier 3
1.2 ≤ Disp < 7	600 < kW ≤ 1000	2018+	Tier 4
1.2 ≤ Disp < 3.5	1000 < kW ≤ 1400	2017+	Tier 4
3.5 ≤ Disp < 7	1000 < kW ≤ 1400	2017+	Tier 4
3.5 ≤ Disp < 7	kW > 1400	2016+	Tier 4
7 ≤ Disp < 15	600 < kW ≤ 1000	2018+	Tier 4
7 ≤ Disp < 15	1000 < kW ≤ 1400	2017+	Tier 4
7 ≤ Disp < 15	1400 < kW ≤ 2000	2016+	Tier 4
7 ≤ Disp < 15	2000 < kW ≤ 3700	2014+	Tier 4
7 ≤ Disp < 15	kW > 3700	2014-2016	Tier 4
7 ≤ Disp < 15	kW > 3700	2017+	Tier 4
15 ≤ Disp < 30	1400 < kW ≤ 2000	2016+	Tier 4
	2000 < kW ≤ 3700	2014+	Tier 4
	kW > 3700	2014-2016	Tier 4
	kW > 3700	2017+	Tier 4

Appendix B. Locomotive Fuel Efficiency Calculations

The fuel efficiency value for linehaul locomotives was derived using activity data in ton-miles and fuel consumption data in gallons from the Surface Transportation Board's Annual Report Financial Data from 2021. The ton-miles and gallons of fuel consumed were extracted for each class railroad (column 'Class' in Table B1) for "Freight Train," which was assumed to be linehaul locomotives. Then, the activity and fuel data were summed across all lines. Dividing the two sums produces an average ton-miles per gallon fuel efficiency for linehaul locomotives (Table B1).

Table B1. Calculated Locomotive Fuel Efficiency[22]

Class	Ton-miles of freight	Gallons of fuel consumed	Average ton-miles/gallon
BNSF	671,524,622,000	1,365,879,827	491.6425
CSX	199,252,270,221	391,789,172	508.5701
GTC	63,271,335,000	121,385,446	521.2432
KCS	35,585,756,000	66,093,931	538.4119
NS	194,504,355,000	450,600,488	431.6559
SOO	37,762,579,000	69,180,249	545.8578
UP	428,533,971,000	965,706,090	443.7520
All Railroads	1,630,434,888,221	3,430,635,203	475.2600

[22] Surface Transportation Board, https://www.stb.gov/reports-data/economic-data/annual-report-financial-data/.