CMAQ Emissions Calculator Toolkit

Documentation of Emissions Data for the Locomotive & Marine Engine Retrofit and Replacement Tool

This document supplements the User Guide for the Locomotive & Marine Engine Retrofit and Replacement 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 this 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 highlights the emissions data obtained from the U.S. Environmental Protection Agency (EPA) for both locomotives[1] and marine vessels[2].

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[1] U.S. Environmental Protection Agency. 2009. *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.

[2] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

EMISSION RATE DATA SUMMARY

Emission rates and emission reductions for the Locomotive & Marine Engine Retrofit and Replacement Tool were acquired from four main sources:

1. EPA's *Emission Factors for Locomotives*[3]
2. EPA's *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories* report[4]
3. Industry report evaluating liquefied natural gas (LNG) locomotives[5]
4. EPA's Diesel Emission Quantifier (DEQ):[6]
    - Emission reductions by use of selective catalytic reduction (SCR)
    - Emission reductions by use of a diesel particulate filter

MOVES

EPA's MOtor Vehicle Emissions Simulator (MOVES) does not include emission rates for locomotive or commercial marine applications. Therefore, the Locomotive & Marine Engine Retrofit and Replacement Tool uses EPA's published emission factors as estimates of emission rates.

EMISSIONS METHODOLOGY

The following sections provide a detailed description of emission rate equations and default input parameters for both the Engine Retrofit module and Engine Repower or Replacement module. The appendix lists the relevant emissions factors for both locomotives and marine vessels (Tables A1 & A2).

Engine Retrofit

The equations below summarize how the Engine Retrofit module calculates emissions reductions for locomotives and marine vessels. The emissions reduction is the difference between emissions from the baseline engine and emissions from the same engine with an emissions control retrofit. Emission reductions reported in kilograms per day (kg/day) are calculated for a given pollutant as:

$$\Delta Emissions = Baseline\ Emissions - Retrofitted\ Emissions \quad (1)$$

Thus, a positive change in emissions is equivalent to an emissions reduction (benefit), while a negative change in emissions can be interpreted as an emissions increase (disbenefit).

[3] U.S. Environmental Protection Agency. 2009. *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.

[4] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

[5] BNSF Railway Company, Union Pacific Railroad Company, The Association of American Railroads, and California Environmental Associates. 2007. *An Evaluation of Natural Gas-fueled Locomotives* (report). Available at: https://ww3.arb.ca.gov/railyard/ryagreement/112807lngqa.pdf.

[6] U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2. Available at: https://cfpub.epa.gov/quantifier/.

For locomotives, the EPA emission factors 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 two locomotive applications included in this tool are line-hauling (both large and small, including passenger trains) and switching. To calculate the grams of pollutant from the gallons of diesel fuel used, a conversion factor of 20.8 bhp-hr/gal or 15.2 bhp-hr/gal is applied to line-haul and switch locomotives, respectively. These conversion factors were calculated by EPA based on the duty cycle of the two different locomotive applications.[7] The emission calculation is summarized as:

$$E_{baseline}\left(\frac{kg}{day}\right) = EPA_{emission\ factor}\left(\frac{g}{bhp-hr}\right) * CF\left(\frac{bhp-hr}{gal}\right) * Fuel(gal) * \left(\frac{1\ yr}{365\ day}\right) * \left(\frac{1\ kg}{1000\ g}\right) \quad (2)$$

where $E_{baseline}$ is the baseline emission, *CF* is the EPA conversion factor by locomotive application, and *Fuel* is the annual fuel consumption in gallons of diesel for a single representative locomotive. Conversion factors are then used to convert baseline emissions into units of kg/day.

For marine vessels, the EPA emission factors are listed in grams of pollutant per kilowatt-hour (g/kWh). The emission calculation for vessels is summarized as:

$$E_{baseline}\left(\frac{kg}{day}\right) = EPA_{emission\ factor}\left(\frac{g}{kWh}\right) * Pwr\ (kW) * OpHr\ (hr) * LF * \left(\frac{1\ yr}{365\ day}\right) * \left(\frac{1\ kg}{1000\ g}\right) \quad (3)$$

where $E_{baseline}$ is the baseline emission, *Pwr* is the engine's rated power in kW, *OpHr* is the annual operating hours for the vessel, and *LF* is the load factor. Conversion factors are then used to convert baseline emissions into units of kg/day. Load factors are pre-defined as 0.51 for engines ≤560 kW and 0.72 for engines >560 kW based on average load factors for propulsion and auxiliary engines for marine applications.[8]

For both locomotive and marine vessel applications, retrofitted emissions are calculated based on a percent reduction of emissions by pollutant. Retrofitted emissions are calculated as:

$$E_{retrofit}\left(\frac{kg}{day}\right) = E_{baseline}\left(\frac{kg}{day}\right) - \left(E_{baseline}\left(\frac{kg}{day}\right) * \frac{Reduction\ (\%)}{100}\right) \quad (4)$$

where $E_{retrofit}$ is the emission after applying a retrofit technology to the engine or exhaust. The tool assumes the engines used in the baseline emissions calculations are all diesel powered. Table 1 gives the percent reductions in emissions by control technology.

[7] U.S. Environmental Protection Agency. 2009. *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.

[8] U.S. Environmental Protection Agency. 2008. *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder*, EPA-420-R-08-001a. Available at: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P10024CN.TXT.

Table 1. Emission Reductions by Control Technology[9]

Emission	Control Technology Emissions Savings (%)	
	Selective Catalytic Reduction (applies to locomotives)	*Diesel Particulate Filter (applies to marine vessels)*
CO	70	0
NO_X	70	0
$PM_{2.5}$	10	50
PM_{10}	10	50
VOC	90	0
CO_2	0	0

For all calculations, $PM_{2.5}$ emissions are estimated as 97% of PM_{10} emissions.[10]

THC-to-VOC Conversion

EPA's 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 following factor:[11]

$$\frac{VOC}{THC} = 1.053 \quad (5)$$

CO_2 Emission Rates

Carbon dioxide (CO_2) emission benefits are also reported in the Engine Retrofit module as CO_2 equivalent (CO_2e). Because neither the SCR or diesel particulate filter technologies reduce CO_2 emissions, CO_2e savings will always be reported as 0 kg/day (i.e., no benefit) for this module.

Engine Repower or Replacement

The equations below summarize how the Engine Repower or Replacement module calculates emissions reductions. As with the Engine Retrofit module, the change in emissions is the difference between the emissions from the baseline equipment/engine and the emissions from the repowered or replacement equipment. Emission reductions reported in kg/day are thus calculated for a given pollutant as follows:

$$\Delta Emissions = Baseline\ Emissions - RR\ Emissions \quad (6)$$

[9] U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2. Available at: https://cfpub.epa.gov/quantifier/.

[10] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

[11] U.S. Environmental Protection Agency. 2005. *Conversion Factors for Hydrocarbon Components,* EPA420-R-05-015. Available at: https://19january2017snapshot.epa.gov/www3/otaq/models/nonrdmdl/nonrdmdl2005/420r05015.pdf.

where *RR* represents the *R*epowered or *R*eplacement equipment. A positive change in emissions is equivalent to an emissions reduction (benefit), while a negative change in emissions can be interpreted as an emissions increase (disbenefit).

Both the baseline and RR emissions are calculated using Equations 2 and 3 presented in the previous section for locomotives and marine vessels, respectively. The tool assumes original equipment is powered by diesel fuel. The difference between baseline and RR emissions are based on newer engines meeting the more stringent EPA standards. As with the Engine Retrofit module, $PM_{2.5}$ emissions in this module are estimated as 97% of PM_{10} emissions.

It should be noted that this tool assumes the same amount of diesel fuel (or equivalent) is used post repower or replacement. However, fuel savings are included in the emissions reduction calculation if the diesel GenSet is selected as the replacement engine for switch locomotives (this engine type is unavailable for other applications). The fuel savings for the diesel GenSet are based on the operation of the replacement multi-engine configuration and not because of efficiencies in the engines themselves (refer to Replacement Engine Types for more detail).

When the user selects a marine vessel as the baseline equipment in the Engine Repower or Replacement module the tool gives the option to provide separate inputs for propulsion and auxiliary engines. If only propulsion or only auxiliary engines were repowered/replaced, users only enter information for that engine category. The tool calculates emissions reductions separately for propulsion and auxiliary engines based on the user inputs for each, and then reports the summed results in the output.

THC-to-VOC Conversion

EPA's hydrocarbon emission factors were reported in terms of THC. THC were converted to VOC for consistency with tool output and CMAQ reporting requirements, using the following factors.[12]

Diesel:

$$\frac{VOC}{THC} = 1.053 \quad (7)$$

Liquefied Petroleum Gas (for LNG):

$$\frac{VOC}{THC} = 0.995 \quad (8)$$

CO_2 Emission Rates

CO_2 emission benefits are also calculated in the Engine Repower or Replacement module, reported as CO_2e. CO_2 emissions are based on the carbon content of the fuel. For diesel in locomotives, the carbon content is 3,200 g

[12] U.S. Environmental Protection Agency. 2005. *Conversion Factors for Hydrocarbon Components,* EPA420-R-05-015. Available at: https://19january2017snapshot.epa.gov/www3/otaq/models/nonrdmdl/nonrdmdl2005/420r05015.pdf.

CO_2 per gallon diesel; for liquefied natural gas (LNG), the carbon content is 4,366 g CO_2 per gallon LNG.[13] For diesel in marine vessels, which is assumed to be ultra-low sulfur diesel for C1 or C2 vessels and distillate marine gas oil (MGO) or marine diesel oil (MDO) for C3 vessels, the carbon content is 3.19 and 3.206 g CO_2 per g fuel, respectively; for LNG, the carbon content is 2.75 g CO_2 per g fuel.[14] Carbon content in marine vessel fuel is converted to g CO_2 per kWh using the brake specific fuel consumption (BSFC) specific to different marine vessel categories and fuel type. BSFC rates used in this tool are provided in Table 2.

Table 2. BSFC Rates by Marine Vessel Category[15]

Marine Engine Category	Fuel Type	Power Range (kW)	BSFC Rate (g/kWh)
C1 or C2	ULSD	< 37	248
C1 or C2	ULSD	≥ 37	213
C3 (propulsion)	MGO/MDO	Any	205*
C3 (auxiliary)	MGO/MDO	Any	217*
Any	LNG	Any	166‡

* Assumes C3 engines are medium-speed diesel (MSD; typical engine speed range = 500-1,400 rpm).

‡ BSFC rate given is for C3 marine vessels. The tool assumes this same rate for C1 and C2 marine vessels.

If the repowered/replacement engine selected is 'Diesel' (regardless of the emissions Tier), the CO_2e benefit will be reported as 0 kg/day, as there is no change in fuel type or the amount of fuel used. If 'Diesel GenSet' is selected, the tool will report a CO_2e benefit despite no change in fuel type. This is because the tool estimates a 25% savings in diesel fuel use with this replacement engine (refer to *Diesel GenSet* under Replacement Engine Types for more detail). Selecting 'Diesel-Electric Hybrid' or 'All-Electric or Equivalent' as the repowered/replacement engine type will result in CO_2e benefits as less diesel fuel is used as compared to the original engine. Switching from diesel to LNG will result in negative CO_2e benefits (i.e., a disbenefit) for locomotive applications due to the higher carbon content of LNG and the assumption that fuel consumption remains the same.

Replacement Engine Types

The Engine Repower or Replacement module allows users to select five different engine replacement options: diesel, diesel GenSet (switch locomotives only), LNG, diesel-electric hybrid (marine vessels only), or all-electric or equivalent. Sources for each emission rate by engine type are summarized in Table 3. Additional details are given below.

[13] Smith, T. W. P., et al., Third IMO Greenhouse Gas Study 2014: Executive Summary and Final Report, International Maritime Organization (IMO), London, UK, April 2015. Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third Greenhouse Gas Study/GHG3 Executive Summary and Report.pdf.

[14] Ibid.

[15] Ibid.

Table 3. Emissions Source by Engine Type

Engine Type	Application	Emissions Rate Source
Diesel	Locomotive & Marine	EPA[1, 2]
Diesel GenSet	Locomotive (Switch only)	California Air Resources Board[16]
LNG	Locomotive	Report[5]
LNG	Marine	EPA[2]
Diesel-Electric Hybrid	Marine	EPA[2]
All-Electric or Equivalent	Locomotive & Marine	EPA[6]

Diesel

Selecting 'Diesel' as the engine type for the repowered or replacement equipment does not by itself result in emissions savings. The emissions savings in this case are due to the assumption that a repowered or replacement engine will be newer and held to a higher Tier. Item 4 in the Engine Repower or Replacement module requires users to input the emissions Tier to which the repowered or replacement diesel engine will be held. While the tool does allow users to input a lower Tier for the repowered/replacement engine than the baseline engine, it is not expected to be common practice as it would lead to increased emissions. The module assumes the same amount of diesel fuel is used pre- and post-repower or replacement.

Diesel GenSet

The 'Diesel GenSet' option is only available for switch locomotives at this time. While it is technically feasible for a diesel GenSet to be used for other applications, they are not commonly used in line-haul locomotives or marine vessels. Diesel GenSets are a multi-engine configuration (typically 2-3 engines) that run in series with each engine powering up as the load increases. These engines are designed for switch locomotives operating in rail yards where locomotives can spend the majority of time idling. During idle, two of the engines in a three-engine GenSet can be turned off with only one engine idling. Compared to a single diesel engine with the same load capacity as the three-engine GenSet, emissions will be lower (mainly due to reductions in fuel use). As the load increases on the GenSet (e.g., the switcher begins moving rail cars around the yard), additional engines power up to meet the work demand. GenSets are typically built with non-road diesel engines/generators and are certified at EPA's Tier 4 emissions standard for switch locomotive applications.[17] When selected as the repowered/replacement equipment type, the module calculates emissions at the EPA Tier 4 standard for switch locomotives. For this engine type only, fuel savings are incorporated into the emissions benefit calculation. It should be noted that these fuel savings are assumed only due to the operation of the multi-engine configuration and not based on assumptions with individual engine characteristics, such as age. While the actual fuel savings accrued will vary by

[16] California Air Resources Board. Accessed 2020. Locomotive Emission Verifications, Technology Demonstrations, and Incentives (webpage). Available at: https://ww2.arb.ca.gov/our-work/programs/reducing-rail-emissions-california/locomotive-emission-verifications-technology.

[17] Ibid.

switcher use, it is estimated that rail yards can observe 20-50% fuel savings.[18] This module uses a conservative estimate of 25% fuel savings in the emissions calculations, which results in a 25% reduction of Tier-4-based emissions.

LNG

Selecting 'LNG' as the engine type for the repowered or replacement equipment directs the module to use pre-defined emission factors (not based on emission Tiers). LNG use by locomotives and marine vessels is currently not common, but pilot studies on the use of natural gas for locomotives have been completed[19] and the fuel is seen as a potential alternative to diesel. Emission factors for LNG for both switch and line-haul locomotives are based on a joint report by the BNSF Railway Company, the Union Pacific Railroad Company, and the Association of American Railroads.[20] Emission factors for LNG for marine vessels are based on EPA's *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories.*[21] Due to the lower energy content of LNG as compared to diesel,[22, 23] emission factors for LNG for locomotive applications, which are based on gallons of LNG, have been converted to gallons of diesel using the following ratio:

$$1.7\ gal\ LNG = 1\ gal\ diesel \quad (9)$$

The user does not need to adjust the fuel-use input (Question 7 in the tool) as the module does the calculation automatically. The emission factors for LNG for marine applications are based on energy use in kWh (as opposed to fuel use), so no conversion is necessary between LNG and diesel.

[18] Manufacturer claims and demonstrations, including: https://www.dot.ny.gov/recovery/repository/NYSDOT%20Narrative%20FINAL.pdf, https://archive.epa.gov/midwestcleandiesel/web/pdf/il2008.pdf, and https://ww3.arb.ca.gov/railyard/docs/nre_finalreport_201507.pdf.

[19] TIAX. 2010. Demonstration of a Liquid Natural Gas Fueled Switcher Locomotive at Pacific Harbor Line, Inc. (presentation prepared for The Port of Long Beach). Available at: http://www.cleanairactionplan.org/documents/pacific-harbor-line-lng-locomotive-demonstration-final-report-april-2010.pdf/

[20] BNSF Railway Company, Union Pacific Railroad Company, The Association of American Railroads, and California Environmental Associates. 2007. *An Evaluation of Natural Gas-fueled Locomotives* (report). Available at: https://ww3.arb.ca.gov/railyard/ryagreement/112807lngqa.pdf.

[21] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.

[22] U.S. Department of Energy, Energy Efficiency & Renewable Energy. Accessed 2019. Alternative Fuels Data Center: Gasoline and Diesel Gallon Equivalency Methodology (website). Available at: https://afdc.energy.gov/fuels/equivalency_methodology.html.

[23] Alaska Department of Military and Veteran Affairs, Division of Homeland Security & Emergency Management. Accessed 2019. Liquefied Gas Conversion Chart (table). Available at: https://dec.alaska.gov/media/18793/gasconversionchartpublic.pdf.

Diesel-Electric Hybrid

The 'Diesel-Electric Hybrid' option is only available for marine vessels at this time and emission benefits are based on emission reductions as reported in EPA's DEQ.[24] Emission reductions are a fixed percent reduction in the baseline equipment emissions (given the baseline emissions Tier). The reductions are: NO_X = 30%, $PM_{2.5}$ = 25%, PM_{10} = 25%, VOC = 15%, CO = 35%, and CO_2 = 30%.

All-Electric or Equivalent

Selecting 'All-Electric or Equivalent' as the engine type for the repowered or replacement equipment results in zero emissions from the repowered or replacement equipment. This category can be applied to a variety of zero-emission solutions, including (but not limited to): batteries, hydrogen fuel cells,[25] and connection to the grid via overhead lines (for locomotives).

[24] U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2. Available at: https://cfpub.epa.gov/quantifier/.

[25] Fuelcell Propulsion Institute. 2010. *Demonstration of a Hydrogen Fuel-Cell Locomotive*. Available at: https://pdfs.semanticscholar.org/bc5b/8df3251a993d608295aad4ae795678c046cf.pdf.

Appendix – Emissions Tables

Table A 1. Locomotive Emission Factors[26]

			Emission Factors (g/bhp-hr)			
Fuel Type	**Year of Manufacture**	**Tier**	**NO_X**	**PM**	**HC**	**CO**
Diesel (Line-haul)	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
Diesel (Switch)	Pre-1973	Uncontrolled	17.40	0.44	1.01	1.83
	1973-2001	Tier 0	12.60	0.44	1.01	1.83
	1973-2001	Tier 0+	10.60	0.23	0.57	1.83
	2002-2004	Tier 1	9.90	0.43	1.01	1.83
	2002-2004	Tier 1+	9.90	0.23	0.57	1.83
	2005-2010	Tier 2	7.30	0.19	0.51	1.83
	2005-2010	Tier 2+	7.30	0.11	0.26	1.83
	2011-2014	Tier 3	4.50	0.08	0.26	1.83
	2015+	Tier 4	1.00	0.015	0.08	1.83
GenSet*	2015+	Tier 4	1.00	0.015	0.08	1.83
LNG‡	All	N/A	2.4	0.15	5.5	3.7
Electric◊ (or equivalent)	All	N/A	0.0	0.0	0.0	0.0

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.

* Emission rates are estimated at the Tier 4 switch locomotive emission rates (refer to Emissions Data document for details).

‡ Emission rates take into account energy difference for equal volume of fuel type (i.e., 1.7 gal LNG = 1.00 gal diesel in energy equivalence).

◊ Source: U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2.

[26] U.S. Environmental Protection Agency. 2009. *Emission Factors for Locomotives*, EPA-420-F-09-025. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100500B.TXT.

Table A 2. Marine Vessel Emission Factors[27]

				Emission Factors (g/kWh)			
Fuel Type	**Vessel Category**	**Year of Manufacture**	**Tier***	**NO_X**	**PM**	**VOC**	**CO**
Diesel (as ultra low sulfur diesel; ULSD)	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
Diesel (as marine diesel oil; MDO)	C3 (propulsion)	Pre-2000	Tier 0	13.2	0.19	0.53	1.1
	C3 (propulsion)	2000-2010	Tier 1	12.2	0.19	0.53	1.1
	C3 (propulsion)	2011-2015	Tier 2	10.5	0.19	0.53	1.1
	C3 (propulsion)	2016+	Tier 3	2.6	0.19	0.53	1.1
	C3 (auxiliary)	Pre-2000	Tier 0	10.9	0.19	0.42	1.1
	C3 (auxiliary)	2000-2010	Tier 1	9.8	0.19	0.42	1.1
	C3 (auxiliary)	2011-2015	Tier 2	7.7	0.19	0.42	1.1
	C3 (auxiliary)	2016+	Tier 3	2.0	0.19	0.42	1.1
Diesel-Electric Hybrid◊	Any	Any	N/A	Refer to information below			
LNG	Any	Any	N/A	1.3	0.03	0.0	1.3
Electric◊ (or equivalent)	Any	Any	N/A	0.0	0.0	0.0	0.0

* Refer to Table A3 for assistance in determining the appropriate Tier for C1 and C2 marine vessels.

◊ Source: U.S. Environmental Protection Agency. 2019. Diesel Emissions Quantifier (DEQ) version 8.2.

Emission factors for diesel-electric hybrid engines are based on percent reductions on the baseline equipment emissions Tier. The reductions are: NO_X = 30%, PM = 25%, VOC = 15%, CO = 35%, and CO_2 = 30%. For example, if the baseline equipment was a Tier 3 C2 vessel, the NO_X emission factor for the diesel-electric hybrid repowering would be a 30% reduction from the 4.7 g/kWh NO_X Tier 3 emission factor, or 3.3 g/kWh.

[27] U.S. Environmental Protection Agency, Office of Transportation Air Quality. 2020. *Draft Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories*. EPA-420-D-20-001. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf.