SAN PEDRO BAY PORTS
EMISSIONS INVENTORY
METHODOLOGY REPORT

Version 2 - 2021

September 2021

San Pedro Bay Ports
Emissions Inventory Methodology Report

Version 2 (starting with CY 2020 EI)

Prepared for:

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SECTION 1 INTRODUCTION

Since 2005, the ports of Long Beach and Los Angeles (San Pedro Bay Ports or the Ports) have independently developed annual Air Emissions Inventory (EI)[1] reports. In 2006, both ports approved the landmark San Pedro Bay Ports (SPBP) Clean Air Action Plan (CAAP)[2], which has been updated twice, in 2010 and 2017. The SPBP's activity-based annual emissions inventories serve as the primary tool to track the ports' efforts to reduce air emissions from maritime industry-related sources through implementation of measures identified in the SPBP CAAP and regulations promulgated at the state, federal and international levels. Development of the annual air emissions estimates and this technical methodology report are coordinated with a technical working group (TWG) comprised of representatives from the Ports and the air regulatory agencies: U.S. Environmental Protection Agency, Region 9 (EPA), California Air Resources Board (CARB), and the South Coast Air Quality Management District (SCAQMD).

The annual reports were streamlined following publication of the 2013 EI reports in large part by removing the detailed methodology sections. Starting with the 2014 EI and continuing through the 2017 EI, the annual EI reports reference the 2013 EI methodology sections for each source category and only the improvements and/or changes to methodology are discussed in the current annual EI reports, along with the calendar year activity, fleet characteristics and annual emissions and comparisons.

After 4 years of streamlined reports, the Ports decided to develop a joint San Pedro Bay Ports Emissions Inventory Methodology report published in 2019 entitled "San Pedro Bay Ports Emissions Inventory Methodology Report Version 1"[3] (SPBP EI Methodology Report Version 1).

This methodology report (SPBP EI Methodology Report Version 2) is an update to SPBP EI Methodology Report Version 1. This update will serve as a reference for the 2020 and later annual EIs (until it is superseded) and it is based on the methodology used for the latest published 2020 EI report. This report is updated for revisions made for the ocean-going vessel (OGV) and heavy-duty vehicle (HDV) emissions calculation methodologies. It will not be updated annually, but a new version will be prepared when the methodology changes are deemed substantial. Improvements and minor changes to methodology will continue to be described in the annual EI reports. This methodology report contains one section per source category:

> Section 2 – Ocean-going vessel (OGV) methodology – update included
> Section 3 – Harbor craft methodology – no update
> Section 4 – Cargo handling equipment (CHE) methodology – no update
> Section 5 – Locomotive methodology – no update
> Section 6 – Heavy-duty vehicle (HDV) methodology – update included

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[1] See: *www.polb.com/environment/air/emissions.asp* and *www.portoflosangeles.org/environment/studies_reports.asp*

[2] See: *www.cleanairactionplan.org*

[3] See: *www.polb.com/environment/air#emissions-inventory* OR *www.portoflosangeles.org/environment/air-quality/air-emissions-inventory*

1.1 Geographic Domain

The geographical extent of the inventory includes emissions from the maritime industry-related emission sources operating within the harbor district. For commercial marine vessels and harbor crafts, the domain lies within the harbor and up to the study area boundary comprised of an over-water area bounded in the north by the southern Ventura County line at the coast, and in the south with the southern Orange county line at the coast.

For rail locomotives and on-road trucks, the domain extends from the Port to the cargo's first point of rest within the South Coast Air Basin (SoCAB) or up to the SoCAB boundary, whichever comes first.

Figure 1.1 shows the over the water geographical extent of the SPBP emissions inventory, and other overlapping regulatory boundaries.

Figure 1.1: Emissions Inventory Geographical Extent

Figures 1.2 and 1.3 show the land area of active Port terminals at the Port of Long Beach and the Port of Los Angeles, respectively. The geographical scope for cargo handling equipment is the terminals and facilities on which they operate. For the Port of Los Angeles EI report, the CHE emissions from the UP ICTF are included since UP ICTF is on port property. In the future, terminals may close or change their name, therefore the reader is cautioned to refer to the latest streamlined annual emissions reports for the latest terminal configuration and their names.

Figure 1.2: Port of Long Beach Terminals

Figure 1.3: Port of Los Angeles Terminals
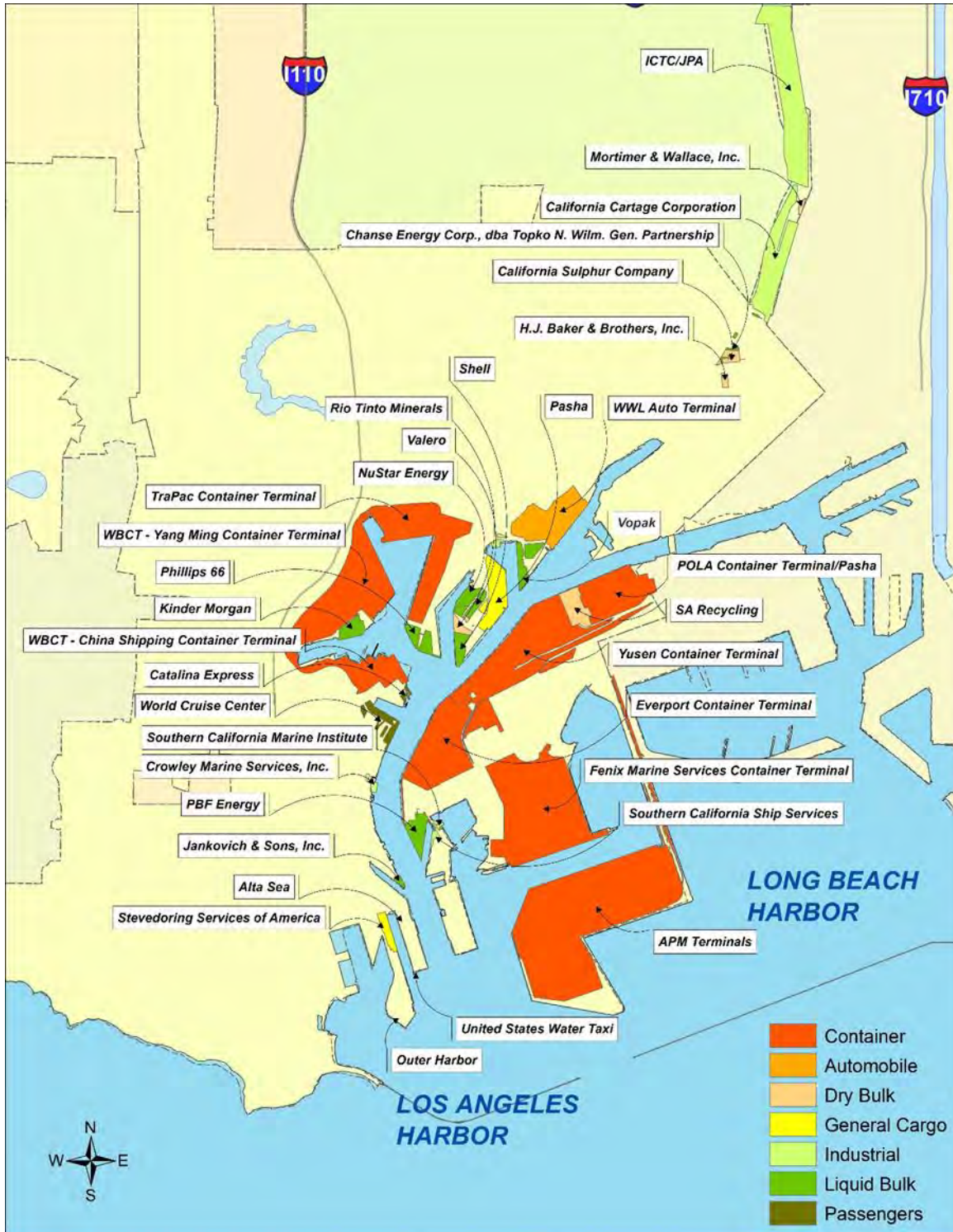
1.2 Pollutants

Exhaust emissions of the following pollutants that can cause regional and local air quality impacts have been estimated:

- ➢ Particulate matter (PM) (10-micron, 2.5-micron)
- ➢ Diesel particulate matter (DPM)
- ➢ Oxides of nitrogen (NO_x)
- ➢ Oxides of sulfur (SO_x)
- ➢ Hydrocarbons (HC)
- ➢ Carbon monoxide (CO)

The reports also include estimates of greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emitted from maritime industry-related tenant operational mobile sources. To normalize the three GHG values into a single number representing CO_2 equivalents (CO_2e) the GHG emission estimates are multiplied by the following values and summed.[4]

- ➢ CO_2 – 1
- ➢ CH_4 – 25
- ➢ N_2O - 298

Only CO_2e values are presented in the reports because they include all three GHGs in an equivalent measure to CO_2, which makes up by far the greatest mass of GHG emissions from the emission source categories included in this inventory. The GHG emissions are presented in metric tons (tonnes) while the criteria pollutants and other emissions are shown in tons.

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[4]EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*, April 2021.

SECTION 2 OGV METHODOLOGY

The vessel types that are included in the Port of Los Angeles and Port of Long Beach annual emission inventories are:

- Auto Carrier
- Articulated Tug Barge (ATB)
- Bulk
- Containerships
- Cruise

- General Cargo
- Miscellaneous
- Reefers
- RoRo
- Tankers

Emissions are estimated from the following sources on board OGVs:

- Propulsion systems or propulsion engines that move the ship through water;
- Auxiliary power systems or auxiliary engines (diesel generators) that provide electricity during ship operations; and
- Auxiliary boilers that produce hot water and steam for use in the engine room and for crew amenities.

Incinerators are not included in the emission estimates because incinerators are not used within the study area. Interviews with the vessel operators and marine industry indicate that vessels do not use their incinerators while at berth or near coastal waters.

2.1 Data and Information Acquisition

The following sources of data and operational knowledge about the Port's marine activities are used to compile the data necessary to estimate emissions from OGVs:

- Marine Exchange of Southern California (MarEx)[5] for most of the OGV speed information
- Vessel Speed Reduction Program (VSR) speed data obtained from MarEx at the 10, 15, 20, 25, 30, 35, and 40 nm collected from MarEx's Automated Identification System (AIS) and radar data
- Jacobsen Pilot Service at the Port of Long Beach and the Los Angeles Pilot Service at the Port of Los Angeles for determining vessel activity within the harbor
- IHS Markit (IHS), formerly Lloyd's Fairplay, Maritime World Register of Ships[6] for determining specific OGV and OGV main engine characteristics
- Vessel Boarding Program (VBP) data, the primary source of auxiliary engine and boiler loads
- Environmental Ship Index (ESI) data to obtain fuel and engine data
- Port tanker load and discharge activity data
- Port and terminal shore power activity data, including the use of alternative at-berth emission control technologies such as the Advanced Maritime Emission Control System (AMECS) and the Maritime Emissions Treatment System (METS-1)

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[5] *See: www.mxsocal.org/*
[6] *See: www.ihsmarkit.com/products/maritime-world-ship-register.html*

The Ports' latest annual EI reports include information on new or revised data sources.

2.2 Overview of Vessel Activity Modes

Vessel movement activity is defined as the number of ship trips by trip type and segment. A trip type defines the ship's movement and the segment defines the geographical area that the ship is operating within. Vessel trip types include arrivals, departures, and shifts. Ship movements are tracked by MarEx as the following trip types:

 ➢ Arrivals - inbound trips from the inventory boundary to berth or to anchorage
 ➢ Departures - outbound trips from a berth or anchorage to the inventory boundary
 ➢ Shifts - inter-port, intra-port, and anchorage shifts

Arrivals include inbound trips from the sea to a berth and inbound trips from the sea to an anchorage. An inbound trip from the sea to an anchorage is assigned to the Port if the next port of call after the anchorage is a berth at POLB or POLA. A call is made up of an arrival to, shift(s) as applicable, and departure from the emissions inventory domain.

Trip segments are defined as:

 ➢ Between the at-sea portion and the Precautionary Zone (PZ) of the transit route of the ship trip. The PZ is an area contained within defined limits where ships must navigate with caution.
 ➢ Each segment within the PZ
 ➢ Each segment inside the breakwater

These trips are then processed to define time in mode and geographical segment. The purpose of this step is to estimate power demand (engine load) for each segment and multiply power by the amount of time spent in that particular mode, which estimates energy demand expressed as load times unit of time, e.g., kilowatt-hour (kW-hr). Each vessel-by-vessel activity is analyzed by trip type and trip segment for the EI calendar year. In addition to vessel movement activity, ships spend time while stationary at anchorage and at berth. Energy demand from the auxiliary engines and boilers is estimated for relevant transit time as well as at-berth and/or at-anchorage time. The following vessel operational modes are used to define the characteristics of a ship's operation within the emission inventory domain:

Transit: Ship is operating in open water, also identified as "at-sea mode." Ship is traveling at its sea-speed or cruising speed unless observing slow steaming or the vessel speed reduction program.

Maneuvering: Ship is operating within the breakwater. Additional auxiliary power is typically brought online as a safety measure since the ship is traveling in restricted waters and bow or stern thrusters are needed for maneuverability. Maneuvering time is based on the type of ship, associated speed, and distance traveled between the berth and the breakwater.

At Berth: Ship is stationary at the dock/berth; typically, this is during loading and unloading of cargo. Ship is typically still active, operating auxiliary engines (unless on shore power) and boilers, but not operating its propulsion engines.

At Anchorage: Ship is anchored inside or just outside the breakwater waiting for reassignment, an open berth, or maintenance. Ship is typically still active, operating auxiliary engines and boilers, but not operating its propulsion engines.

Shift: Ship movement other than an arrival or departure. Ship moves from one berth to another berth within the Port or between the two ports, or from/to an anchorage. A ship can have zero to several shifts per call. There are three broad categories of shift movements:

➢ Intra-port shifts: within a port from one berth to another.
➢ Inter-port shifts: between berths in adjacent ports. This is a common occurrence in collocated ports such as Long Beach and Los Angeles.
➢ Anchorage shifts: between a terminal and an anchorage in either direction. For example, a vessel receives a partial load, goes to anchorage, and then returns to the terminal (or to another terminal) to complete loading. This example includes two shifts, one to anchorage and one from anchorage.

Each call has an associated maneuvering time as the vessel travels within the breakwater. Maneuvering times inside the breakwater are developed annually for each terminal based on Pilot's detailed call data, which is aggregated to determine the average time ships spend maneuvering.

2.3 Emission Estimation Methodology

Vessel activity data and the methods of estimating emissions are discussed below for propulsion engines, auxiliary engines and boilers. Differences in methods of estimation between the various modes of operation, at-berth and maneuvering, are discussed where applicable. In general, emissions are estimated as a function of vessel power demand with energy expressed in kW-hr multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). Emission factor adjustments (for low propulsion engine load, different fuel usage, or emission controls) are then applied to the various activity and operational data. Equations 2.1 and 2.2 report the basic equations used in estimating emissions by mode.

Equation 2.1

$$E_i = Energy_i \times EF \times FCF \times CF$$

Where:
E_i = Emissions by mode
$Energy_i$ = Energy demand by mode, calculated using Equation 2.2 below as the energy output of the engine(s) or boiler(s) over the period of time, kW-hr
EF = Emission factor, expressed in terms of g/kWh, depends on engine type, IMO level of NO_x control (tier) and fuel used
FCF = Fuel correction factors are used to adjust from a base fuel associated with the EF and the fuel being used, dimensionless
CF = Control factor(s) for emission reduction technologies, dimensionless

The 'Energy' term of the equation is where most of the location-specific information is used. Energy by mode is calculated using Equation 2.2:

Equation 2.2

$$Energy_i = Load_i \times Activity_i$$

Where:

Energy$_i$ = Energy demand by mode, kW-hr
Load$_i$ = maximum continuous rated (MCR) propulsion engine power times load factor (LF), kW; reported auxiliary engine(s) operational load by mode i, kW; or auxiliary boiler operational load by mode i, kW
Activity$_i$ = time of activity for mode i, hours

Vessel IMO numbers from MarEx data for the vessels that operated in the EI calendar year are matched with IHS Markit data to determine the type of vessel (Auto, Bulk, Container etc.) keel laid date (that determines age, IMO tier level, and emission factor for the vessel) and type of engine (slow speed, medium speed, or high speed).

2.4 Propulsion Engine Maximum Continuous Rated Power (MCR)

MCR power is defined as the manufacturer's tested maximum engine power and is used to determine propulsion engine load by mode. The international convention is to document MCR in kilowatts, and it is the highest power available from a ship engine during average cargo and sea conditions. For the Ports' annual EIs, it is assumed that the 'Power' value in the IHS data is the best proxy for MCR power. For diesel-electric configured ships, MCR is the combined electric propulsion engine(s) rating, in kW.

2.5 Propulsion Engine Load Factor

The propulsion engine load factor is used to estimate how much of the propulsion engine(s') MCR is being used. The propulsion engine load factor is estimated using the Propeller Law, which states that propulsion engine load varies with the cube of the ratio of actual speed to the ship's maximum rated speed, as illustrated by the following equation.

Equation 2.3

$$LF = (Speed_{Actual} / Speed_{Maximum})^3$$

Where:

LF = load factor, dimensionless
Speed$_{Actual}$ = actual speed, knots
Speed$_{Maximum}$ = maximum speed, knots

For the purpose of estimating emissions, the load factor has been capped at 1.0 so that there are no calculated propulsion engine load factors greater than 100% (i.e., calculated load factors above 1.0 are assigned a load factor of 1.0). This may occur when, for example, a ship is moving with a tide and with the wind and the tide and wind action moves the ship faster than the rated speed even though the propulsion engine is set for less than the rated speed. In such a case the calculated load would not accurately reflect the actual operating load on the engine.

2.6 Propulsion Engine Activity

Activity is measured in hours of operation. At-berth and anchorage times are determined either from MarEx or the Ports' Pilots arrival and departure data. The transit times within the PZ and along the various routes from outside the PZ to the edge of the geographical boundary are estimated using equation 2.4 which divides the segment distance traveled by ship speed.

Equation 2.4

$$Activity = D/Speed_{Actual}$$

Where:
  Activity = activity, hours
  D = distance, nautical miles
  $Speed_{Actual}$ = actual ship speed, knots

Actual speeds provided by MarEx are used for estimating the route transit time. Vessel speeds are recorded by MarEx at the 10, 15, 20, 25, 30, 35 and 40 nm waypoints. The Vessel Speed Reduction Program (VSR) is a voluntary program that requests reduced speeds of 12 knots or slower during transiting outside the harbor and within 40 nm of San Pedro Bay.

Based on information obtained from the Pilots on operational speeds in the PZ by vessel class, the average speeds presented in Table 2.1, are assigned by vessel type.

Table 2.1: Precautionary Zone Average Speed, knots

Vessel Type	Vessel Class	Average Speed
Auto Carrier	Fast	11
Bulk	Slow	9
Containership	Fast	11
Cruise	Fast	11
General Cargo	Slow	9
Miscellaneous	Slow	9
Ocean Tugboat (ATB/ITB)	Slow	9
Reefer	Slow	9
RoRo	Slow	9
Tanker	Slow	9

2.7 Propulsion Engine Emission Factors

Diesel cycle engines are the most prevalent type of propulsion engines on vessels that visit SPBP. The two predominant diesel propulsion engine types installed on vessels that come to the SPBP are:

➢ Slow speed diesel engines, having maximum engine speeds less than 130 rpm
➢ Medium speed diesel engines, having maximum engine speeds over 130 rpm (typically greater than 400 rpm) and less than 2,000 rpm.

In addition to diesel propulsion engines, a few visiting ships have been equipped with either a steam turbine or a gas turbine propulsion system. The steam turbine has a fuel oil/marine distillate fired boiler that produces steam to drive the steam turbine engine for propulsion. The gas turbine uses fuel oil/marine distillate fueled combustion to drive a gas turbine for propulsion

Emission factors for all engine types used in this study were obtained from equations or values included in USEPA's document entitled "Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions," dated September 2020 (USEPA's EI Guidance Document)[7]. The PM_{10} and DPM emission factors are based on the following equation:

Equation 2.5

$$PM \text{ or } DPM\ EF\ =\ PM_{base} \text{ or } DPM_{base} + (S_{act} \times BSFC \times 0.02247 \times 7)$$

Where:
PM or DPM EF = PM_{10} or DPM emission factors adjusted for the fuel type and S content of the fuel (g/kW-hr)
PM_{base} or DPM_{base}= Base emission factor assuming zero fuel sulfur (g/kWhr)
   = 0.1545 g/kW-hr for distillate fuel (MGO and MDO)
   = 0.5761 g/kW-hr for residual fuel (HFO)
S_{act} = actual fuel sulfur level (weight ratio)
BSFC = brake specific fuel consumption in g/kW-hr
0.02247 is fraction of sulfur in fuel that is converted to direct sulfate
7 is molecular weight ratio of sulfate PM to sulfur = 224/32 = 7

The $PM_{2.5}$ emission factor is based on the following equation:

Equation 2.6

$$PM_{2.5}\ EF\ =\ PM\ EF \times Fraction$$

Where:
PM EF = PM_{10} emission factor in g/kW-hr
Fraction = $PM_{2.5}$ to PM_{10} ratio dependent on fuel type
   = 0.8 for HFO
   = 0.92 for MGO and MDO

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[7] *www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance*

The SO_x emission factor is based on the following equation:

Equation 2.7

$$SO_2\ EF\ =\ S_{act} \times BSFC \times 2 \times 0.97753$$

Where:
> SO_2 EF = SO_x emission factor (g/kW-hr)
> S_{act} = actual fuel sulfur level (weight ratio)
> BSFC = brake specific fuel consumption in g/kW-hr
> 0.97753 is the fraction of fuel sulfur converted to SO_2 and
> 2 is the ratio of molecular weights of SO_2 and S.=64/32 = 2

The CO_x emission factor is based on the following equation:

Equation 2.8

$$CO_2\ EF\ =\ BSFC \times CCF$$

Where:
> CO_2 EF = CO_x emission factor (g/kW-hr)
> BSFC = brake specific fuel consumption in g/kW-hr
> CCF= carbon content factor as a function of fuel type(CO2/g fuel)
> > = 3.206 for MGO/MDO
> > = 3.114 for HFO

For regulatory purposes, all diesel cycle fuel oil/marine distillate fueled engines are divided into Tier 0 to Tier III as per the NO_x standards and by engine rated speed, in revolutions per minute or rpm, as listed below:

- ➢ Slow speed engines: less than 130 rpm
- ➢ Medium speed engines: between 130 and 2,000 rpm
- ➢ High speed engines: greater than or equal to 2,000 rpm

Per IMO regulation, NOx emission factors vary by engine Tier

Starting on January 1, 2014, CARB's final fuel standard for ships operating in California waters required use of 0.1% or less sulfur marine distillate or marine gas oil (MDO or MGO) fuel. As of January 2015, all vessels calling the San Pedro Bay Ports were assumed to be also compliant with the IMO North American Emissions Control Area (ECA) requirement to use 0.1% sulfur (S) content fuel. During the emissions inventory estimation process if the actual S content of the fuel which could be lower than 0.1% used by a vessel is available, it is reflected in the emissions calculations. The emission factors for HFO with 2.7% sulfur content and fuel currently being required by CARB regulation (MGO 0.1% sulfur content) are shown in tables 2.3 and 2.4.

Table 2.2 shows BSFC by engine type used in equations for PM, SO$_x$ and CO$_2$ emission factors.

Table 2.2: BSFC by Engine Type and Fuel Type for Ocean Going Vessels, g/kW-hr

Engine Category	IMO Tier	Model Year Range	BSFC
Using HFO Fuel			
Slow speed propulsion	All	All	195
Medium speed propulsion	All	All	215
Medium speed auxiliary	All	All	227
High speed auxiliary	All	All	227
Steam propulsion engine and boiler	All	All	305
Gas Turbile	All	All	305
Using MGO Fuel			
Slow speed propulsion	All	All	185
Medium speed propulsion	All	All	205
Medium speed auxiliary	All	All	217
High speed auxiliary	All	All	217
Steam propulsion engine and boiler	All	All	300
Gas Turbile	All	All	300

Table 2.3: Pollutant Emission Factors for Diesel Propulsion, Steam Propulsion and Gas Turbine Engines, g/kW-hr

Engine Category	IMO Tier	Model Year Range	PM$_{10}$	PM$_{2.5}$	DPM	NO$_x$	SOx	CO	HC
Using 2.7% Sulfur HFO Fuel									
Slow speed propulsion	Tier 0	1999 and older	1.40	1.12	1.40	18.1	10.3	1.4	0.6
Slow speed propulsion	Tier I	2000 to 2011	1.40	1.12	1.40	17.0	10.3	1.4	0.6
Slow speed propulsion	Tier II	2011 to 2016	1.40	1.12	1.40	15.3	10.3	1.4	0.6
Slow speed propulsion	Tier III		1.40	1.12	1.40	3.6	10.3	1.4	0.6
Medium speed propulsion	Tier 0	1999 and older	1.49	1.19	1.49	14.0	11.3	1.1	0.5
Medium speed propulsion	Tier I	2000 to 2011	1.49	1.19	1.49	13.0	11.3	1.1	0.5
Medium speed propulsion	Tier II	2011 to 2016	1.49	1.19	1.49	11.2	11.3	1.1	0.5
Medium speed propulsion	Tier III	2016 and newer	1.49	1.19	1.49	2.8	11.3	1.1	0.5
Gas turbine	na	All	0.06	0.05	0.00	6.1	16.1	0.2	0.1
Steam propulsion engine	na	All	1.87	1.50	0.00	2.1	16.1	0.2	0.1
Using 0.1% S MGO Fuel									
Slow speed propulsion	Tier 0	1999 and older	0.184	0.169	0.184	17.0	0.362	1.4	0.6
Slow speed propulsion	Tier I	2000 to 2011	0.184	0.169	0.184	16.0	0.362	1.4	0.6
Slow speed propulsion	Tier II	2011 to 2016	0.184	0.169	0.184	14.4	0.362	1.4	0.6
Slow speed propulsion	Tier III		0.184	0.169	0.184	3.4	0.362	1.4	0.6
Medium speed propulsion	Tier 0	1999 and older	0.187	0.172	0.187	13.2	0.401	1.1	0.5
Medium speed propulsion	Tier I	2000 to 2011	0.187	0.172	0.187	12.2	0.401	1.1	0.5
Medium speed propulsion	Tier II	2011 to 2016	0.187	0.172	0.187	10.5	0.401	1.1	0.5
Medium speed propulsion	Tier III	2016 and newer	0.187	0.172	0.187	2.6	0.401	1.1	0.5
Gas turbine	na	All	0.010	0.009	0.000	5.7	0.587	0.2	0.1
Steam propulsion	na	All	0.202	0.186	0.000	2.0	0.587	0.2	0.1

When available, vessel specific NO_x emission factors from Engine International Air Pollution Prevention[8] (EIAPP) certificates are being used instead of defaults shown in table 2.3 for propulsion and auxiliary engines. NO_x emission factors are based on the IMO Tier of the vessel engines, which is based on the keel laid date provided in the IHS data.

Mounting evidence from engine manufacturers[9] and classification societies[10] suggest that Tier III propulsion engines will not meet Tier III emission standards when operating below 25% load because the exhaust heat does not reach the necessary temperature for selective catalytic reduction (SCR) or exhaust gas recirculation (EGR) systems to effectively reduce emissions. As such, when Tier III main engines operated below 25% within the emissions inventory domain, the default Tier II NOx emission factor or, if available, Tier II EIAPP NO_x factors were used in emission calculations.

Table 2.4: GHG Emission Factors for Diesel Propulsion, Steam Propulsion and Gas Turbine Engines, g/kW-hr

Using 2.7% Sulfur HFO Fuel					
Engine Category	**IMO Tier**	**Model Year Range**	**CO_2**	**N_2O**	**CH_4**
Slow speed propulsion	Tier 0	1999 and older	607	0.031	0.012
Slow speed propulsion	Tier I	2000 to 2011	607	0.031	0.012
Slow speed propulsion	Tier II	2011 to 2016	607	0.031	0.012
Slow speed propulsion	Tier III	2016 and newer	607	0.031	0.012
Medium speed propulsion	Tier 0	1999 and older	670	0.031	0.010
Medium speed propulsion	Tier I	2000 to 2011	670	0.031	0.010
Medium speed propulsion	Tier II	2011 to 2016	670	0.031	0.010
Medium speed propulsion	Tier III	2016 and newer	670	0.031	0.010
Gas turbine	na	All	950	0.08	0.002
Steam propulsion	na	All	950	0.08	0.002
Using 0.1% S MGO Fuel					
Slow speed propulsion	Tier 0	1999 and older	593	0.029	0.012
Slow speed propulsion	Tier I	2000 to 2011	593	0.029	0.012
Slow speed propulsion	Tier II	2011 to 2016	593	0.029	0.012
Slow speed propulsion	Tier III	2016 and newer	593	0.029	0.012
Medium speed propulsion	Tier 0	1999 and older	657	0.029	0.010
Medium speed propulsion	Tier I	2000 to 2011	657	0.029	0.010
Medium speed propulsion	Tier II	2011 to 2016	657	0.029	0.010
Medium speed propulsion	Tier III	2016 and newer	657	0.029	0.010
Gas turbine	na	All	962	0.075	0.002
Steam propulsion	na	All	962	0.075	0.002

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[8] See: *www.navsregs.wordpress.com/2017/01/03/engine-international-air-pollution-prevention-certificate-a-handy-guide/*
[9] See: MAN Diesel & Turbo, "Tier III Two-Stroke Technology"
[10] DNV-GL, "NOx Tier III Update: Choices and challenges for on-time compliance," November 2017.

2.8 Propulsion Engines Low Load Emission Factors

In general terms, diesel-cycle engines are not as efficient when operated at low loads compared with higher load operation. An EPA study[11] prepared by Energy and Environmental Analysis, Inc. (EEAI) established a formula for calculating emission factors for low engine load conditions such as those encountered during harbor maneuvering and when traveling slowly at sea (e.g. in the reduced speed zone) This formula was later used and described in a study conducted for the EPA by ENVIRON.[12] While mass emissions in pounds per hour tend to go down as vessel speeds and engine loads decrease, the emission factors in g/kW-hr increase.

Equation 2.9 is the equation developed by EEAI to generate emission factors for the range of load factors from 2% to 20% for each pollutant:

<div align="right">Equation 2.9</div>

$$y = a\,(fractional\ load)^{-x} + b$$

Where:

y = emissions, g/kW-hr
a = coefficient, dimensionless
b = intercept, dimensionless
x = exponent, dimensionless
fractional load = propulsion engine load factor (2% - 20%), derived from the Propeller Law, percent

Table 2.5 presents the variables for equation 2.9.

Table 2.5: Low-Load Emission Factor Regression Equation Variables

Pollutant	Exponent (x)	Intercept (b)	Coefficient (a)
PM	1.5	0.2551	0.0059
NO_x	1.5	10.4496	0.1255
CO	1.0	0.1548	0.8378
HC	1.5	0.3859	0.0667

The base emission factors used in the development of the low-load regression equation are not the currently accepted emission factors for OGV propulsion engines. Therefore, Starcrest developed low-load adjustment (LLA) multipliers by dividing the emission factors for each load increment between 2% and 20% by the emission factor at 20% load. These LLA multipliers are listed in Table 2.6. In keeping with the Port's emission estimating practice of assuming a minimum propulsion engine load of 2%, the table of LLA factors does not include values for 1% load. During emission estimation, the LLA factors are multiplied by the latest emission factors for 2-stroke (slow speed) non-MAN diesel propulsion engines, adjusted for fuel differences between the actual fuel and the fuel used when the emission factors were developed. Adjustments to N_2O and CH_4 emission factors are made based on the NO_x and HC low load adjustments, respectively. The LLA adjustments are applied only to engine

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[11] EPA, *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data,* February 2000
[12] EPA, *Commercial Marine Inventory Development,* July 2002

loads less than 20%. Low load emission factor adjustments do not apply to steamships or ships having gas turbines because the EPA study referenced above only observed an increase in emissions from diesel engines.

Table 2.6: Low Load Adjustment Multipliers for Emission Factors[13]

Load	PM	NO_x	SO_2	CO	VOC	CO_2	N_2O	CH_4
2%	7.29	4.63	3.30	9.68	21.18	3.28	4.63	21.18
3%	4.33	2.92	2.45	6.46	11.68	2.44	2.92	11.68
4%	3.09	2.21	2.02	4.86	7.71	2.01	2.21	7.71
5%	2.44	1.83	1.77	3.89	5.61	1.76	1.83	5.61
6%	2.04	1.60	1.60	3.25	4.35	1.59	1.60	4.35
7%	1.79	1.45	1.47	2.79	3.52	1.47	1.45	3.52
8%	1.61	1.35	1.38	2.45	2.95	1.38	1.35	2.95
9%	1.48	1.27	1.31	2.18	2.52	1.31	1.27	2.52
10%	1.38	1.22	1.26	1.96	2.18	1.25	1.22	2.18
11%	1.30	1.17	1.21	1.79	1.96	1.21	1.17	1.96
12%	1.24	1.14	1.17	1.64	1.76	1.17	1.14	1.76
13%	1.19	1.11	1.14	1.52	1.60	1.14	1.11	1.60
14%	1.15	1.08	1.11	1.41	1.47	1.11	1.08	1.47
15%	1.11	1.06	1.09	1.32	1.36	1.08	1.06	1.36
16%	1.08	1.05	1.06	1.24	1.26	1.06	1.05	1.26
17%	1.06	1.03	1.05	1.17	1.18	1.04	1.03	1.18
18%	1.04	1.02	1.03	1.11	1.11	1.03	1.02	1.11
19%	1.02	1.01	1.01	1.05	1.05	1.01	1.01	1.05
20%	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The low load emission factor is calculated for each pollutant using Equation 2.10.

Equation 2.10

$$EF = Adjusted\ EF \times LLA$$

Where:

EF = calculated low load emission factor, expressed in terms of g/kW-hr

Adjusted EF = fuel adjusted emission factor for 2-stroke diesel propulsion engines, g/kW-hr

LLA = low load adjustment multiplier, dimensionless

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[13] The LLA multipliers for N_2O and CH_4 are based on NO_x and HC, respectively.

Starting with the 2014 emissions inventories, the emissions from MAN 2-stroke propulsion (main) engines were adjusted as a function of engine load using test data from the San Pedro Bay Ports' (SPBP) *MAN Slide Valve Low-Load Emissions Test Final Report* (Slide Valve Test)[14] completed under the SPBP Technology Advancement Program (TAP) in conjunction with MAN and Mitsui. The following enhancements are incorporated into the emissions estimates for applicable propulsion engines based on the findings of the study and coordinated with the Technical Working Group[15]:

➢ Emission factor adjustment (EFA) is applied to pollutants for which test results were significantly different in magnitude than the base emission factors used in the inventory. A slide valve EFA (EFA_{SV}) is applied only to vessels equipped with slide valves (SV), which include 2004 or newer MAN 2-stroke engines and vessels identified in the VBP data as having slide valves. A conventional nozzle (C3) EFA (EFA_{C3}) is used for all other MAN 2-stroke engines, which are typically older than 2004 vessels. EFAs were developed by compositing the test data into the E3 duty cycle load weighting and comparing them to the E3-based EFs used in the inventories. The following EFAs are used:

    a. NO_x: $EFA_{SV} = 1.0$ $EFA_{C3} = 1.0$
    b. PM: $EFA_{SV} = 1.0$ $EFA_{C3} = 1.0$
    c. THC: $EFA_{SV} = 0.43$ $EFA_{C3} = 1.0$
    d. CO: $EFA_{SV} = 0.59$ $EFA_{C3} = 0.44$
    e. CO_2: $EFA_{SV} = 1.0$ $EFA_{C3} = 1.0$

➢ Load adjustment factors (LAF) are calculated and applied to the EF x EFA across all loads (0% to 100%). The LAF is pollutant based and valve specific (SV or C3), using the same criteria as stated above for EFA. The adjusted equation for estimating OGV MAN propulsion engine emissions is:

<div align="right">Equation 2.11</div>

$$Ei = Energy \times EF \times EFA \times LAFi \times FCF \times CF$$

Where,
        Ei = Emission by load i, g
        Energy = Energy demand by mode, kW-hr
        EF = default emission factor (E3 duty cycle by pollutant or GHG), g/kW-hr
        EFA = emission factor adjustment by pollutant or GHG, dimensionless
        LAF_i = test-based EF_i (by valve type and pollutant or GHG) at load i / test-based composite EF (E3 duty cycle), dimensionless
        FCF = fuel correction factor by pollutant or GHG, dimensionless
        CF = control factor (by pollutant or GHG) for any emission reduction program, dimensionless

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[14] As referenced in the Emission Estimating Methodology and Enhancements Section.
[15] Made up of POLB, Port of Los Angeles, CARB, South Coast Air Quality Management District, and EPA

Tables 2.7 and 2.8 present the LAFs used across the entire engine load range.

Table 2.7: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
1%	0.36	0.36	0.36	1.90	1.10	0.12	1.36	1.10	1.90	1.36
2%	0.37	0.37	0.37	1.86	1.10	0.12	1.32	1.10	1.86	1.32
3%	0.38	0.38	0.38	1.82	1.09	0.12	1.28	1.09	1.82	1.28
4%	0.38	0.38	0.38	1.78	1.09	0.12	1.24	1.09	1.78	1.24
5%	0.39	0.39	0.39	1.74	1.09	0.12	1.20	1.09	1.74	1.20
6%	0.40	0.40	0.40	1.70	1.08	0.12	1.17	1.08	1.70	1.17
7%	0.41	0.41	0.41	1.67	1.08	0.12	1.14	1.08	1.67	1.14
8%	0.41	0.41	0.41	1.63	1.08	0.12	1.11	1.08	1.63	1.11
9%	0.42	0.42	0.42	1.60	1.07	0.12	1.08	1.07	1.60	1.08
10%	0.43	0.43	0.43	1.57	1.07	0.12	1.05	1.07	1.57	1.05
11%	0.44	0.44	0.44	1.53	1.07	0.26	1.02	1.07	1.53	1.02
12%	0.45	0.45	0.45	1.50	1.07	0.39	0.99	1.07	1.50	0.99
13%	0.45	0.45	0.45	1.47	1.06	0.52	0.97	1.06	1.47	0.97
14%	0.46	0.46	0.46	1.45	1.06	0.64	0.94	1.06	1.45	0.94
15%	0.47	0.47	0.47	1.42	1.06	0.75	0.92	1.06	1.42	0.92
16%	0.48	0.48	0.48	1.39	1.06	0.85	0.90	1.06	1.39	0.90
17%	0.49	0.49	0.49	1.37	1.05	0.95	0.88	1.05	1.37	0.88
18%	0.49	0.49	0.49	1.34	1.05	1.04	0.86	1.05	1.34	0.86
19%	0.50	0.50	0.50	1.32	1.05	1.12	0.84	1.05	1.32	0.84
20%	0.51	0.51	0.51	1.30	1.05	1.20	0.82	1.05	1.30	0.82
21%	0.52	0.52	0.52	1.28	1.04	1.27	0.81	1.04	1.28	0.81
22%	0.53	0.53	0.53	1.26	1.04	1.34	0.79	1.04	1.26	0.79
23%	0.54	0.54	0.54	1.24	1.04	1.40	0.78	1.04	1.24	0.78
24%	0.54	0.54	0.54	1.22	1.04	1.46	0.76	1.04	1.22	0.76
25%	0.55	0.55	0.55	1.20	1.03	1.51	0.75	1.03	1.20	0.75

Table 2.7 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
26%	0.56	0.56	0.56	1.19	1.03	1.55	0.74	1.03	1.19	0.74
27%	0.57	0.57	0.57	1.17	1.03	1.59	0.73	1.03	1.17	0.73
28%	0.58	0.58	0.58	1.16	1.03	1.63	0.72	1.03	1.16	0.72
29%	0.59	0.59	0.59	1.14	1.03	1.66	0.71	1.03	1.14	0.71
30%	0.60	0.60	0.60	1.13	1.02	1.68	0.70	1.02	1.13	0.70
31%	0.60	0.60	0.60	1.12	1.02	1.70	0.70	1.02	1.12	0.70
32%	0.61	0.61	0.61	1.10	1.02	1.72	0.69	1.02	1.10	0.69
33%	0.62	0.62	0.62	1.09	1.02	1.74	0.69	1.02	1.09	0.69
34%	0.63	0.63	0.63	1.08	1.02	1.75	0.68	1.02	1.08	0.68
35%	0.64	0.64	0.64	1.07	1.02	1.75	0.68	1.02	1.07	0.68
36%	0.65	0.65	0.65	1.06	1.01	1.75	0.68	1.01	1.06	0.68
37%	0.66	0.66	0.66	1.05	1.01	1.75	0.67	1.01	1.05	0.67
38%	0.67	0.67	0.67	1.05	1.01	1.75	0.67	1.01	1.05	0.67
39%	0.68	0.68	0.68	1.04	1.01	1.74	0.67	1.01	1.04	0.67
40%	0.69	0.69	0.69	1.03	1.01	1.73	0.67	1.01	1.03	0.67
41%	0.70	0.70	0.70	1.03	1.01	1.72	0.67	1.01	1.03	0.67
42%	0.70	0.70	0.70	1.02	1.01	1.71	0.68	1.01	1.02	0.68
43%	0.71	0.71	0.71	1.02	1.01	1.69	0.68	1.01	1.02	0.68
44%	0.72	0.72	0.72	1.01	1.00	1.67	0.68	1.00	1.01	0.68
45%	0.73	0.73	0.73	1.01	1.00	1.65	0.69	1.00	1.01	0.69
46%	0.74	0.74	0.74	1.00	1.00	1.62	0.69	1.00	1.00	0.69
47%	0.75	0.75	0.75	1.00	1.00	1.60	0.70	1.00	1.00	0.70
48%	0.76	0.76	0.76	1.00	1.00	1.57	0.70	1.00	1.00	0.70
49%	0.77	0.77	0.77	0.99	1.00	1.54	0.71	1.00	0.99	0.71
50%	0.78	0.78	0.78	0.99	1.00	1.51	0.71	1.00	0.99	0.71

Table 2.7 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
51%	0.79	0.79	0.79	0.99	1.00	1.48	0.72	1.00	0.99	0.72
52%	0.80	0.80	0.80	0.99	1.00	1.45	0.73	1.00	0.99	0.73
53%	0.81	0.81	0.81	0.99	1.00	1.41	0.74	1.00	0.99	0.74
54%	0.82	0.82	0.82	0.99	1.00	1.38	0.75	1.00	0.99	0.75
55%	0.83	0.83	0.83	0.98	0.99	1.35	0.75	0.99	0.98	0.75
56%	0.84	0.84	0.84	0.98	0.99	1.31	0.76	0.99	0.98	0.76
57%	0.85	0.85	0.85	0.98	0.99	1.27	0.77	0.99	0.98	0.77
58%	0.86	0.86	0.86	0.98	0.99	1.24	0.78	0.99	0.98	0.78
59%	0.87	0.87	0.87	0.98	0.99	1.20	0.80	0.99	0.98	0.80
60%	0.88	0.88	0.88	0.98	0.99	1.16	0.81	0.99	0.98	0.81
61%	0.89	0.89	0.89	0.98	0.99	1.13	0.82	0.99	0.98	0.82
62%	0.90	0.90	0.90	0.98	0.99	1.09	0.83	0.99	0.98	0.83
63%	0.91	0.91	0.91	0.99	0.99	1.06	0.84	0.99	0.99	0.84
64%	0.92	0.92	0.92	0.99	0.99	1.02	0.85	0.99	0.99	0.85
65%	0.93	0.93	0.93	0.99	0.99	0.98	0.87	0.99	0.99	0.87
66%	0.94	0.94	0.94	0.99	0.99	0.95	0.88	0.99	0.99	0.88
67%	0.95	0.95	0.95	0.99	0.99	0.92	0.89	0.99	0.99	0.89
68%	0.97	0.97	0.97	0.99	0.99	0.88	0.91	0.99	0.99	0.91
69%	0.98	0.98	0.98	0.99	0.99	0.85	0.92	0.99	0.99	0.92
70%	0.99	0.99	0.99	0.99	0.99	0.82	0.93	0.99	0.99	0.93
71%	1.00	1.00	1.00	0.99	0.99	0.79	0.95	0.99	0.99	0.95
72%	1.01	1.01	1.01	0.99	0.99	0.76	0.96	0.99	0.99	0.96
73%	1.02	1.02	1.02	0.99	0.99	0.74	0.98	0.99	0.99	0.98
74%	1.03	1.03	1.03	0.99	0.99	0.71	0.99	0.99	0.99	0.99
75%	1.04	1.04	1.04	0.99	0.99	0.69	1.00	0.99	0.99	1.00

Table 2.7 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
76%	1.05	1.05	1.05	0.99	0.99	0.66	1.02	0.99	0.99	1.02
77%	1.06	1.06	1.06	0.99	0.99	0.64	1.03	0.99	0.99	1.03
78%	1.07	1.07	1.07	0.99	0.99	0.63	1.05	0.99	0.99	1.05
79%	1.09	1.09	1.09	0.99	0.99	0.61	1.06	0.99	0.99	1.06
80%	1.10	1.10	1.10	0.99	0.99	0.60	1.08	0.99	0.99	1.08
81%	1.11	1.11	1.11	0.99	0.99	0.58	1.09	0.99	0.99	1.09
82%	1.12	1.12	1.12	0.99	0.99	0.57	1.10	0.99	0.99	1.10
83%	1.13	1.13	1.13	0.98	0.99	0.57	1.12	0.99	0.98	1.12
84%	1.14	1.14	1.14	0.98	0.99	0.56	1.13	0.99	0.98	1.13
85%	1.15	1.15	1.15	0.98	0.99	0.56	1.15	0.99	0.98	1.15
86%	1.16	1.16	1.16	0.98	0.99	0.56	1.16	0.99	0.98	1.16
87%	1.18	1.18	1.18	0.97	0.99	0.56	1.18	0.99	0.97	1.18
88%	1.19	1.19	1.19	0.97	0.99	0.57	1.19	0.99	0.97	1.19
89%	1.20	1.20	1.20	0.96	0.99	0.58	1.20	0.99	0.96	1.20
90%	1.21	1.21	1.21	0.96	0.99	0.59	1.22	0.99	0.96	1.22
91%	1.22	1.22	1.22	0.95	1.00	0.61	1.23	1.00	0.95	1.23
92%	1.23	1.23	1.23	0.95	1.00	0.63	1.24	1.00	0.95	1.24
93%	1.25	1.25	1.25	0.94	1.00	0.65	1.25	1.00	0.94	1.25
94%	1.26	1.26	1.26	0.93	1.00	0.67	1.27	1.00	0.93	1.27
95%	1.27	1.27	1.27	0.93	1.00	0.70	1.28	1.00	0.93	1.28
96%	1.28	1.28	1.28	0.92	1.00	0.73	1.29	1.00	0.92	1.29
97%	1.29	1.29	1.29	0.91	1.00	0.77	1.30	1.00	0.91	1.30
98%	1.31	1.31	1.31	0.90	1.00	0.81	1.31	1.00	0.90	1.31
99%	1.32	1.32	1.32	0.89	1.00	0.85	1.32	1.00	0.89	1.32
100%	1.33	1.33	1.33	0.88	1.00	0.90	1.34	1.00	0.88	1.34

Table 2.8: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
1%	0.84	0.84	0.84	1.91	1.10	1.38	2.53	1.10	1.91	2.53
2%	0.83	0.83	0.83	1.86	1.10	1.36	2.45	1.10	1.86	2.45
3%	0.83	0.83	0.83	1.82	1.09	1.34	2.37	1.09	1.82	2.37
4%	0.82	0.82	0.82	1.77	1.09	1.33	2.30	1.09	1.77	2.30
5%	0.82	0.82	0.82	1.72	1.09	1.31	2.23	1.09	1.72	2.23
6%	0.81	0.81	0.81	1.68	1.08	1.29	2.16	1.08	1.68	2.16
7%	0.81	0.81	0.81	1.64	1.08	1.28	2.10	1.08	1.64	2.10
8%	0.80	0.80	0.80	1.60	1.08	1.26	2.03	1.08	1.60	2.03
9%	0.80	0.80	0.80	1.56	1.07	1.25	1.97	1.07	1.56	1.97
10%	0.79	0.79	0.79	1.52	1.07	1.24	1.91	1.07	1.52	1.91
11%	0.79	0.79	0.79	1.49	1.07	1.22	1.86	1.07	1.49	1.86
12%	0.78	0.78	0.78	1.45	1.07	1.21	1.80	1.07	1.45	1.80
13%	0.78	0.78	0.78	1.42	1.06	1.20	1.75	1.06	1.42	1.75
14%	0.78	0.78	0.78	1.39	1.06	1.19	1.70	1.06	1.39	1.70
15%	0.77	0.77	0.77	1.36	1.06	1.18	1.65	1.06	1.36	1.65
16%	0.77	0.77	0.77	1.33	1.06	1.17	1.61	1.06	1.33	1.61
17%	0.77	0.77	0.77	1.30	1.05	1.16	1.56	1.05	1.30	1.56
18%	0.77	0.77	0.77	1.28	1.05	1.15	1.52	1.05	1.28	1.52
19%	0.76	0.76	0.76	1.25	1.05	1.14	1.48	1.05	1.25	1.48
20%	0.76	0.76	0.76	1.23	1.05	1.13	1.44	1.05	1.23	1.44
21%	0.76	0.76	0.76	1.20	1.04	1.13	1.41	1.04	1.20	1.41
22%	0.76	0.76	0.76	1.18	1.04	1.12	1.37	1.04	1.18	1.37
23%	0.76	0.76	0.76	1.16	1.04	1.11	1.34	1.04	1.16	1.34
24%	0.75	0.75	0.75	1.14	1.04	1.10	1.31	1.04	1.14	1.31
25%	0.75	0.75	0.75	1.12	1.03	1.10	1.28	1.03	1.12	1.28

Table 2.8 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
26%	0.75	0.75	0.75	1.11	1.03	1.09	1.25	1.03	1.11	1.25
27%	0.75	0.75	0.75	1.09	1.03	1.08	1.22	1.03	1.09	1.22
28%	0.75	0.75	0.75	1.07	1.03	1.08	1.20	1.03	1.07	1.20
29%	0.75	0.75	0.75	1.06	1.03	1.07	1.17	1.03	1.06	1.17
30%	0.75	0.75	0.75	1.05	1.02	1.07	1.15	1.02	1.05	1.15
31%	0.75	0.75	0.75	1.03	1.02	1.06	1.13	1.02	1.03	1.13
32%	0.75	0.75	0.75	1.02	1.02	1.06	1.11	1.02	1.02	1.11
33%	0.75	0.75	0.75	1.01	1.02	1.05	1.09	1.02	1.01	1.09
34%	0.75	0.75	0.75	1.00	1.02	1.05	1.08	1.02	1.00	1.08
35%	0.76	0.76	0.76	0.99	1.02	1.04	1.06	1.02	0.99	1.06
36%	0.76	0.76	0.76	0.98	1.01	1.04	1.05	1.01	0.98	1.05
37%	0.76	0.76	0.76	0.98	1.01	1.03	1.04	1.01	0.98	1.04
38%	0.76	0.76	0.76	0.97	1.01	1.03	1.02	1.01	0.97	1.02
39%	0.76	0.76	0.76	0.96	1.01	1.02	1.01	1.01	0.96	1.01
40%	0.76	0.76	0.76	0.96	1.01	1.02	1.00	1.01	0.96	1.00
41%	0.77	0.77	0.77	0.95	1.01	1.01	0.99	1.01	0.95	0.99
42%	0.77	0.77	0.77	0.95	1.01	1.01	0.99	1.01	0.95	0.99
43%	0.77	0.77	0.77	0.94	1.01	1.01	0.98	1.01	0.94	0.98
44%	0.78	0.78	0.78	0.94	1.00	1.00	0.97	1.00	0.94	0.97
45%	0.78	0.78	0.78	0.94	1.00	1.00	0.97	1.00	0.94	0.97
46%	0.78	0.78	0.78	0.94	1.00	0.99	0.96	1.00	0.94	0.96
47%	0.79	0.79	0.79	0.94	1.00	0.99	0.96	1.00	0.94	0.96
48%	0.79	0.79	0.79	0.93	1.00	0.98	0.96	1.00	0.93	0.96
49%	0.79	0.79	0.79	0.93	1.00	0.98	0.96	1.00	0.93	0.96
50%	0.80	0.80	0.80	0.93	1.00	0.98	0.96	1.00	0.93	0.96

Table 2.8 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
51%	0.80	0.80	0.80	0.94	1.00	0.97	0.95	1.00	0.94	0.95
52%	0.81	0.81	0.81	0.94	1.00	0.97	0.95	1.00	0.94	0.95
53%	0.81	0.81	0.81	0.94	1.00	0.96	0.95	1.00	0.94	0.95
54%	0.82	0.82	0.82	0.94	1.00	0.96	0.95	1.00	0.94	0.95
55%	0.82	0.82	0.82	0.94	0.99	0.96	0.96	0.99	0.94	0.96
56%	0.83	0.83	0.83	0.94	0.99	0.95	0.96	0.99	0.94	0.96
57%	0.84	0.84	0.84	0.95	0.99	0.95	0.96	0.99	0.95	0.96
58%	0.84	0.84	0.84	0.95	0.99	0.95	0.96	0.99	0.95	0.96
59%	0.85	0.85	0.85	0.95	0.99	0.94	0.96	0.99	0.95	0.96
60%	0.86	0.86	0.86	0.95	0.99	0.94	0.97	0.99	0.95	0.97
61%	0.86	0.86	0.86	0.96	0.99	0.93	0.97	0.99	0.96	0.97
62%	0.87	0.87	0.87	0.96	0.99	0.93	0.97	0.99	0.96	0.97
63%	0.88	0.88	0.88	0.96	0.99	0.93	0.98	0.99	0.96	0.98
64%	0.89	0.89	0.89	0.97	0.99	0.93	0.98	0.99	0.97	0.98
65%	0.89	0.89	0.89	0.97	0.99	0.92	0.98	0.99	0.97	0.98
66%	0.90	0.90	0.90	0.98	0.99	0.92	0.99	0.99	0.98	0.99
67%	0.91	0.91	0.91	0.98	0.99	0.92	0.99	0.99	0.98	0.99
68%	0.92	0.92	0.92	0.98	0.99	0.91	0.99	0.99	0.98	0.99
69%	0.93	0.93	0.93	0.99	0.99	0.91	1.00	0.99	0.99	1.00
70%	0.94	0.94	0.94	0.99	0.99	0.91	1.00	0.99	0.99	1.00
71%	0.94	0.94	0.94	0.99	0.99	0.91	1.00	0.99	0.99	1.00
72%	0.95	0.95	0.95	1.00	0.99	0.91	1.01	0.99	1.00	1.01
73%	0.96	0.96	0.96	1.00	0.99	0.91	1.01	0.99	1.00	1.01
74%	0.97	0.97	0.97	1.00	0.99	0.91	1.01	0.99	1.00	1.01
75%	0.98	0.98	0.98	1.01	0.99	0.90	1.01	0.99	1.01	1.01

Table 2.8 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
76%	0.99	0.99	0.99	1.01	0.99	0.90	1.01	0.99	1.01	1.01
77%	1.00	1.00	1.00	1.01	0.99	0.90	1.01	0.99	1.01	1.01
78%	1.01	1.01	1.01	1.01	0.99	0.91	1.01	0.99	1.01	1.01
79%	1.03	1.03	1.03	1.02	0.99	0.91	1.01	0.99	1.02	1.01
80%	1.04	1.04	1.04	1.02	0.99	0.91	1.01	0.99	1.02	1.01
81%	1.05	1.05	1.05	1.02	0.99	0.91	1.01	0.99	1.02	1.01
82%	1.06	1.06	1.06	1.02	0.99	0.91	1.01	0.99	1.02	1.01
83%	1.07	1.07	1.07	1.02	0.99	0.92	1.01	0.99	1.02	1.01
84%	1.08	1.08	1.08	1.02	0.99	0.92	1.00	0.99	1.02	1.00
85%	1.10	1.10	1.10	1.02	0.99	0.92	1.00	0.99	1.02	1.00
86%	1.11	1.11	1.11	1.02	0.99	0.93	0.99	0.99	1.02	0.99
87%	1.12	1.12	1.12	1.02	0.99	0.93	0.99	0.99	1.02	0.99
88%	1.13	1.13	1.13	1.02	0.99	0.94	0.98	0.99	1.02	0.98
89%	1.15	1.15	1.15	1.01	0.99	0.95	0.97	0.99	1.01	0.97
90%	1.16	1.16	1.16	1.01	0.99	0.95	0.97	0.99	1.01	0.97
91%	1.17	1.17	1.17	1.01	1.00	0.96	0.96	1.00	1.01	0.96
92%	1.19	1.19	1.19	1.00	1.00	0.97	0.94	1.00	1.00	0.94
93%	1.20	1.20	1.20	1.00	1.00	0.98	0.93	1.00	1.00	0.93
94%	1.22	1.22	1.22	0.99	1.00	0.99	0.92	1.00	0.99	0.92
95%	1.23	1.23	1.23	0.99	1.00	1.01	0.91	1.00	0.99	0.91
96%	1.24	1.24	1.24	0.98	1.00	1.02	0.89	1.00	0.98	0.89
97%	1.26	1.26	1.26	0.97	1.00	1.03	0.87	1.00	0.97	0.87
98%	1.28	1.28	1.28	0.97	1.00	1.05	0.86	1.00	0.97	0.86
99%	1.29	1.29	1.29	0.96	1.00	1.07	0.84	1.00	0.96	0.84
100%	1.31	1.31	1.31	0.95	1.00	1.08	0.82	1.00	0.95	0.82

2.9 Propulsion Engine Power Rating

OGVs calling either Port are matched by IMO number with data collected during the VBP and the most current IHS Markit data to determine propulsion engine power ratings. For vessels missing propulsion engine power rating, vessel class specific average values are used.

2.10 Auxiliary Engine Emission Factors

OGVs visiting the SPBP are equipped with the following types of auxiliary engines:

> ➢ Medium speed diesel engines (most common), having maximum engine speeds over 130 rpm (typically greater than 400 rpm) and less than 2,000 rpm.
> ➢ High speed diesel engines, having maximum engine speeds equal to or greater than 2,000 rpm.

Emission factors for all engine types used in this study were obtained from equations or values included in USEPA's EI Guidance document. Equations used to calculate PM_{10}, $PM_{2.5}$, DPM, SO_x and CO_2 are same as included in for propulsion engines in section 2.6 . The emission factors for base fuel (HFO with 2.7% sulfur content) and fuel currently being required by CARB regulation (MDO/MGO 0.1% sulfur content) are shown in tables 2.9 and 2.10. When available, vessel specific NO_x emission factors from EIAPP certificates are utilized. Vessel that did not provide EIAPP NO_x emission factors used the default NO_x emission factors shown in tables below As of January 2014, the auxiliary engines used 0.1% S fuel due to the CARB and ECA requirements.

Table 2.9: Pollutant Emission Factors for Auxiliary Engines, g/kW-hr

Using 2.7% Sulfur HFO Fuel									
Engine Category	**IMO Tier**	**Model Year Range**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**NOx**	**SOx**	**CO**	**HC**
Medium speed auxiliary	Tier 0	1999 and older	1.54	1.23	1.54	14.7	11.98	1.1	0.4
Medium speed auxiliary	Tier I	2000 to 2011	1.54	1.23	1.54	13.0	11.98	1.1	0.4
Medium speed auxiliary	Tier II	2011 to 2016	1.54	1.23	1.54	11.2	11.98	1.1	0.4
Medium speed auxiliary	Tier III	2016 and newer	1.54	1.23	1.54	2.8	11.98	1.1	0.4
High speed auxiliary	Tier 0	1999 and older	1.54	1.23	1.54	11.6	11.98	0.9	0.4
High speed auxiliary	Tier I	2000 to 2011	1.54	1.23	1.54	10.4	11.98	0.9	0.4
High speed auxiliary	Tier II	2011 to 2016	1.54	1.23	1.54	8.2	11.98	0.9	0.4
High speed auxiliary	Tier III	2016 and newer	1.54	1.23	1.54	2.1	11.98	0.9	0.4
Using 0.1% S MGO Fuel									
Medium speed auxiliary	Tier 0	1999 and older	0.189	0.174	0.189	13.8	0.424	1.1	0.4
Medium speed auxiliary	Tier I	2000 to 2011	0.189	0.174	0.189	12.2	0.424	1.1	0.4
Medium speed auxiliary	Tier II	2011 to 2016	0.189	0.174	0.189	10.5	0.424	1.1	0.4
Medium speed auxiliary	Tier III		0.189	0.174	0.189	2.6	0.424	1.1	0.4
High speed auxiliary	Tier 0	1999 and older	0.189	0.174	0.189	10.9	0.424	0.9	0.4
High speed auxiliary	Tier I	2000 to 2011	0.189	0.174	0.189	9.8	0.424	0.9	0.4
High speed auxiliary	Tier II	2011 to 2016	0.189	0.174	0.189	7.7	0.424	0.9	0.4
High speed auxiliary	Tier III	2016 and newer	0.189	0.174	0.189	2.0	0.424	0.9	0.4

Table 2.10: GHG Emission Factors for Auxiliary Engines, g/kW-hr

Using 2.7% Sulfur HFO Fuel					
Engine Category	IMO Tier	Model Year Range	CO$_2$	N$_2$O	CH$_4$
Medium speed auxiliary	Tier 0	1999 and older	707	0.031	0.008
Medium speed auxiliary	Tier I	2000 to 2011	707	0.031	0.008
Medium speed auxiliary	Tier II	2011 to 2016	707	0.031	0.008
Medium speed auxiliary	Tier III	2016 and newer	707	0.031	0.008
High speed auxiliary	Tier 0	1999 and older	707	0.031	0.008
High speed auxiliary	Tier I	2000 to 2011	707	0.031	0.008
High speed auxiliary	Tier II	2011 to 2016	707	0.031	0.008
High speed auxiliary	Tier III	2016 and newer	707	0.031	0.008
Using 0.1% S MGO Fuel					
Medium speed auxiliary	Tier 0	1999 and older	696	0.029	0.008
Medium speed auxiliary	Tier I	2000 to 2011	696	0.029	0.008
Medium speed auxiliary	Tier II	2011 to 2016	696	0.029	0.008
Medium speed auxiliary	Tier III	2016 and newer	696	0.029	0.008
High speed auxiliary	Tier 0	1999 and older	696	0.029	0.008
High speed auxiliary	Tier I	2000 to 2011	696	0.029	0.008
High speed auxiliary	Tier II	2011 to 2016	696	0.029	0.008
High speed auxiliary	Tier III	2016 and newer	696	0.029	0.008

2.11 Auxiliary Engine Load Defaults

The IHS Markit database contains limited auxiliary engine installed power information or information on use by mode, because neither the IMO nor the classification societies require vessel owners to provide this information. In addition, there is a wide array of auxiliary engine system configurations in the worldwide fleet of seagoing vessels, a lack of relatively complete data sets on installed equipment, and numerous other factors that make determining auxiliary power requirements a challenge without input from vessel operators.

The primary data source for the Ports' EI related auxiliary load data is the Vessel Boarding Program (VBP) implemented by the Ports since 2003. Under VBP, vessels are boarded during their visits to the Port of Los Angeles or the Port of Long Beach and information is collected on auxiliary engine and boiler loads and other aspects of OGV engine operations needed to verify or refine OGV emissions inventory estimation. When estimating auxiliary engine emissions, the following hierarchy is followed: 1) Shore power records for at-berth electrical loads, when available, 2) VBP data if the vessel has been boarded, 3) VBP data if the vessel is a sister to a boarded vessel, and 4) average auxiliary engine load defaults derived from VBP data. Default average auxiliary engine loads are calculated using the VBP dataset. The Ports continuously expend resources to improve the data used to refine the auxiliary engine load defaults and they use the best currently available information in making the refinements.

The default values are reviewed annually. For the CY 2020, auxiliary engine default values were produced by calculating the call-weighted average of all VBP data points collected from 2005-2020 for each vessel type. Since these engine defaults are based on ongoing VBP data collection, the reader is advised to refer to the latest emissions inventory reports for the most up to date information.

Cruise ships are typically built to one of two configurations. The most common is 'full' diesel-electric in which all the power for the ship's propulsion and auxiliary usage comes from a common set of diesel-electric generators. The other type is equipped with dedicated propulsion engines that provide propulsion power in a geared or direct drive configuration and the auxiliary diesel-electric engines are used only for auxiliary functions (house loads). Most cruise ships calling the Port are full diesel-electric configured cruise ships.

The auxiliary engine load defaults for cruise ships are also produced by calculating the call-weighted average of all VBP data points collected from 2005-2020 VBP. The cruise ship defaults vary by mode based on passenger capacity ranges. Since these engine defaults are based on ongoing VBP data collection, the reader is advised to refer to the latest emissions inventory reports for the most up to date information.

2.12 Auxiliary Boiler Emission Factors

In addition to the auxiliary engines that are used to generate electricity for on-board uses, most OGVs have one or more boilers used for fuel heating and for producing hot water and steam. Emission factors for the steam boilers are listed in Tables 2.11 and 2.12.

Table 2.11: Pollutant Emission Factors for Auxiliary Boilers, g/kW-hr

Using 2.7% Sulfur HFO Fuel									
Engine Category	IMO Tier	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NOx	SOx	CO	HC
Steam boiler	na	All	1.87	1.50	0.00	2.1	16.1	0.2	0.1
Using 0.1% S MGO Fuel									
Steam boiler	na	All	0.202	0.186	0.000	2.0	0.587	0.2	0.1

Table 2.12: GHG Emission Factors for Auxiliary Boilers, g/kW-hr

Using 2.7% Sulfur HFO Fuel					
Engine Category	IMO Tier	Model Year Range	CO_2	N_2O	CH_4
Steam boiler	na	All	950	0.08	0.002
Using 0.1% S MGO Fuel					
Steam boiler	na	All	962	0.075	0.002

The boiler fuel consumption data collected from vessels during the VBP is continued to be converted to equivalent kilowatts using specific fuel consumption (SFC) factors found in the 2002 Entec report. The average SFC value for distillate fuel is 290 grams of fuel per kW-hour, and 305 grams of fuel per kW-hour for residual fuel. The average kW for auxiliary boilers using distillate fuel is calculated using the following equation.

Equation 2.9

$$Average\ kW\ = \ (daily\ fuel/24)\ \times\ 1,000,000)/290$$

Where:
    Average kW = average energy output of boilers, kW
    daily fuel = boiler fuel consumption, tonnes per day

As with auxiliary engines, the primary source of boiler fuel consumption data is from the VBP, and direct values for vessels boarded are used on an individual basis for vessels boarded and their sister ships. The IHS Markit database does not provide boiler engine load or fuel consumption data. For vessels not boarded or vessels that did not have any sister vessels boarded through the VBP, call-weighted average of all VBP data points collected from 2005-2020are used as defaults. The latest emissions inventory reports provide information on the most up-to-date information on boiler engine load by mode.

Tankers' boilers produce steam for steam-powered liquid cargo pumps when discharging, steam powered inert gas fans, and to heat fuel for pumping. Less steam is needed when liquid cargo is being loaded. Since loading and discharging data were available for the tankers that visited the Port, a lower boiler load of 875 kW was used for tankers known to be loading cargo while at berth, while the higher boiler load listed in the emissions inventory report table was used as a default for the tanker calls that were discharging cargo.

2.13 Control Factors for Emission Reduction Technologies

Control factors are used to reflect the emissions benefits associated with emission reduction technologies installed on vessels and/or engines.

For shore side electrical power used at berth to comply with CARB's At-Berth Regulation, shore power vessel connection and disconnection times to the shoreside electrical grid are provided to each port by the terminal operators. This information is used to determine the duration of time that the auxiliary engines are shut off and not producing emissions.

Since 2015, some of the container ships have used CARB-certified capture and control systems while at berth to treat auxiliary engine exhaust. The two systems certified by CARB for container vessels are Advanced Marine Emissions Control System (AMECS) and Marine Exhaust Treatment System-1 (METS-1).

Using the information on capture efficiency and emissions control efficiency by pollutant in CARB's executive orders AB 15-01 (EO 15-01) for METS-1 and AB 15-02 (EO 15-02) for AMEC, control factors are used in equation 2.1 when estimating auxiliary engine emissions at berth:

METS-1
NO_x CF = 0.19
$PM_{10}/PM_{2.5}/DPM$ CF = 0.145
Since the METS-1 system treats NO_x and PM only, the CF for all other pollutants and GHG is 1.0

AMECS
NO_x CF = 0.28
$PM_{10}PM_{2.5}/DPM$ CF = 0.24
Since the AMECS system treats NO_x and PM only, the CF for all other pollutants and GHG is 1.0

2.14 Emissions from Generator Engines Used During Operation of METS-1 and AMECS

METS-1
The METS-1 system barge is equipped with two tier 3 certified diesel generators. Exhaust from these generator engines is treated by the METS-1 system during the time it is treating exhaust from ship's auxiliary engine. However, the generators' exhaust is not treated during start-up or shut-down. If the duration of start-up/shut-down is not available, four hours is assumed based on discussions with the METS-1 representative. Equation 2.1 is used to calculate emissions from generators when the METS-1 system is used.

Based on information provided by METS-1:
Maximum horsepower rating of each of the engines is assumed to be 183 kW
The average load factor is 0.22

Table 2.13 shows the EFs for the METS-1 diesel generator engines.

Table 2.13: METS-1 Diesel Generator Emission Factors, g/kWh

PM_{10}	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	CH_4	N_2O
0.13	0.12	0.13	5.76	0.05	5.00	0.20	652.00	0.02	0.03

The METS-1 CF described above for auxiliary engines is also used when calculating emissions from METS-1 generators during the treatment of auxiliary engine exhaust. During METS-1 start-up or shut-down, diesel generators exhaust is not treated and the CFs for all pollutants and GHGs is 1.0.

AMECS

The AMECS systems barge is equipped and permitted by SCAQMD to run two diesel generators. Exhaust from these generator engines is not treated by the AMECS system. If start-up and shut-down time is not available, four hours is assumed based on discussions with AMEC's representative. Equation 2.1 ($E = Energy \times EF \times FCF \times CF$) is used to calculate emissions from generators when the AMECs system is used.

Maximum horsepower rating of each engine is 240 HP.
The load factor assumed is 0.80.

Table 2.14 shows the EFs for the AMECS diesel generator engines.

Table 2.14: AMECS Diesel Generator Emission Factors, g/kW-hr

PM$_{10}$	PM$_{2.5}$	DPM	NOx	SOx	CO	HC	CO$_2$	CH$_4$	N$_2$O
0.0028	0.0025	0.0028	0.11	0.08	2.95	0.19	762	0.053	0.024

While the AMECS system does treat some of the SO$_x$ emissions with a SO$_x$ scrubber, CARB has only verified the PM and NO$_x$ reductions, so we conservatively assume no SO$_x$ control because the actual control is not known. The CF for all pollutants and GHGs is 1.00 for the entire duration the generators are operating.

SECTION 3 HARBOR CRAFT METHODOLOGY

Harbor craft are commercial vessels that spend the majority of their time within or near the Port and harbor. The harbor craft emissions inventory consists of the following vessel types:

- Assist tugboats
- Commercial fishing vessels
- Crew boats
- Ferry vessels
- Excursion vessels
- Government vessels
- Pilot Boats
- Tugboats
- Ocean tugs
- Work boats

Recreational vessels are not considered to be commercial harbor craft; therefore, their emissions are not included in this inventory.

3.1 Data and Information Acquisition

The following sources were used to collect data for the harbor craft inventory:

- Vessel owners and/or operators
- Port Wharfingers data for commercial fishing vessels at Port-owned berths
- SCAQMD Carl Moyer Program for engine repower information, when the data is not readily available from owner (e.g. commercial fishing vessels)

The operating parameters of interest include the following:

- Vessel type
- Number, type and horsepower (or kilowatts) of main propulsion engine(s)
- Number, type and horsepower (or kilowatts) of auxiliary engines
- Activity hours
- Annual fuel consumption
- Qualitative information regarding how the vessels are used in service
- Main and auxiliary engine model year
- Repowered (replaced) engines
- Emission reduction strategies, if any (e.g., shore power, retrofits with after-treatment technologies).

Emissions from the following sources are estimated for harbor craft:

- Propulsion engines that move the harbor craft through water;
- Auxiliary Engines that provide power for electricity and other house loads

3.2 Emissions Estimation Methodology

Harbor craft emissions are estimated for each engine individually, based on the engine's model year, power rating, and annual hours of operation. The San Pedro Bay Ports (SPBP) harbor craft emission calculation methodology is similar to the methodology used by the CARB to estimate emissions for commercial harbor craft emissions operating in California.[16]

The basic equation used to estimate emissions from harbor craft engines is shown below in Equation 3.1.

Equation 3.1

$$E \;=\; Power \;\times\; Activity \;\times\; LF \;\times\; EF \;\times\; FCF \;\times\; CF$$

Where:

E = emissions, grams/year
Power = maximum rated power of the engine, hp or kW
Activity = engine activity, hours/year
LF = load factor (ratio of average power used during normal operations as compared to maximum rated power), dimensionless
EF = emission factor, grams of pollutant per unit of work, g/hp-hr or g/kW-hr
FCF = fuel correction factors are used to adjust EF associated with a base fuel to the fuel being used to reflect changes in fuel properties that have occurred over time, dimensionless
CF = control factor to reflect changes in emissions due to installation of emission reduction technologies not originally reflected in the emission factors, dimensionless

Power and Activity
Power is defined as the manufacturer's maximum rated power for an engine. Power and activity information is obtained during data acquisition process.

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[16] CARB, *Commercial Harbor Craft Regulatory Activities*, Appendix B: Emissions Estimation Methodology for Commercial Harbor Craft Operating in California. See: *www.arb.ca.gov/regact/2007/chc07/appb.pdf*. Viewed April 2011.

3.3 Load Factors

Engine load factors are used in emission calculations to reflect the fact that, on average, engines are operated at power levels lower than their maximum power rating. Table 3.1 summarizes the average engine load factors used for harbor craft propulsion and auxiliary engines. The engine load factors are from CARB's emission estimation methodology report[17], except for the 31% engine load factor for assist tugboats and harbor tugboats, which is based on actual engine load readings collected in the San Pedro Bay and published in the 2001 Port of Los Angeles EI report[18].

Table 3.1: Harbor Craft Engine Load Factors

Harbor Craft Type	Auxiliary Engines	Main Engines
Assist tug	0.43	0.31
Commercial fishing	0.43	0.27
Crew boat	0.32	0.38
Excursion	0.43	0.42
Ferry	0.43	0.42
Government/Pilot	0.43	0.51
Ocean tug	0.43	0.68
Tugboat	0.43	0.31
Work boat	0.32	0.38

3.4 Emission Factors

Harbor craft emission factors included in equation 3.1 have two components: zero-hour rate and deterioration rate. These are obtained from CARB's latest emission estimation methodology report that was also the source of load factors mentioned above. The source for greenhouse gas emission factors and the calculation of SO_x emission factor are discussed below.

The EF is a function of the zero-hour (ZH) emission rate for the engine model year, in the absence of any malfunction or tampering of engine components that can change emissions, deterioration rate, and cumulative hours. The deterioration rate (DR) takes into account the change in the engine's base emissions (ZH) as the equipment is used, due to wear of various engine parts or reduced efficiency of emission control devices. DR is expressed as a function of cumulative hours reflecting the engine usage in terms of the total number of hours accumulated on the engine at the time of emissions rate calculation. The ZH emission rate for harbor craft are included in Appendix A of this report.

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[17] CARB, *Emissions Estimation Methodology for Commercial Harbor Craft Operating in California*, Appendix B.
[18] Port of Los Angeles, *2001 Baseline Air Emissions Inventory,* Prepared by Starcrest Consulting Group, LLC, July 2005.

The cumulative hours reflect the engine's total operating hours at the time emissions are calculated.

The emission factor is calculated as:

Equation 3.2

$$EF = ZH + (DR \times Cumulative\ Hours)$$

Where:

> EF = emission factor. g/hp-hr or g/kW-hr
> ZH = zero-hour emission rate for a given horsepower category and model year when the engine is new and the emissions control systems are functioning normally, g/hp-hr or g/kW-hr
> DR = deterioration rate (rate of change of emissions as a function of equipment age), g/hp-hr^2 or g/kW-hr^2
> Cumulative hours = total number of hours the engine has been in use and calculated as annual operating hours times age of the engine, hours

The equation for the deterioration rate is shown in Equation 3.3. Table 3.2 lists the engine deterioration factors for harbor craft diesel engines, and Table 3.6 lists the useful life of harbor craft in years.

Equation 3.3

$$DR = (DF \times ZH) / cumulative\ hours\ at\ the\ end\ of\ useful\ life$$

Where:

> DR = deterioration rate, g/hp-hr^2 or g/kW-hr^2
> DF = deterioration factor; percent increase in emissions at the end of the useful life, %
> ZH = emission rate for a given engine size category and model year when the engine is new and the emissions control systems are functioning normally, g/hp-hr or g/kW-hr
> Cumulative hours at the end of useful life = annual operating hours times useful life in years, hours

Table 3.2: Engine Deterioration Factors for Harbor Craft Diesel Engines

Horsepower Range	PM	NO$_x$	CO	HC
25 – 50	0.31	0.06	0.41	0.51
51 – 250	0.44	0.14	0.16	0.28
> 251	0.67	0.21	0.25	0.44

CARB defines the useful life of harbor craft as the age at which 50% of the engines are retired from the fleet; it is assumed that 100% of the engines will be retired at the age of twice the useful life.

Table 3.3: Useful Life by Harbor Craft Type, years

Harbor Craft Type	Auxiliary Engines	Main Engines
Assist tug	23	21
Crew boat	28	28
Excursion	20	20
Ferry	20	20
Government	25	19
Ocean tug	25	26
Tugboat	23	21
Work boat	28	28

Harbor Craft Greenhouse Gas Emission Factors
Emission factors for CO_2, CH_4, and N_2O are sourced from the 2004 IVL study, and are listed in Appendix C.[19] The IVL study establishes the CH_4 emission factor as 2% of the hydrocarbon emission factor.

Harbor Craft SO$_x$ Emissions
The SO$_x$ emissions are a function of sulfur content in the fuel. The SO$_x$ emission factors are developed to reflect the use of 15 ppm ultra-low sulfur diesel (ULSD) using a mass balance approach, which assumes that all of the sulfur (S) in the fuel is converted to SO_2 and emitted during the combustion process. While the mass balance approach calculates SO_2 specifically, it is used as a reasonable approximation of SO$_x$. The following example shows the calculation of the SO$_x$ emission factor.

Equation 3.4

$$SOx\ EF\ =\ ULSD\ S\ content\ \times\ \frac{molecular\ mass\ of\ SO_2}{atomic\ mass\ of\ S}\ \times\ BSFC$$

Where:
SO$_x$ EF = Emission factor for SO$_x$, g/hp-hr
ULSD S content = sulfur content of the ULSD fuel, 15 grams of S/1,000,000 g of fuel
BSFC = Brake Specific Fuel Consumption, g/hp-hr

In the calculation above, the ULSD sulfur content is shown as 15 grams per sulfur per million grams of fuel. Two grams of SO_2 is emitted for each gram of sulfur in the fuel because the atomic weight of sulfur is 32 while the molecular weight of SO_2 is 64, meaning that the mass of SO_2 is two times that

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[19] IVL, Methodology for Calculating Emissions from Ships: Update on Emission Factors, 2004. Prepared by IVL Swedish Environmental Research Institute for the Swedish Environmental Protection Agency.

of sulfur. According to CARB's methodology for estimating emissions from commercial harbor craft, a brake specific fuel consumption rate of 184 gram per brake horsepower-hour is assumed.[20]

3.5 Fuel Correction Factors

Emission factors developed for harbor craft assume engines are based on diesel fuel with higher sulfur content than is currently used. To account for the required use of ULSD in harbor craft engines, the fuel correction factors in Table 3.4 are used in equation 3.1. The fuel correction factor for SO_x reflects the change from diesel fuel with an average sulfur content of 350 parts per million (ppm) to ULSD (15 ppm). There is no available data that reflects the effect of different fuels on N_2O and CH_4 emissions, so it is assumed that the fuel correction factor for NO_x is also applicable to N_2O emissions and the fuel correction factor for HC is also applicable to CH_4 emissions, since N_2O is an oxide of nitrogen and CH_4 is a component of hydrocarbons.

Table 3.4: Harbor Craft ULSD Fuel Correction Factors

Equipment MY	PM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
1995 and older	0.720	0.930	0.043	1	0.72	1	0.930	0.72
1996 to 2010	0.800	0.948	0.043	1	0.72	1	0.948	0.72
2011 and newer	0.852	0.948	0.043	1	0.72	1	0.948	0.72

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[20] CARB*, Commercial Harbor Craft Regulatory Activities. Appendix B: Emissions Estimation Methodology for Commercial Harbor Craft Operating in California. See: www.arb.ca.gov/msei/chc-appendix-b-emission-estimates-ver02-27-2012.pdf.*

SECTION 4 CARGO HANDLING EQUIPMENT (CHE) METHODOLOGY

The CHE category includes equipment that moves cargo (including containers, general cargo, and bulk cargo) to and from marine vessels, railcars, and on-road trucks. The equipment is typically operated at marine terminals or at rail yards and not on public roadways. This emissions inventory includes cargo handling equipment fueled by diesel, gasoline, propane, liquefied natural gas (LNG), and electricity. Due to the diversity of cargo handled by the Port's terminals, there is a wide range of equipment types. The majority of cargo handling equipment can be classified into one of the following equipment types:

- ➢ Cone vehicles
- ➢ Forklift
- ➢ Rubber tired gantry (RTG) crane
- ➢ Side pick
- ➢ Sweeper

- ➢ Straddle Carriers
- ➢ Top handler
- ➢ Yard tractor
- ➢ Other Such as Bulldozers, Material Handlers, Rail Pushers

CHE are used at container, dry bulk, break bulk, liquid bulk, auto, and cruise terminals that operate cargo handling equipment, as well as those equipment at UP's Intermodal Containers Transfer Facility (ICTF) and smaller facilities located within Port boundaries and covered under the port's jurisdiction.

4.1 Data and Information Acquisition

At the beginning of the EI update, the maintenance and/or CHE operating staff of each terminal are contacted in person, by e-mail, or by telephone to obtain equipment count and activity information on the CHE specific to their terminal's operation for the calendar year EI is being updated. The following is the list of information sought during data collection:

- ➢ Equipment type
- ➢ Equipment identification number
- ➢ Equipment make and model
- ➢ Engine make and model
- ➢ Rated horsepower (or kilowatts)
- ➢ Equipment and engine model year
- ➢ Type of fuel used (ULSD, gasoline or propane)
- ➢ Electric equipment
- ➢ Annual hours of operation (some terminals use hour meters)
- ➢ Installed Emissions reduction technologies
- ➢ New equipment purchased
- ➢ Equipment retired or removed from service

4.2 Emissions Estimation Methodology

The emissions calculation methodology used to estimate CHE emissions is consistent with CARB's latest methodology for estimating emissions from CHE[21]. The basic equation used to estimate CHE emissions is as follows.

Equation 4.1

$$E = Power \times Activity \times LF \times EF \times FCF \times CF$$

Where:

E = emissions, grams/year
Power = maximum rated power of the engine, hp or kW
Activity = equipment's engine activity, hr/year
LF = load factor (ratio of average load used during normal operations as compared to full load at maximum rated horsepower), dimensionless
EF = emission factor, grams of pollutant per unit of work, g/hp-hr or g/kW-hr
FCF = fuel correction factors are used to adjust EF associated with a base fuel to the fuel being used to reflect changes in fuel properties that have occurred over time, dimensionless
CF = control factor to reflect changes in emissions due to installation of emission reduction technologies not originally reflected in the emission factors, dimensionless

The emission factor is a function of the zero-hour emission rate by fuel type (diesel, propane or liquefied natural gas), by CHE engine type (off-road or on-road), for the CHE engine model year (in the absence of any malfunction or tampering of engine components that can change emissions), deterioration rate, and cumulative hours. The deterioration rate reflects the fact that the engine's zero-hour emission rates change as the equipment is used, due to wear of various engine parts or reduced efficiency of emission control devices. The cumulative hours reflect the CHE engine's total operating hours. The emission factor is calculated as:

Equation 4.2

$$EF = ZH + (DR \times Cumulative\ Hours)$$

Where:

EF = emission factor, g/hp-hr or g/kW-hr
ZH = zero-hour emission rate by fuel type by CHE engine type for a given horsepower category and model year, g/hp-hr or g/kW-hr
DR = deterioration rate (rate of change of emissions as a function of CHE engine age), g/hp-hr^2 or g/kW-hr^2
Cumulative hours = number of hours the CHE engine has been in use and calculated as annual operating hours times age of the CHE engine, hours

Power and Activity
Power and activity for each CHE engine is obtained during data collection. Averages by CHE engine and fuel type are used as defaults for the missing information.

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[21] CARB, Appendix B: *Emission Estimation Methodology for Cargo Handling Equipment Operating at Ports and Intermodal Rail Yards in California.*

4.3 Load Factors

Because engines are not continually operated at their maximum horsepower rating during normal operation, the engine load factor represents the average percentage of power that is applied during the engine's operation. Load factors for CHE were primarily obtained from CARB's CHE methodology; however, the load factors for RTG cranes and yard tractors were revised based on studies conducted by the ports of Long Beach and Los Angeles in consultation with CARB. [22] Specifically, the yard tractor load factor of 39% or 0.39 has been used since 2006, and the load factor of 20% or 0.20 for RTG cranes has been used since 2008. Table 4.1 lists the load factors for specified CHE.

Table 4.1: Cargo Handling Equipment Engine Load Factors

CHE Type	Load Factor
Cone vehicle	0.51
RTG crane	0.20
Crane	0.43
Excavator	0.55
Forklift	0.30
Loader, backhoe	0.55
Top handler, side pick, reach stacker	0.59
Truck, other with off-road engine	0.51
Truck, other with on-road engine	0.51
Straddle carrier	0.20
Sweeper	0.68
Yard tractor with off-road engine	0.39
Yard tractor with on-road engine	0.39

4.4 Emission Factors

The EF is a function of the zero-hour (ZH) emission rate for the engine model year, in the absence of any malfunction or tampering of engine components that can change emissions, deterioration rate, and cumulative hours. The deterioration rate (DR) takes into account the change in the engine's base emissions (ZH) as the equipment is used, due to wear of various engine parts or reduced efficiency of emission control devices. DR is expressed as a function of cumulative hours reflecting the engine usage in terms of the total number of hours accumulated on the engine at the time of emissions rate calculation. The ZH emission rates and DR vary by engine horsepower and model year depending upon the size of the engines, engine technology. ZH rates and DR by horsepower and engine year were used for diesel engines certified to off-road and on-road emission standards, as well as gasoline and propane engines certified to large spark ignited engine emission standards[23]. The ZH emission and DR are consistent with those in CARB's latest emissions calculations methodology for cargo

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[22] Port of Long Beach and Port of Los Angeles, *San Pedro Bay Ports Yard Tractor Load Factor Study and San Pedro Bay Ports Rubber-Tired Gantry Crane*, Prepared by Starcrest Consulting Group, LLC.

[23] See: *www.epa.gov/emission-standards-reference-guide/epa-emission-standards-nonroad-engines-and-vehicles*

handling equipment. Please refer to Appendix B for a full list of the zero-hour emissions rates used to estimate emissions from cargo handling equipment.

4.5 Fuel Correction Factors

In 1993, CARB implemented the Low Sulfur Diesel Fuel Rule, which ultimately limited the sulfur content of diesel fuel marketed in California to 15 parts per million (ppm); this fuel is known as ULSD fuel[24]. To account for the differences in the fuel properties of CARB ULSD and previously available diesel fuel, fuel correction factors (FCF) were obtained from CARB and are shown in Table 4.2. The fuel correction factor for SO_x reflects the reduction in the sulfur content of diesel fuel from 140 ppm to 15 ppm ULSD.

Table 4.2: Fuel Correction Factors for ULSD

Equipment Model Year	PM	NOx	SOx	CO	HC	CO2	N2O	CH4
1995 and older	0.720	0.930	0.110	1	0.720	1	0.930	0.720
1996 to 2010	0.800	0.948	0.110	1	0.720	1	0.948	0.720
2011 and newer	0.852	0.948	0.110	1	0.720	1	0.948	0.720

Table 4.3 shows the dimensionless fuel correction factors for gasoline engines[25]. LNG and propane engines have no FCF.

Table 4.3: Fuel Correction Factors for Gasoline

Equipment Model Year	PM	NOx	SOx	CO	HC	CO2	N2O	CH4
1997 and older	1.000	0.867	1.000	0.795	0.850	1.000	0.867	0.850
1998 and newer	1.000	0.977	1.000	1.000	1.000	1.000	0.977	1.000

[24] CARB, See: *www.arb.ca.gov/fuels/diesel/081404dslregs.pdf;* Refer to The California Diesel Fuel Regulation; Title 13, California Code of Regulation, Sections 2281-2285 & Title 17, California Code of Regulation, Section 93114.
[25] CARB, See: *www.arb.ca.gov/msei/offroad/techmemo/arb_offroad_fuels.pdf*

4.6 CHE Emission Reduction Technologies and Control Factors

Control factors are used to reflect the changes in emissions due to the use of various technologies such as DOCs and DPFs. The emission reduction percentages associated with the various emission reduction strategies have been either verified by or developed in consultation with CARB. Table 4.4 shows the emission reduction percentages by air pollutant for the various technologies used on CHE.

It should be noted that some equipment utilized more than one emission reduction technology. The majority of the emission reduction technologies were installed either voluntarily or in order to meet requirements of CARB's Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards regulation adopted in 2005[26].

Table 4.4: Emission Reductions Achieved from Control Technologies Used in CHE, %

Technology	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
Nett BlueCat 300™	0%	0%	0%	85%	na	0%	85%	na	0%	0%
DOC	30%	30%	30%	0%	na	70%	70%	na	0%	70%
DPF CARB Level 3	85%	85%	85%	0%	na	0%	0%	na	0%	0%
DPF CARB Level 2	50%	50%	50%	0%	na	0%	0%	na	0%	0%
Vycon REGEN	25%	25%	25%	30%	15%	0%	0%	15%	30%	0%
Vycon + DPF Level 2	62.5%	62.5%	62.5%	30%	15%	0%	0%	15%	30%	0%

As shown in Table 4.5, the control factor is determined by subtracting the emission reduction percentage associated with the control technology (converted to decimal form) from 1.0. For example, a technology that achieves an emissions reduction of 70%, or 0.70, would have a control factor of 0.3 (1.0 – 0.7 = 0.3).

Table 4.5: Control Factors for Control Technologies Used in CHE

Technology	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
Nett BlueCat for LSI	1.00	1.00	1.00	0.15	na	1.00	0.15	na	1.00	1.00
DOC	0.70	0.70	0.70	1.00	na	0.30	0.30	na	1.00	0.30
DPF level 3	0.15	0.15	0.15	1.00	na	1.00	1.00	na	1.00	1.00
DPF level 2	0.50	0.50	0.50	1.00	na	1.00	1.00	na	1.00	1.00
Vycon's REGEN	0.75	0.75	0.75	0.70	0.85	1.00	1.00	0.85	0.70	1.00
Vycon + DPF level 2	0.375	0.375	0.375	0.70	0.85	1.00	1.00	0.85	0.70	1.00

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[26] CARB, *See: www.arb.ca.gov/regact/cargo2005/cargo2005.htm;* Final rule posted on October 23, 2006.

SECTION 5 LOCOMOTIVE METHODOLOGY

Railroad operations are typically described in terms of two different types of operations, line haul and switching. Line haul refers to the movement of cargo by train over long distances. Line haul operations occur at or near the Port as the initiation or termination of a line haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas. Switching refers to short movements of rail cars, such as in the assembling and disassembling of trains at various locations in and around the Port, sorting of the cars of inbound cargo trains into contiguous "fragments" for subsequent delivery to terminals, and the short distance hauling of rail cargo within the Port. Locomotives used for line haul operations are typically equipped with large, powerful engines of 4,400 hp or more, while switch engines are smaller, typically having one or more engines totaling 1,200 to 3,000 hp. The locomotives used in switching service at the Port are primarily new, low-emitting locomotives specifically designed for switching duty. The switching locomotives are operated by PHL within the Port and by UP at the near-port railyard.

5.1 Data and Information Acquisition

To estimate emissions associated with maritime industry-related activities of locomotives operating both within the Port and outside the Port to the boundary of the SoCAB, information has been obtained from:

- Previous emissions studies
- Port cargo statistics
- Input from railroad operators
- Published information sources
- CARB MOU line-haul fleet compliance data

The Port continues to use the most recent, locally-specific data available, including MOU compliance data reflective of actual recent line haul fleet mix characteristics in the SoCAB.

5.2 Emission Estimation Methodology

Emissions are estimated for locomotives operating in both switching and line haul service, on-port and off-port. The following subsections provide a description of the methods used to estimate emissions from switching and line haul locomotives operating within the Ports and in the SoCAB. Emissions have been estimated using information provided by the railroads and the terminals, and from published information sources such as the EPA's "Emission Factors for Locomotives"[27] and their Regulatory Support Document (RSD),[28] Both EPA documents were published as background to EPA's locomotive rule-making processes.

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[27] EPA, *EPA-420-F-09-025*, April 2009
[28] EPA, *Locomotive Emission Standards Regulatory Support Document,* April 1998, revised

Fuel use information provided by the on-port switching company (PHL) has been used along with EPA and manufacturer information on emission rates to estimate on-port switching emissions. Off-Port switching emissions have been estimated using fuel use data for the ICTF previously provided by UP for CY 2005, scaled to the change in facility throughput between 2005 and the current year. While not a specific calendar-year fuel consumption measurement, it has been noted that UP has consistently provided fuel use estimates based on EPA-published fuel consumption figures rather than providing actual fueling totals, likely because of difficulties in identifying specific fuel subtotals related to the ICTF. For this reason, scaling past fuel consumption estimates to changes in throughput is a reasonable and consistent way of estimating changes in fuel consumption and emissions from year to year. For the limited line haul operations at the Port (arrivals and departures), emission estimates have been based on schedule and throughput information provided by the railroads and terminal operators, and on EPA operational and emission factors. Off-Port line haul emissions have been estimated using cargo movement information provided by the line haul railroads, and weight and distance information first developed for the 2005 emissions inventory, with updates to the average container weight starting with the 2012 emissions inventory.

Different calculation methods are required for the different types of locomotive activity because different types of information are used for different activities. However, an attempt has been made to standardize the activity measures used as the basis of calculations in order to develop consistent methodologies and results.

5.3 Switching Locomotive Emissions

Emissions from PHL's on-port switching operations are based on the horsepower-hours of work calculated from their reported annual locomotive fuel use, emission factors from the EPA documents cited above, and information published by the locomotive manufacturers. The calculations estimate horsepower-hours worked by each locomotive based on fuel consumption in gallons per year and combine the horsepower-hour estimates with emission factors in terms of grams of emissions per horsepower-hour (g/hp-hr). Fuel usage is converted to horsepower-hours using conversion factors that equate horsepower-hours to gallon of fuel (hp-hr/gal):

Equation 5.1

$$\textbf{\textit{Annual work (hphr/year)}} = \textbf{\textit{gallons/year}} \times \textbf{\textit{hphr/gallon}}$$

The calculation of emissions from horsepower-hours uses the following equation.

Equation 5.2

$$\textbf{\textit{E}} = \frac{\textbf{\textit{Annual work}} \times \textbf{\textit{EF}}}{(\textbf{453.59} \textbf{\textit{g/lb}} \times \textbf{2,000} \textbf{\textit{lb/ton}})}$$

Where:
      E = emissions, tons per year
      Annual work = annual work, hp-hrs/yr
      EF = emission factor, grams pollutant per horsepower-hour

Emission factors have been identified for the locomotive emission tier levels present in PHL's fleet: Tier 3, Tier 3+, Tier 4, and genset. In addition, Tier 0, Tier 1, and Tier 2 emission factors are maintained in the emissions inventory database for use as needed for specialty calculations. In most cases the emission factors are from EPA's in-use emission factors published in the 2009 document cited above. Emission factors for PM_{10}, $PM_{2.5}$, and DPM from the Tier 3+ locomotive engines have been based on the EPA emission certification level of the engines, which is lower than the Tier 3 standard. Manufacturer's published emission rates have been used for the genset switchers, which operate with three diesel engines originally certified to EPA Tier 3 nonroad engine standards. Emission rates published by the locomotives' manufacturer, National Railway Equipment Co. (NRE), have been used instead of the Tier 3 nonroad standards because differences in duty cycle between nonroad and locomotive operation make the nonroad standards less appropriate. The ICTF switching emissions have been calculated using the genset emission factors noted above based on UP's MOU compliance submission to the ARB, and statements made by UP representatives which, together, indicate that the switchers are most likely genset units.

The EPA and NRE emission factors cover particulate, NO_x, CO, and HC emissions. SO_x emission factors have been developed to reflect the use of 15 ppm ULSD using a simplified mass balance approach. This approach assumes that all of the sulfur in the fuel is converted to SO_2 and emitted during the combustion process. While the mass balance approach calculates SO_2 specifically, it is a reasonable approximation of SO_x. The following example shows the calculation of the SO_x emission factor.

Equation 5.3

$$\frac{15 \ g \ S}{1,000,000 \ g \ fuel} \times \frac{3,200 \ g \ fuel}{gal \ fuel} \times \frac{2 \ g \ SO_2}{g \ S} \times \frac{gal \ fuel}{15.2 \ hp \ hr} = 0.006 \ g \ SO_2/hphr$$

In this calculation, 15 ppm S is written as 15 g S per million g of fuel. The value of 15.2 hp-hr/gallon of fuel is the average brake specific fuel consumption (BSFC) noted in EPA's technical literature on locomotive emission factors (EPA, 2009). Two grams of SO_2 is emitted for each gram of sulfur in the fuel because the atomic weight of sulfur is 32 while the molecular weight of SO_2 is 64, meaning that the mass of SO_2 is two times that of sulfur. The BSFC value of 15.2 hp-hr/gallon is used for the Tier 3+ switching locomotives. An evaluation of information released by NRE on the fuel consumption of the genset switchers indicates a BSFC of 17.9 hp-hr/gallon for the genset locomotives. This indicates that they are more fuel efficient and thus can perform more work output (i.e., hp-hr) for a given amount of fuel. Emission factors based on fuel consumption (such as SO_x and CO_2) reflect the different BSFC values.

Greenhouse gas emission factors from EPA references[29] have been used to estimate emissions of the greenhouse gases CO_2, CH_4, and N_2O from locomotives. Additionally, all particulate emissions are assumed to be PM_{10} and DPM; $PM_{2.5}$ emissions have been estimated as 92% of PM_{10} emissions to be consistent with CARB's $PM_{2.5}$ ratio used for offroad diesel equipment.

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[29] EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017,* Draft February 2019

Emission factors for the Tier 3 and genset switching locomotives are listed in Tables 5.1 and 5.2.

Table 5.1: Switching Emission Factors, g/hp-hr

Locomotive Type	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC
RR switch Tier 0	0.44	0.40	0.44	12.6	0.006	1.83	1.01
RR Tier 1	0.32	0.29	0.32	6.7	0.006	1.28	0.47
RR Tier 2	0.19	0.17	0.19	7.3	0.006	1.83	0.51
RR Tier 3	0.08	0.07	0.08	4.5	0.006	1.83	0.26
RR Tier 3+	0.036	0.033	0.036	4.5	0.006	1.83	0.26
RR Tier 4	0.015	0.014	0.015	1	0.006	1.83	0.08
RR Genset	0.05	0.05	0.05	3.37	0.005	1.51	0.04

Table 5.2: Switching GHG Emission Factors, g/hp-hr

Locomotive Type	CO_2	N_2O	CH_4
RR switch Tier 0	678	0.017	0.050
RR Tier 1	678	0.017	0.050
RR Tier 2	678	0.017	0.050
RR Tier 3	678	0.017	0.050
RR Tier 3+	678	0.017	0.050
RR Tier 4	678	0.017	0.050
RR Genset	578	0.015	0.050

The activity measure used in the switching emission estimates is total horsepower-hours of activity, derived from the locomotive-specific fuel use for the on-port switching locomotives, and an estimate of off-port switching fuel use derived from information provided earlier by UP for the ICTF rail yard that is located on Port property.

PHL operates at both ports. While some of the shifts are focused on activities at only one of the ports, other shifts may work at either or both ports depending upon the day's needs for switching services. Since it is not possible to clearly designate which shifts operate solely within the Port boundary, a method was developed for apportioning emissions between the two ports. PHL work shifts have been evaluated as to whether they are likely to work in either port exclusively or in both ports, resulting in a split of 69% of activity within POLA and 31% within POLB. This split will be updated if/when appropriate information is available from PHL.

Rail cargo from both ports is handled at the off-dock ICTF, and the complexities of the rail system are such that apportionment of activity (and emissions) between the two ports is difficult. Based on a throughput comparison, an allocation of 55% POLA and 45% POLB has been adopted. Regardless of apportionment, the sum of the two ports' emissions represents all of the estimated switching emissions from locomotives operated at the ICTF.

5.4 Line Haul Locomotive Emissions

Emissions from line haul locomotives operating in the ports have been estimated on an activity basis consisting of estimates of the number and characteristics of locomotives that arrive and depart with cargo and/or empty containers. The information used in developing these estimates has been obtained from the ports and the terminals. The number of locomotive trips within the ports has been estimated by evaluating cargo movements, percentage of cargo transported by rail, and typical number of locomotives per train, using a methodology similar to that first used for the 2001 POLA and 2002 POLB baseline emissions inventories and subsequent inventories.

5.4.1 On-Port Line Haul Emissions

On-port line haul locomotive activity is estimated through an evaluation of the amount of cargo reported by the terminals to be transported by rail and their reported average or typical number of trains per week or per year. These numbers are combined with assumptions regarding the average number of locomotives involved on-port line haul railroad moves, and the average duration of incoming and outgoing trips. The estimated number of trains per year, the average number of locomotives per train, and the estimated number of on-port hours per train are multiplied together to calculate total number of locomotive hours per year. This activity information is summarized in Table 5.3, using example data from a recent inventory year. While most of the rail cargo, and the basis for these estimates, center on container traffic, the local switching railroad has reported that they prepare an average of one train per day of non-container cargo for transport out of the San Pedro Bay Ports area. Assuming that a similar number of trains is inbound, the number of trains per year includes an average of one non-container train every day in each direction for an annual total of 365 additional non-container trains for each port.

Table 5.3: Example On-Port Line Haul Locomotive Activity

Activity Measure	Inbound	Outbound	Total
Number of trains/years	3,251	3,158	6,409
Number of locomotives/trains	3	3	NA
Hours on Port/trip	1.0	2.5	NA
Locomotive hours/year	9,753	23,685	33,438

The average load factor for a typical line haul locomotive calling at either of the ports has been estimated by multiplying the percentage of full power in each throttle notch setting by the average percentage of line haul locomotive operating time in that setting, as summarized in Table 5.4. Both sets of percentages are EPA averages listed in the RSD documentation. This average load factor is probably overestimated because the throttle notch distribution included in EPA's documentation is representative of nation-wide operation, including time traveling uphill when the higher notch positions are most often used, while the locomotives serving the ports spend most of their time in lower throttle settings for the time they are within either port. However, the railroads have been unable to provide detailed throttle notch information for the time spent on port to enable the development of an average on-port load factor, so the nation-wide average from EPA is used as a default. In the table, DB is short for dynamic braking, an operating mode of locomotive engines.

Table 5.4: Estimated Average Load Factor

Notch	% of Full Power in Notch	% of Operating Time in Notch	% Full Power x % Time
DB	2.1%	12.5%	0.003
Idle	0.4%	38.0%	0.002
1	5.0%	6.5%	0.003
2	11.4%	6.5%	0.007
3	23.5%	5.2%	0.012
4	34.3%	4.4%	0.015
5	48.1%	3.8%	0.018
6	64.3%	3.9%	0.025
7	86.6%	3.0%	0.026
8	102.5%	16.2%	0.166
Average line haul locomotive load factor:			**0.28**

To estimate the total number of horsepower-hours for the year, the estimated number of locomotive hours is multiplied by average locomotive horsepower and the average load factor discussed above:

Equation 5.4

$$33,438 \; locomotive \; \frac{hours}{year} \times 4,000 \; \frac{hp}{locomotive} \times 0.28 = 37.5 \; million \; hp-hr \; (rounded)$$

Emission estimates for on-port line haul locomotive activity are calculated by multiplying this estimate of horsepower-hours by the emission factors listed in Table 5.9 in terms of g/hp-hr.

5.4.2 Out-of-Port Line Haul Emissions

Line haul locomotive activity between the ports and the SoCAB boundary is estimated through an evaluation of the amount of port cargo transported by rail and of average or typical train characteristics such as number of containers and number of gross tons per train. Estimates of gross tons, gross ton-miles, and fuel usage are prepared from these activity estimates.

Four components of locomotive activity are used to develop the off-port emission estimates: number of trains, average weight of each train, distances traveled within the SoCAB, and the amount of fuel used per ton-mile of train activity. The average number of port-related trains is obtained from the Alameda Corridor Transportation Authority (ACTA),[30] whose numbers include non-container trains discussed above and trains unrelated to port activity. The ACTA average is cross-checked against estimates made using average train capacity (recently estimated to be 274 containers per typical train) and port throughput figures for on-dock rail and the ICTF. The gross weight of a typical train, including locomotives, railcars, and freight, is estimated to have been 7,276 tons in recent years, using

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[30] Overall Alameda Corridor traffic for 2016 was an average of 34 per day. See: *www.acta.org/PDF/CorridorTrainCounts.pdf*

the assumptions listed below in Table 5.5. The distance assumptions are 21 miles for the Alameda Corridor and 84 miles between the north end of the Alameda Corridor and the SoCAB boundary.

Gross ton-miles in millions are calculated by multiplying the number of trains, the gross weight per train, and the miles traveled, as illustrated by the example shown in Table 5.6. This example also shows the estimated total fuel usage, estimated by multiplying the gross ton-miles by the average fuel consumption of the two Class 1 railroads. This average fuel consumption has been derived from information reported by the railroads to the U.S. Surface Transportation Board, which has jurisdiction over railroad rate and service issues, in an annual report known as the "R-1."[31] Among the details in this report are the total gallons of diesel fuel used in freight service and the total freight moved in thousand gross ton-miles. The total fuel reported by both railroads was divided by the total gross ton-miles to derive the average factor of 0.990 gallons of fuel per thousand gross ton-miles used in the 2017 emissions inventories. Also listed in Table 5.6 is the estimated total of out-of-port horsepower-hours, calculated by multiplying the estimated fuel use by the fuel use conversion factor of 20.8 hp-hr/gal.

Table 5.5: Assumptions for Gross Weight of Trains

Train Component	Approximate Weight (lbs)	Weight (short tons)	Number per train	Weight (short tons)
Locomotive	420,000	210	4	840
Railcar (per double-stack platform)	40,000	20	130	2,600
Container		14	274	3,836
Total weight per train, gross tons				**7,276**

Table 5.6: Gross Ton-Mile, Fuel Use, and hp-hr Estimate

	Distance (miles)	Trains per year	MMGT per year	MMGT-miles per year
Alameda Corridor	21	5,180	38	798
Central LA to Air Basin Boundary	84	5,180	38	3,192
Million gross ton-miles (MMGT)				**3,990**
Estimated gallons of fuel (millions)				**3.93**
Estimated million hp-hr				**81.7**

Emission estimates for out-of-port line haul locomotive activity are calculated by multiplying the estimate of overall horsepower-hours by the emission factors in terms of g/hp-hr.

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[31] Union Pacific, *Class I Railroad Annual Report R-1 to the Surface Transportation Board for the Year Ending Dec. 31, 2016* and BNSF, *Class I Railroad Annual Report R-1 to the Surface Transportation Board for the Year Ending Dec. 31, 2016,* See: *www.stb.dot.gov/econdata.nsf/FinancialData?OpenView*

5.4.3 Line Haul Locomotive Emission Factors

Line haul locomotive emission factors have been developed from various sources, including the information submitted by the railroads to ARB to demonstrate compliance with the MOU,[32] EPA's recent documentation (EPA-420-F-09-025, cited above) representing EPA's estimates of emissions from line haul locomotives by engine tier level, and an EPA publication on greenhouse gas emissions.[33]

To the extent possible, the MOU compliance data is used to develop the emission factors, since this data is the most location-specific information available. The data is used directly to develop the NO_x emission factor (based on submitted NO_x emission rates). The information on engine tier level frequency is used to develop emission factors for particulate, HC, and CO emissions. The railroads report information by locomotive tier level: pre-Tier 0, Tier 0, Tier 1, Tier 2, Tier 3, Tier 4, and ultra-low emission locomotives (ULEL). The information includes, for each tier level, the number of locomotives that worked in the South Coast Air Basin during the year, the megawatt-hours (MWh) expended by the locomotives while in the basin, the percentage of MW-hr in each tier level, and the weighted average NO_x emissions in grams per horsepower hour (g/hp-hr). The railroads calculate a fleet average NO_x emission rate using the rates by tier level and the percentage of MW-hr in each tier level. In addition, UP uses "ULEL credits" to achieve the required 5.5 g/hp-hr composite emission rate.

The method used to adapt the railroads' NO_x emissions data to the development of a NO_x emission factor for the ports' emissions inventories is to calculate a composite NO_x emission rate using the MW-hr totals by tier level reported by both railroads for their compliance demonstration. The MW-hrs contributed by ULELs are not included because these locomotives are dedicated switchers and should not be part of the line haul emission factor calculations. While the railroads operate some switchers that are not ULELs, nonetheless they are included in the MW-hr totals for their applicable tier levels because it is not possible to remove their contribution to the MW-hr totals. The number of such switchers is insignificant compared to the number of line haul locomotives that visit the South Coast Air Basin, so they are not expected to significantly influence the resulting composite emission factors. Table 5.7 presents the MOU compliance information submitted by both railroads[34], used for the 2017 emissions inventories, and the composite of both railroads' pre-Tier 0 through Tier 4 locomotive NO_x emissions, showing a weighted average NO_x emission factor of 5.40 g/hp-hr. Each year's emissions inventory reports the MOU compliance data used for that inventory.

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[32] CARB, See: *www.arb.ca.gov/railyard/1998agree/1998agree.htm*

[33] EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017,* Draft February 2019

[34] Notes from railroads' MOU compliance submissions:
   1. For more information on the U.S. EPA locomotive emission standards, See: *http://www.epa.gov/oms/locomotives.htm.*
   2. Number of locomotives is the sum of all individual locomotives that visited or operated within the SCAB at any time during 2012.
   3. Many locomotives are certified to emission levels cleaner than the U.S. EPA emission standards or tiers. For the purposes of this table, a locomotive's actual certified emission level is grouped with the required tier level. Within each tier, the Weighted Average NOx Emission Level is calculated by multiplying each individual locomotive's actual certification level by its megawatt-hours of operation.
   4. The Tier Contribution is calculated by multiplying the %MW-hr by Tier Level by the Weighted Average NOx Emission Level.

Table 5.7: MOU Compliance Data, MWh and g NO$_x$/hp-hr

Engine Tier	Number of Locomotives	Megawatt-hours (MWhr)	%MWhrs by Tier Level	Wt'd Avg NOx (g/bhp-hr)	Tier Contribution to Fleet Average (g/bhp-hr)
BNSF					
Pre-Tier 0	41	948	0.4%	12.8	0.05
Tier 0	141	4,409	1.8%	7.6	0.14
Tier 1	1,250	80,060	32%	6.2	2.01
Tier 2	1,320	85,126	34%	5.0	1.72
Tier 3	1,112	67,842	27%	4.6	1.26
Tier 4	236	9,093	3.7%	1.2	0.04
ULEL	0	0	0%	-	-
Total BNSF	**4,100**	**247,478**	**100%**		**5.2**
UP					
Tier not rep'd	5	91	0.1%	10.6	0.01
Pre-Tier 0	14	78	0.0%	14.2	0.01
Tier 0	1,719	32,040	18.8%	7.8	1.47
Tier 1	1,804	29,168	17%	6.5	1.11
Tier 2	1,412	54,955	32%	5.0	1.61
Tier 3	801	46,862	28%	4.8	1.32
Tier 4	101	3,488	2.0%	1.1	0.02
ULEL	44	3,482	2%	2.6	0.05
Total UP	**5,900**	**170,163**	**100%**		**5.6**
			ULEL Credit Used		0.1
			UP Fleet Average		**5.5**
Both RRs, excluding ULELs and ULEL credits					
Pre-Tier 0	55	1,026	0%	12.9	0.03
Tier 0	1,860	36,448	9%	7.8	0.68
Tier 1	3,054	109,228	26%	6.3	1.66
Tier 2	2,732	140,081	34%	5.0	1.69
Tier 3	1,913	114,703	28%	4.7	1.30
Tier 4	337	12,581	3.04%	1.2	0.036
Total both	**9,951**	**414,068**	**97%**		**5.40**

As noted in the text above and shown in Table 5.7, UP at times uses ULEL credits established under the MOU as part of their compliance demonstration. These credits are not used in developing the line haul locomotive NO$_x$ emission factor. Only the data on Pre-Tier 0 and Tiers 0 through 4 locomotives are used, as shown in the lower part of the table.

Emission factors for particulate matter (PM$_{10}$, PM$_{2.5}$, and DPM), HC, and CO are calculated using the tier-specific emission rates for those pollutants published by EPA[35] and the MW-hr figures provided in the railroads' submissions. These results from a recent emissions inventory are presented in Table 5.8. The composites are calculated by multiplying each tier's emission factor by that tier's percentage of total MW-hr and summing the results for all tiers. For example, the PM$_{10}$ tier-specific emission factor is 0.32 g/hp-hr for pre-tier 0 (uncontrolled), Tier 0, and Tier 1 locomotive engines, and 0.18 g/hp-hr for Tier 2 engines. Each tier's emission factor is multiplied by the corresponding percentage of MW-hr (18% for Tier 0, 20% for Tier 1, etc.) with the results entered under the "Fleet Composite" column for PM$_{10}$. The composite PM$_{10}$ emission factor is calculated by summing the four values in that column. The other pollutants in the table are calculated in a similar manner. Tier 4 locomotives are not included in this calculation because their extremely limited presence during the year would have had a negligible effect on the composite emission factors.

Table 5.8: Fleet MW-hr and PM, HC, CO Emission Factors, g/hp-hr

Engine Tier	MWhr	% of MWhr	EPA Tier-specific PM$_{10}$	HC g/bhp-hr	CO	Fleet Composite PM$_{10}$	HC g/bhp-hr	CO
Pre-Tier 0	1,026	0%	0.32	0.48	1.28	0.001	0.00	0.00
Tier 0	36,448	9%	0.32	0.48	1.28	0.028	0.04	0.11
Tier 1	109,228	26%	0.32	0.47	1.28	0.084	0.12	0.34
Tier 2	140,081	34%	0.18	0.26	1.28	0.061	0.09	0.43
Tier 3	114,703	28%	0.08	0.13	1.28	0.022	0.04	0.36
Tier 4	12,581	3.04%	0.015	0.04	1.28	0.000	0.00	0.04
Totals	414,068	100%				0.196	0.29	1.28

The SO$_x$ emission factor has been estimated from assumed fuel sulfur content values using the same mass balance equation as the switching locomotives calculation. Table 5.9 summarizes the emission factors discussed above, presented in units of g/hp-hr.

Table 5.9: Emission Factors for Line Haul Locomotives, g/hp-hr

	PM$_{10}$	PM$_{2.5}$	DPM	NO$_x$	SO$_x$	CO	HC	CO$_2$	N$_2$O	CH$_4$
EF, g/bhp-hr	0.20	0.18	0.20	5.40	0.005	1.28	0.29	494	0.013	0.04

Please note that emission factors for locomotives change from year to year and that the current emission factors will be listed in each port's annual emissions inventory report. Table 5.9 serves as an example and may not be the most current.

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[35] EPA, *EPA-420-F-09-025*, April 2009
EPA, *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*, Table 3.4-8a. May 2004

SECTION 6 HEAVY DUTY VEHICLE METHODOLOGY

In the course of their daily operations, trucks that service SPBP terminals are driven onto and through the terminals, where they deliver and/or pick up cargo. They are also driven on the public roads within the Port boundaries, and on the public roads outside the Port. While most of the trucks are diesel-fueled vehicles, alternatively fueled trucks, primarily those fueled by liquefied natural gas (LNG) also service the SPBP. The emission estimates prepared using this methodology reflect the use of both types of fuel. This is an enhancement compared to the EIs prepared for CY2019 and earlier, which only made adjustments to the DPM estimates to account for the use of natural gas fuel.

The two major geographical components of truck activities have been evaluated for this inventory:

➢ On-terminal operations, which include waiting for terminal entry, transiting the terminal to drop off and/or pick up cargo, and departing the terminal.
➢ On-road operations, consisting of travel on public roads within the SoCAB. This also includes travel on public roads within the Ports' boundaries and those of the adjacent San Pedro Bay Ports.

6.1 Data and Information Acquisition

Data for the HDV emission estimates came from three basic sources: port and terminal activity records, terminal contacts, and computer modeling of on-road HDV traffic volumes, distances, and speeds. These information sources are discussed below.

Information regarding on-terminal truck activity, such as average times and distances while on the terminals, has been collected during in-person and/or telephone interviews with terminal personnel and is updated when terminal contacts are able and willing to provide information. For on-road operations, the volumes (number of trucks), distances, and average speeds on roadway segments between defined intersections are estimated using trip generation and travel demand models that have been developed for these purposes. The trip generation model is used to develop truck trip numbers for container terminals, while the terminal interviews are used to obtain trip counts associated with non-container terminals.

6.2 Emission Estimation Methodology

A simplified equation for estimating the emissions from a fleet of on-road vehicles can be expressed as:

Equation 6.1

$$E = Activity \times EF$$

Where:

E = Emissions (grams/year)
Activity = Activity (average number of miles driven per truck, hours of idle operation)
EF = Emission factor (amount of pollutant emitted per unit of activity), g/mile or g/hour

The emission factors are developed from the latest version of EMFAC,[36] a computer model developed by CARB to estimate emissions from on-road vehicles operating in California. The version currently in use at the time of this methodology is EMFAC2021. A new feature of this version of the model is the ability to obtain emission factors for natural gas fueled trucks in addition to the more common diesel fueled trucks. CARB makes available a web-based database of model results that allows querying for emission factors stratified by speed and vehicle model year for individual air basins or for the state as a whole. The database query performed for the ports' emissions inventories utilizes the South Coast Air Basin factors. The EMFAC2021 output is processed for the emissions inventories in such a way as to develop a single set of composite emission factors for each 5-mph speed increment that represents the fleet's distribution of model years. Activity is estimated as miles driven using computer models to simulate terminal truck counts and on-road driving miles, and hours of idling on-terminal are estimated from information provided by the terminal operators. The activity (miles and hours) and emission factors (g/mile and g/hour) are combined to estimate fleet emissions. The process is described in the following paragraphs.

The EMFAC models, such as EMFAC2021, model the basic emission rate (in grams per mile) as a constant value (over time) with a "zero-mile rate" (ZMR) or intercept representing the emissions of the vehicle when new or like-new (well maintained and un-tampered), plus a "deterioration rate" (DR) or slope representing the gradual increase in the emission rate over time as a function of use (the engine's cumulative mileage). For heavy-duty trucks the deterioration rate is expressed as grams per mile traveled per 10,000 accumulated miles (g/mi/10k mi).

Equation 6.2

$$BER = ZMR + (DR \times CM /10,000)$$

Where:

BER = Basic Emission Rate (amount of pollutants emitted per unit of activity for vehicles of that model year), g/mile
ZMR = Zero Mile Rate (emissions of the vehicle when new or like-new), g/mile
DR = Deterioration Rate (slope representing the gradual increase in the emission rate over time as a functions of use), g/mi/10K miles
CM = Cumulative Mileage (total miles on the vehicle since new), miles

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[36] CARB, See: *https://arb.ca.gov/emfac/*

CARB has published idle emission factors expressed in grams per hour (g/hr)[37] that are used in estimating the idle emissions from HDVs operating at the Port. The idle emission factors are multiplied by the estimated total hours of idle operation to derive the ton-per-year emission estimates.

CARB has developed "low idle" and "high idle" emission rates to represent emissions from different types of truck idling. The "low idle" rates are used in developing the emissions inventory for the Port because the low idle rates are "indicative of a truck in queue to either pick up or drop off a shipment," whereas the "high idle" rates are intended to "reflect activity associated with truck stops, rest areas, and distribution centers" rather than normal port operations.

The low idle emission factors are presented in Table 6.1. Emission factors for diesel trucks of model year 2007 and later are updated from the EMFAC2017 documentation, while the earlier year emission factors remain from the earlier version of the model, EMFAC2014, and the natural gas truck emission factors are from the EMFAC2021 documentation entitled "EMFAC2021 Volume III Technical Document Version 1.0" dated April 2021.[38] Recent model year distributions of port trucks have not included trucks older than model year 2007 so only the emission factors for model years 2007 and newer have been used. The emission factors in Table 6.1 have been corrected to account for differences between current fuels and the fuels used during development of the base emission factors. The low idle emission factors are presented in Table 6.1.

Table 6.1: Low Idle Emission Rates, g/hr

Model Years	HC	CO	NO$_x$	PM	CO$_2$
Diesel					
2010+	1.59	35.7	23.5	0.0042	6,012
2007-09	1.35	3.7	30.7	0.0033	5,318
2003-06	4.36	16.6	88.44	0.53	4,924
1998-02	5.31	17.9	85.28	0.68	4,839
1994-97	6.97	19.8	79.24	0.96	4,712
1991-93	8.71	21.5	72.91	1.28	4,610
1987-90	10.94	23.4	65.29	1.71	4,507
Pre-1987	18.65	28.4	42.5	3.43	4,271
Natural gas					
2018+	33.9	109	14.4	0.066	14,164
2007-17	48.2	48	15.5	0.033	11,224

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[37] CARB, See: *www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf; www.arb.ca.gov/msei/emfac2011-technical-documentation-final-updated-0712-v03.pdf;* and
www.arb.ca.gov/msei/onroad/techmemo/revised_hhddt_emission_factors_and_speed_corr_factors.pdf
[38] CARB, See: *www.content.govdelivery.com/accounts/CARB/bulletins/2d48287*

Under startup conditions, HDVs equipped with SCR emit higher-than-normal amounts of NO_x until the catalyst in the convertor reaches optimum operating temperature. However, not all 2010+ trucks are equipped with SCR. Many 2010+ model year trucks have an exhaust gas recirculation (EGR) system which does not experience start-up emissions. Because the prevalence of EGR-equipped trucks decreases with each new model year, CARB has developed average emission factors for each model year of truck starting with 2010 which have been used to estimate start emissions for the HDVs in this EI. The start emissions contribute a very small amount of NO_x, approximately 0.5% of overall HDV NO_x emissions in the 2020 EIs.

EMFAC2021 provides start emissions in g NO_x per trip for each model year 2010 and newer. The average start emissions per trip are listed in Table 6.2, along with the 2020 model year distribution leading to a composite start emission factor of 1.234 g NO_x/trip. Overall start emissions of NO_x are calculated using the following equation for each model year of diesel fueled vehicle, and summing the results for all model years:

Equation 6.5

$$NO_x \text{ start emissions } (ton/year) = \Sigma \frac{EF_{startMY} \times tripsMY/year)}{(453.59\frac{g}{lb} \times 2,000 \text{ } lb/ton)}$$

Where:

$EF_{startsMY}$ = Model year-specific NO_x start emission factor as described above, g NO_x/trip

TripsMY/year = Number of trips per year taken by each model year – diesel fueled vehicles only

Table 6.2: 2020 MY Distribution and Start NO_x Emission Factors, g/start

Model Year	Call fraction by MY (EMFAC2021)	Grams NO_x / start
Composite	**1.0000**	**1.2342**
2021	0.0079	2.5439
2020	0.0162	2.5439
2019	0.0236	2.5439
2018	0.0127	2.5439
2017	0.0176	2.5439
2016	0.0554	2.5439
2015	0.0771	2.1127
2014	0.00784	2.1127
2013	0.0976	2.1127
2012	0.1186	1.8907
2011	0.0696	1.5391
2010	0.1043	0.2763
2009	0.1781	0
2008	0.1423	0
2007	0.0006	0

6.3 Model Year Distribution

Because vehicle emissions vary according to the vehicle's model year and age, the activity level of trucks within each model year is an important part of developing emission estimates. The model year distribution is based on call data originating from the RFID data associated with the Clean Truck Program (CTP), which tracked over 7 million truck calls made to both San Pedro Bay ports in 2020, and body model year data drawn from the PDTR, which contains model year information on all trucks registered to do business at the Port's container terminals. Under the CTP, each container terminal has installed a system to read and record the RFID number of each registered truck that enters the terminal. Trucks that are not registered but are otherwise eligible to enter are provided a "day pass" that is also recorded by the terminal. These records of truck entries were matched up with the truck characteristics data in the PDTR to develop the overall model year distribution of trucks calling at the Port. In addition to providing the number of calls made by each model year, the PDTR data also includes each vehicle's fuel type, which, along with new EMFAC2021 natural gas emission factors, allows the development of composite emission factors that include emissions from natural gas fueled vehicles.

The distribution of the truck fleet's body model years by calls, which is used to develop the composite emission factors for 2020 as discussed below, is presented in Figure 6.1 as an example. The call weighted average age of the Port-related fleet in 2020 was approximately 7 years. The body model year distribution will change with each emissions inventory update. Readers are advised to refer to the latest annual EI report for the most up to date information.

Figure 6.1: 2020 Body Model Year Distribution of the Heavy-Duty Truck Fleet
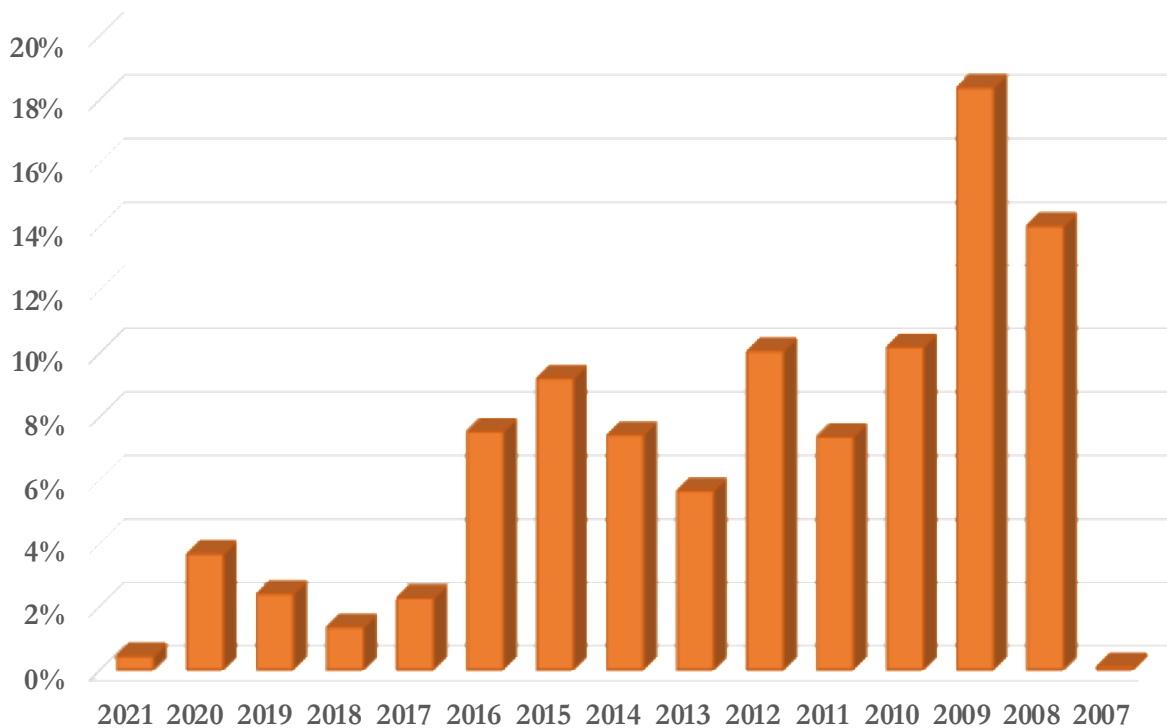
6.4 Speed-Specific Emission Factors

The model year and speed specific gram-per-mile emission rates are composited to reflect the distribution of truck calls by fuel and by model year within the fleet of trucks calling at Port terminals, with a single emission factor for each 5-mile-per-hour speed increment representing the distribution of model years using the call-weighted model year distribution discussed in the previous subsection. A single set of pollutant specific gram-per-hour idle emission rates is derived using the distribution of truck calls by model year.

Idling emission rates of N_2O are based on an average fuel consumption rate of 0.48 gallons of diesel per hour during idling, derived from an analysis of the idling CO_2 emission factor established by CARB. Table 6.3 summarizes the speed-specific emission factors developed as described above and used to estimate emissions for 2020. These composite emission factors include emissions from diesel and natural gas fueled vehicles. The units are in grams per mile, except for the idle emission factors (0 mph), which are in grams per hour of idling.

The composite emission factors for heavy duty vehicles change from year to year and the current emission factors will be listed in each port's annual emissions inventory report. Table 6.3 serves as an example and may not be the most current. The emission factors presented in Table 6.3 are multiplied by the on-road and on-terminal VMT and on-terminal idling hours to yield the overall on-road and on-terminal emissions.

Table 6.3: 2020 Speed-Specific Composite Emission Factors, g/hr and g/mi

Speed (mph)	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4	Units
0 (Idle)	0.0057	0.0055	0.0037	25.3384	0.0516	27.1457	3.1002	6,082	0.8982	0.6750	g/hr
5	0.0355	0.0339	0.0352	12.9219	0.0330	4.3541	1.2013	3,691	0.5912	0.4985	g/mi
10	0.0318	0.0304	0.0315	10.4890	0.0285	3.4697	0.8752	3,176	0.5082	0.3279	g/mi
15	0.0271	0.0260	0.0269	7.9551	0.0235	2.5107	0.5652	2,609	0.4168	0.1929	g/mi
20	0.0241	0.0231	0.0239	6.5259	0.0205	1.9222	0.4007	2,275	0.3633	0.1349	g/mi
25	0.0222	0.0212	0.0220	5.6270	0.0186	1.5186	0.2989	2,051	0.3273	0.1027	g/mi
30	0.0211	0.0202	0.0210	4.9551	0.0170	1.2114	0.2285	1,880	0.3000	0.0821	g/mi
35	0.0208	0.0199	0.0207	4.4357	0.0158	0.9728	0.1775	1,748	0.2788	0.0679	g/mi
40	0.0213	0.0203	0.0212	4.0530	0.0150	0.7908	0.1402	1,649	0.2630	0.0576	g/mi
45	0.0224	0.0214	0.0223	3.7950	0.0144	0.6569	0.1129	1,580	0.2519	0.0498	g/mi
50	0.0241	0.0231	0.0241	3.6581	0.0140	0.5644	0.0930	1,539	0.2453	0.0439	g/mi
55	0.0265	0.0253	0.0264	3.6395	0.0139	0.5087	0.0789	1,525	0.2429	0.0392	g/mi
60	0.0297	0.0284	0.0296	3.7771	0.0141	0.4961	0.0762	1,549	0.2467	0.0390	g/mi
65	0.0337	0.0322	0.0336	4.0575	0.0147	0.5047	0.0787	1,607	0.2558	0.0391	g/mi
70	0.0337	0.0322	0.0336	4.0761	0.0147	0.5049	0.0787	1,607	0.2558	0.0391	g/mi

APPENDIX A – HARBOR CRAFT EMISSION FACTORS

Engine	Engine				Zero Hour Emission Factor (g/kw-hr)							
Type	Year		Power (kW)		PM	NO$_x$	SO$_2$	CO	HC	CO$_2$	N$_2$O	CH$_4$
	min	max	min	max								
propulsion	0	1998	0	38	0.97	10.91	0.17	4.89	2.47	652	0.031	0.049
propulsion	1998	2000	0	38	0.97	10.91	0.17	4.89	2.41	652	0.031	0.048
propulsion	2000	2005	0	38	0.97	9.8	0.17	4.89	2.41	652	0.031	0.048
propulsion	2005	2009	0	38	0.4	7.13	0.17	5	2.41	652	0.031	0.048
propulsion	2009	2040	0	38	0.29	7.13	0.17	5	2.41	652	0.031	0.048
propulsion	0	1997	38	90	1.07	20.56	0.17	4.69	1.93	652	0.031	0.039
propulsion	1997	2000	38	90	0.88	13.85	0.17	3.42	1.33	652	0.031	0.027
propulsion	2000	2005	38	90	0.88	9.8	0.17	3.42	1.33	652	0.031	0.027
propulsion	2005	2009	38	90	0.4	7.13	0.17	5	1.33	652	0.031	0.027
propulsion	2009	2040	38	90	0.29	7.13	0.17	5	1.33	652	0.031	0.027
propulsion	0	1971	90	131	0.98	22.14	0.17	4.3	1.77	652	0.031	0.035
propulsion	1971	1979	90	131	0.84	20.56	0.17	4.3	1.47	652	0.031	0.029
propulsion	1979	1984	90	131	0.7	18.98	0.17	4.3	1.34	652	0.031	0.027
propulsion	1984	1987	90	131	0.7	17.4	0.17	4.21	1.26	652	0.031	0.025
propulsion	1987	1996	90	131	0.7	17.4	0.17	4.12	1.18	652	0.031	0.024
propulsion	1996	2000	90	131	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2004	90	131	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2004	2013	90	131	0.29	6.84	0.17	5	0.91	652	0.031	0.018
propulsion	2013	2040	90	131	0.12	5.09	0.17	5	0.91	652	0.031	0.018
propulsion	0	1971	131	187	0.98	22.14	0.17	4.3	1.77	652	0.031	0.035
propulsion	1971	1979	131	187	0.84	20.56	0.17	4.3	1.47	652	0.031	0.029
propulsion	1979	1984	131	187	0.7	18.98	0.17	4.3	1.34	652	0.031	0.027
propulsion	1984	1987	131	187	0.7	17.4	0.17	4.21	1.26	652	0.031	0.025
propulsion	1987	1995	131	187	0.7	17.4	0.17	4.12	1.18	652	0.031	0.024
propulsion	1995	2000	131	187	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2004	131	187	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2004	2014	131	187	0.2	6.84	0.17	5	0.91	652	0.031	0.018
propulsion	2014	2040	131	187	0.11	5.35	0.17	5	0.91	652	0.031	0.018
propulsion	0	1971	187	374	0.94	22.14	0.17	4.12	1.69	652	0.031	0.034
propulsion	1971	1979	187	374	0.8	20.56	0.17	4.12	1.41	652	0.031	0.028
propulsion	1979	1984	187	374	0.67	18.98	0.17	4.12	1.27	652	0.031	0.025
propulsion	1984	1987	187	374	0.67	17.4	0.17	4.12	1.21	652	0.031	0.024
propulsion	1987	1995	187	374	0.67	17.4	0.17	4.01	1.13	652	0.031	0.023
propulsion	1995	2000	187	374	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2004	187	374	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2004	2014	187	374	0.2	6.84	0.17	5	0.91	652	0.031	0.018
propulsion	2014	2040	187	374	0.11	5.35	0.17	5	0.91	652	0.031	0.018
propulsion	0	1971	374	560	0.94	22.14	0.17	4.12	1.69	652	0.031	0.034
propulsion	1971	1979	374	560	0.8	20.56	0.17	4.12	1.41	652	0.031	0.028
propulsion	1979	1984	374	560	0.67	18.98	0.17	4.12	1.27	652	0.031	0.025
propulsion	1984	1987	374	560	0.67	17.4	0.17	4.12	1.21	652	0.031	0.024
propulsion	1987	1995	374	560	0.67	17.4	0.17	4.01	1.13	652	0.031	0.023
propulsion	1995	2000	374	560	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2007	374	560	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2007	2013	374	560	0.2	6.84	0.17	5	0.91	652	0.031	0.018
propulsion	2013	2040	374	560	0.11	5.35	0.17	5	0.91	652	0.031	0.018
propulsion	0	1971	560	1,418	0.94	22.14	0.17	4.12	1.69	652	0.031	0.034

Engine	Engine				Zero Hour Emission Factor (g/kw-hr)							
Type	Year		Power (kW)		PM	NO_x	SO_2	CO	HC	CO_2	N_2O	CH_4
	min	max	min	max								
propulsion	1971	1979	560	1,418	0.8	20.56	0.17	4.12	1.41	652	0.031	0.028
propulsion	1979	1984	560	1,418	0.67	18.98	0.17	4.12	1.27	652	0.031	0.025
propulsion	1984	1987	560	1,418	0.67	17.4	0.17	4.12	1.21	652	0.031	0.024
propulsion	1987	1999	560	1,418	0.67	17.4	0.17	4.01	1.13	652	0.031	0.023
propulsion	1999	2000	560	1,418	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2007	560	1,418	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2007	2012	560	1,418	0.27	7.41	0.17	5	0.91	652	0.031	0.018
propulsion	2012	2017	560	1,418	0.11	5.48	0.17	5	0.91	652	0.031	0.018
propulsion	2017	2040	560	1,418	0.04	1.74	0.17	5	0.24	652	0.031	0.005
propulsion	0	1971	1,418	2,462	0.94	22.14	0.17	4.12	1.69	652	0.031	0.034
propulsion	1971	1979	1,418	2,462	0.8	20.56	0.17	4.12	1.41	652	0.031	0.028
propulsion	1979	1984	1,418	2,462	0.67	18.98	0.17	4.12	1.27	652	0.031	0.025
propulsion	1984	1987	1,418	2,462	0.67	17.4	0.17	4.12	1.21	652	0.031	0.024
propulsion	1987	1999	1,418	2,462	0.67	17.4	0.17	4.01	1.13	652	0.031	0.023
propulsion	1999	2000	1,418	2,462	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2007	1,418	2,462	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2007	2013	1,418	2,462	0.27	7.41	0.17	5	0.91	652	0.031	0.018
propulsion	2013	2016	1,418	2,462	0.13	5.86	0.17	5	0.91	652	0.031	0.018
propulsion	2016	2040	1,418	2,462	0.04	1.74	0.17	5	0.24	652	0.031	0.005
propulsion	0	1971	2,462	7,456	0.94	22.14	0.17	4.12	1.69	652	0.031	0.034
propulsion	1971	1979	2,462	7,456	0.8	20.56	0.17	4.12	1.41	652	0.031	0.028
propulsion	1979	1984	2,462	7,456	0.67	18.98	0.17	4.12	1.27	652	0.031	0.025
propulsion	1984	1987	2,462	7,456	0.67	17.4	0.17	4.12	1.21	652	0.031	0.024
propulsion	1987	1999	2,462	7,456	0.67	17.4	0.17	4.01	1.13	652	0.031	0.023
propulsion	1999	2000	2,462	7,456	0.48	12.92	0.17	2.64	0.91	652	0.031	0.018
propulsion	2000	2007	2,462	7,456	0.48	9.8	0.17	2.64	0.91	652	0.031	0.018
propulsion	2007	2014	2,462	7,456	0.27	7.41	0.17	5	0.91	652	0.031	0.018
propulsion	2014	2016	2,462	7,456	0.34	6.62	0.17	5	0.91	652	0.031	0.018
propulsion	2016	2040	2,462	7,456	0.04	1.74	0.17	5	0.24	652	0.031	0.005
auxiliary	0	1998	0	38	0.86	9.25	0.17	6.9	2.94	652	0.031	0.059
auxiliary	1998	2000	0	38	0.86	9.25	0.17	6.9	2.87	652	0.031	0.057
auxiliary	2000	2005	0	38	0.86	9.25	0.17	6.9	2.87	652	0.031	0.057
auxiliary	2005	2009	0	38	0.4	7.13	0.17	5	2.87	652	0.031	0.057
auxiliary	2009	2040	0	38	0.29	7.13	0.17	5	2.87	652	0.031	0.057
auxiliary	0	1997	38	90	0.95	17.43	0.17	6.62	2.29	652	0.031	0.046
auxiliary	1997	2000	38	90	0.78	11.73	0.17	4.81	1.58	652	0.031	0.032
auxiliary	2000	2005	38	90	0.78	9.8	0.17	4.81	1.58	652	0.031	0.032
auxiliary	2005	2009	38	90	0.4	7.13	0.17	5	1.58	652	0.031	0.032
auxiliary	2009	2040	38	90	0.29	7.13	0.17	5	1.58	652	0.031	0.032
auxiliary	0	1971	90	131	0.87	18.77	0.17	6.07	2.1	652	0.031	0.042
auxiliary	1971	1979	90	131	0.74	17.43	0.17	6.07	1.76	652	0.031	0.035
auxiliary	1979	1984	90	131	0.62	16.09	0.17	6.07	1.6	652	0.031	0.032
auxiliary	1984	1987	90	131	0.62	14.75	0.17	5.94	1.5	652	0.031	0.030
auxiliary	1987	1996	90	131	0.62	14.75	0.17	5.8	1.41	652	0.031	0.028
auxiliary	1996	2000	90	131	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2004	90	131	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2004	2013	90	131	0.29	6.84	0.17	5	1.09	652	0.031	0.022

Engine Type	Engine Year		Engine Power (kW)		Zero Hour Emission Factor (g/kw-hr)							
	min	max	min	max	PM	NO_x	SO_2	CO	HC	CO_2	N_2O	CH_4
auxiliary	2013	2040	90	131	0.12	5.09	0.17	5	1.09	652	0.031	0.022
auxiliary	0	1971	131	187	0.87	18.77	0.17	6.07	2.1	652	0.031	0.042
auxiliary	1971	1979	131	187	0.74	17.43	0.17	6.07	1.76	652	0.031	0.035
auxiliary	1979	1984	131	187	0.62	16.09	0.17	6.07	1.6	652	0.031	0.032
auxiliary	1984	1987	131	187	0.62	14.75	0.17	5.94	1.5	652	0.031	0.030
auxiliary	1987	1995	131	187	0.62	14.75	0.17	5.8	1.41	652	0.031	0.028
auxiliary	1995	2000	131	187	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2004	131	187	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2004	2014	131	187	0.2	6.84	0.17	5	1.09	652	0.031	0.022
auxiliary	2014	2040	131	187	0.11	5.35	0.17	5	1.09	652	0.031	0.022
auxiliary	0	1971	187	374	0.83	18.77	0.17	5.8	2.01	652	0.031	0.040
auxiliary	1971	1979	187	374	0.71	17.43	0.17	5.8	1.68	652	0.031	0.034
auxiliary	1979	1984	187	374	0.6	16.09	0.17	5.8	1.51	652	0.031	0.030
auxiliary	1984	1987	187	374	0.6	14.75	0.17	5.8	1.43	652	0.031	0.029
auxiliary	1987	1995	187	374	0.6	14.75	0.17	5.66	1.34	652	0.031	0.027
auxiliary	1995	2000	187	374	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2004	187	374	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2004	2014	187	374	0.2	6.84	0.17	5	1.09	652	0.031	0.022
auxiliary	2014	2040	187	374	0.11	5.35	0.17	5	1.09	652	0.031	0.022
auxiliary	0	1971	374	560	0.83	18.77	0.17	5.8	2.01	652	0.031	0.040
auxiliary	1971	1979	374	560	0.71	17.43	0.17	5.8	1.68	652	0.031	0.034
auxiliary	1979	1984	374	560	0.6	16.09	0.17	5.8	1.51	652	0.031	0.030
auxiliary	1984	1987	374	560	0.6	14.75	0.17	5.8	1.43	652	0.031	0.029
auxiliary	1987	1995	374	560	0.6	14.75	0.17	5.66	1.34	652	0.031	0.027
auxiliary	1995	2000	374	560	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2007	374	560	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2007	2013	374	560	0.2	6.84	0.17	5	1.09	652	0.031	0.022
auxiliary	2013	2040	374	560	0.11	5.35	0.17	5	1.09	652	0.031	0.022
auxiliary	0	1971	560	1,418	0.83	18.77	0.17	5.8	2.01	652	0.031	0.040
auxiliary	1971	1979	560	1,418	0.71	17.43	0.17	5.8	1.68	652	0.031	0.034
auxiliary	1979	1984	560	1,418	0.6	16.09	0.17	5.8	1.51	652	0.031	0.030
auxiliary	1984	1987	560	1,418	0.6	14.75	0.17	5.8	1.43	652	0.031	0.029
auxiliary	1987	1999	560	1,418	0.6	14.75	0.17	5.66	1.34	652	0.031	0.027
auxiliary	1999	2000	560	1,418	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2007	560	1,418	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2007	2012	560	1,418	0.27	7.41	0.17	5	1.09	652	0.031	0.022
auxiliary	2012	2017	560	1,418	0.11	5.48	0.17	5	1.09	652	0.031	0.022
auxiliary	2017	2040	560	1,418	0.04	1.74	0.17	5	0.24	652	0.031	0.005
auxiliary	0	1971	1,418	2,462	0.83	18.77	0.17	5.8	2.01	652	0.031	0.040
auxiliary	1971	1979	1,418	2,462	0.71	17.43	0.17	5.8	1.68	652	0.031	0.034
auxiliary	1979	1984	1,418	2,462	0.6	16.09	0.17	5.8	1.51	652	0.031	0.030
auxiliary	1984	1987	1,418	2,462	0.6	14.75	0.17	5.8	1.43	652	0.031	0.029
auxiliary	1987	1999	1,418	2,462	0.6	14.75	0.17	5.66	1.34	652	0.031	0.027
auxiliary	1999	2000	1,418	2,462	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2007	1,418	2,462	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2007	2013	1,418	2,462	0.27	7.41	0.17	5	1.09	652	0.031	0.022
auxiliary	2013	2016	1,418	2,462	0.13	5.86	0.17	5	1.09	652	0.031	0.022

Engine Type	Engine				Zero Hour Emission Factor (g/kw-hr)							
	Year		Power (kW)		PM	NO_x	SO_2	CO	HC	CO_2	N_2O	CH_4
	min	max	min	max								
auxiliary	2016	2040	1,418	2,462	0.04	1.74	0.17	5	0.24	652	0.031	0.005
auxiliary	0	1971	2,462	7,456	0.83	18.77	0.17	5.8	2.01	652	0.031	0.040
auxiliary	1971	1979	2,462	7,456	0.71	17.43	0.17	5.8	1.68	652	0.031	0.034
auxiliary	1979	1984	2,462	7,456	0.6	16.09	0.17	5.8	1.51	652	0.031	0.030
auxiliary	1984	1987	2,462	7,456	0.6	14.75	0.17	5.8	1.43	652	0.031	0.029
auxiliary	1987	1999	2,462	7,456	0.6	14.75	0.17	5.66	1.34	652	0.031	0.027
auxiliary	1999	2000	2,462	7,456	0.43	10.95	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2000	2007	2,462	7,456	0.43	9.8	0.17	3.73	1.09	652	0.031	0.022
auxiliary	2007	2014	2,462	7,456	0.27	7.41	0.17	5	1.09	652	0.031	0.022
auxiliary	2014	2016	2,462	7,456	0.34	6.62	0.17	5.03	1.09	652	0.031	0.022
auxiliary	2016	2040	2,462	7,456	0.04	1.74	0.17	5.03	0.24	652	0.031	0.005

APPENDIX B – CHE EMISSION FACTORS

Engine Type	Engine Year		Power (kW)		Zero Hour Emission Factor (g/kW-hr) and Deterioration Rate (gm/kW-hr^2)																		
	min	max	min	max	PM ZH	PM DR	PM$_{2.5}$ ZH	PM$_{2.5}$ DR	DPM ZH	DPM DR	NO$_x$ ZH	NO$_x$ DR	SO$_2$ ZH	SO$_2$ DR	CO ZH	CO DR	HC ZH	HC DR	CO$_2$ ZH	CO$_2$ DR	N$_2$O ZH	N$_2$O DR	CH$_4$ ZH	CH$_4$ DR
Diesel	0	1988	0	38	1.0200	0.00007899	0.9380	0.00007267	1.0200	0.00007899	9.3872	0.00014081	0.0920	0.0	6.7051	0.00068794	2.4700	0.00031514	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	1988	1997	0	38	1.0200	0.00007899	0.9380	0.00007267	1.0200	0.00007899	9.2500	0.00013947	0.0920	0.0	6.7051	0.00068794	2.4100	0.00030844	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	1997	1999	0	38	1.0200	0.00007899	0.9380	0.00007267	1.0200	0.00007899	9.2500	0.00013947	0.0920	0.0	6.7051	0.00068794	2.4100	0.00030844	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	1999	2004	0	38	0.8000	0.00006236	0.7360	0.00005737	0.8000	0.00006236	7.4400	0.00013813	0.0920	0.0	5.4982	0.00056323	1.9400	0.00024809	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	2004	2005	0	38	0.5800	0.00004506	0.5340	0.00004145	0.5800	0.00004506	6.8392	0.00012512	0.0920	0.0	4.3851	0.00044790	0.8600	0.00013142	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	2005	2006	0	38	0.5100	0.00003929	0.4690	0.00003615	0.5100	0.00003929	6.6381	0.00012968	0.0920	0.0	4.0200	0.00040901	0.5000	0.00009253	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	2006	2008	0	38	0.4700	0.00003648	0.4320	0.00003356	0.4700	0.00003648	6.5400	0.00013182	0.0920	0.0	3.8353	0.00038890	0.3200	0.00007309	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	2008	2013	0	38	0.2100	0.00001636	0.1930	0.00001505	0.2100	0.00001636	6.4369	0.00013410	0.0920	0.0	3.6476	0.00037012	0.1300	0.00005364	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	2013	2040	0	38	0.0134	0.00000149	0.0120	0.00000137	0.0134	0.00000149	3.8890	0.00008100	0.0920	0.0	3.6476	0.00037012	0.1300	0.00005364	762	0.0	0.0270	0.0	0.0610	0.0
Diesel	0	1988	38	56	1.1265	0.00008194	1.0360	0.00007538	1.1265	0.00008194	17.4333	0.00040365	0.0800	0.0	6.4369	0.00017031	1.9300	0.00008931	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	1988	1997	38	56	0.9300	0.00006732	0.8560	0.00006193	0.9300	0.00006732	11.7300	0.00027089	0.0800	0.0	4.6800	0.00012378	1.3300	0.00006142	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	1997	1998	38	56	0.9300	0.00006732	0.8560	0.00006193	0.9300	0.00006732	11.7300	0.00027089	0.0800	0.0	4.6800	0.00012378	1.3300	0.00006142	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	1998	2004	38	56	0.9300	0.00006732	0.8560	0.00006193	0.9300	0.00006732	9.2500	0.00021456	0.0800	0.0	4.6800	0.00012378	1.3300	0.00006142	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2004	2005	38	56	0.5200	0.00003822	0.4780	0.00003516	0.5200	0.00003822	7.5600	0.00013813	0.0800	0.0	4.3300	0.00011466	0.6200	0.00004466	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2005	2006	38	56	0.3900	0.00002843	0.3590	0.00002616	0.3900	0.00002843	7.0000	0.00011265	0.0800	0.0	4.2100	0.00011171	0.3800	0.00003916	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2006	2008	38	56	0.3200	0.00002360	0.2940	0.00002171	0.3200	0.00002360	6.7185	0.00009991	0.0800	0.0	4.1400	0.00011010	0.2600	0.00003634	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2008	2013	38	56	0.1877	0.00001381	0.1730	0.00001271	0.1877	0.00001381	3.8756	0.00005096	0.0800	0.0	4.0900	0.00010862	0.1300	0.00003353	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2013	2040	38	56	0.0134	0.00000125	0.0120	0.00000115	0.0134	0.00000125	3.8756	0.00005096	0.0800	0.0	4.0900	0.00010862	0.1300	0.00003353	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	0	1988	56	75	1.1300	0.00008194	1.0400	0.00007538	1.1300	0.00008194	17.4333	0.00040365	0.0800	0.0	6.4369	0.00017031	1.9300	0.00008931	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	1988	1997	56	75	0.9300	0.00006732	0.8560	0.00006193	0.9300	0.00006732	11.7300	0.00027089	0.0800	0.0	4.6800	0.00012378	1.3300	0.00006142	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	1997	1998	56	75	0.9300	0.00006732	0.8560	0.00006193	0.9300	0.00006732	11.7300	0.00027089	0.0800	0.0	4.6800	0.00012378	1.3300	0.00006142	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	1998	2004	56	75	0.9300	0.00006732	0.8560	0.00006193	0.9300	0.00006732	9.2500	0.00021456	0.0800	0.0	4.6800	0.00012378	1.3300	0.00006142	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2004	2005	56	75	0.5200	0.00003822	0.4780	0.00003516	0.5200	0.00003822	7.5600	0.00013813	0.0800	0.0	4.3300	0.00011466	0.6200	0.00004466	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2005	2006	56	75	0.3900	0.00002843	0.3590	0.00002616	0.3900	0.00002843	7.0000	0.00011265	0.0800	0.0	4.2100	0.00011171	0.3800	0.00003916	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2006	2008	56	75	0.3200	0.00002360	0.2940	0.00002171	0.3200	0.00002360	6.7185	0.00009991	0.0800	0.0	4.1400	0.00011010	0.2600	0.00003634	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2008	2012	56	75	0.2548	0.00001877	0.2340	0.00001727	0.2548	0.00001877	3.8756	0.00005096	0.0800	0.0	4.0900	0.00010862	0.1300	0.00003353	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2012	2015	56	75	0.0134	0.00000063	0.0120	0.00000058	0.0134	0.00000063	0.1332	0.00000175	0.0800	0.0	4.0900	0.00010862	0.1207	0.00002910	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	2015	2040	56	75	0.0134	0.00000063	0.0120	0.00000058	0.0134	0.00000063	0.1332	0.00000175	0.0800	0.0	4.0900	0.00010862	0.0671	0.00001569	762	0.0	0.0240	0.0	0.0560	0.0
Diesel	0	1970	75	131	1.0300	0.00007510	0.9480	0.00006909	1.0300	0.00007510	18.7743	0.00043449	0.0800	0.0	5.9000	0.00015556	1.7700	0.00008194	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1970	1972	75	131	0.8851	0.00006437	0.8140	0.00005922	0.8851	0.00006437	17.4333	0.00040365	0.0800	0.0	5.9000	0.00015556	1.4751	0.00006826	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1972	1979	75	131	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	16.0923	0.00037280	0.0800	0.0	5.9000	0.00015556	1.3400	0.00006209	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1979	1980	75	131	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	16.0923	0.00037280	0.0800	0.0	5.9000	0.00015556	1.3400	0.00006209	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1980	1985	75	131	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	14.7512	0.00034062	0.0800	0.0	5.7664	0.00015288	1.2600	0.00005833	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1985	1988	75	131	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	14.7512	0.00034062	0.0800	0.0	5.6300	0.00014885	1.1800	0.00005458	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1988	1997	75	131	0.5100	0.00003701	0.4690	0.00003405	0.5100	0.00003701	10.9561	0.00025345	0.0800	0.0	3.6200	0.00009575	0.9100	0.00004224	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1997	2003	75	131	0.5100	0.00003701	0.4690	0.00003405	0.5100	0.00003701	9.2500	0.00021456	0.0800	0.0	3.6200	0.00009575	0.9100	0.00004224	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2003	2004	75	131	0.3200	0.00002280	0.2940	0.00002097	0.3200	0.00002280	7.0500	0.00012927	0.0800	0.0	3.6200	0.00009575	0.4400	0.00003741	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2004	2005	75	131	0.2548	0.00001810	0.2340	0.00001666	0.2548	0.00001810	6.3300	0.00010084	0.0800	0.0	3.6200	0.00009575	0.3000	0.00003527	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2005	2007	75	131	0.2100	0.00001582	0.1930	0.00001456	0.2100	0.00001582	5.9500	0.00008663	0.0800	0.0	3.6200	0.00009575	0.2100	0.00003446	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2007	2012	75	131	0.1900	0.00001341	0.1750	0.00001234	0.1900	0.00001341	3.2855	0.00004291	0.0800	0.0	3.6200	0.00009575	0.1300	0.00003353	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2012	2015	75	131	0.0134	0.00000063	0.0120	0.00000058	0.0134	0.00000063	3.0441	0.00003969	0.0800	0.0	3.6200	0.00009575	0.1207	0.00002910	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2015	2040	75	131	0.0134	0.00000063	0.0120	0.00000058	0.0134	0.00000063	0.3621	0.00000477	0.0800	0.0	3.6200	0.00009575	0.0671	0.00001569	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	0	1970	131	224	1.0300	0.00007510	0.9480	0.00006909	1.0300	0.00007510	18.7743	0.00043449	0.0800	0.0	5.9000	0.00015556	1.7700	0.00008194	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1970	1972	131	224	0.8851	0.00006437	0.8140	0.00005922	0.8851	0.00006437	17.4333	0.00040365	0.0800	0.0	5.9000	0.00015556	1.4751	0.00006826	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1972	1979	131	224	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	16.0923	0.00037280	0.0800	0.0	5.9000	0.00015556	1.3400	0.00006209	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1979	1980	131	224	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	16.0923	0.00037280	0.0800	0.0	5.9000	0.00015556	1.3400	0.00006209	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1980	1985	131	224	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	14.7512	0.00034062	0.0800	0.0	5.7664	0.00015288	1.2600	0.00005833	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1985	1988	131	224	0.7400	0.00005364	0.6810	0.00004935	0.7400	0.00005364	14.7512	0.00034062	0.0800	0.0	5.6300	0.00014885	1.1800	0.00005458	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1988	1996	131	224	0.5100	0.00003701	0.4690	0.00003405	0.5100	0.00003701	10.9561	0.00025345	0.0800	0.0	3.6200	0.00009575	0.9100	0.00004224	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1996	1997	131	224	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00019445	0.0800	0.0	1.2300	0.00003259	0.4300	0.00001985	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	1997	2003	131	224	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00019445	0.0800	0.0	1.2300	0.00003259	0.4300	0.00001985	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2003	2004	131	224	0.1600	0.00000873	0.1470	0.00000803	0.1600	0.00000873	6.7051	0.00012136	0.0800	0.0	1.2300	0.00003259	0.2548	0.00002803	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2004	2005	131	224	0.1500	0.00000809	0.1380	0.00000744	0.1500	0.00000809	6.1400	0.00009696	0.0800	0.0	1.2300	0.00003259	0.1900	0.00003084	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2005	2007	131	224	0.1500	0.00000776	0.1380	0.00000714	0.1500	0.00000776	5.8700	0.00008489	0.0800	0.0	1.2300	0.00003259	0.1600	0.00003218	762	0.0	0.0240	0.0	0.0530	0.0

Engine Type	Engine Year min	max	Engine Power (kW) min	max	PM ZH	PM DR	PM$_{2.5}$ ZH	PM$_{2.5}$ DR	DPM ZH	DPM DR	NO$_x$ ZH	NO$_x$ DR	SO$_2$ ZH	SO$_2$ DR	CO ZH	CO DR	HC ZH	HC DR	CO$_2$ ZH	CO$_2$ DR	N$_2$O ZH	N$_2$O DR	CH$_4$ ZH	CH$_4$ DR
Diesel	2007	2011	131	224	0.1500	0.00000744	0.1380	0.00000685	0.1500	0.00000744	3.2855	0.00004264	0.0800	0.0	1.2300	0.00003259	0.1300	0.00003353	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2011	2014	131	224	0.0134	0.00000050	0.0120	0.00000046	0.0134	0.00000050	1.8238	0.00002374	0.0800	0.0	1.2300	0.00003259	0.0939	0.00002454	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	2014	2040	131	224	0.0134	0.00000050	0.0120	0.00000046	0.0134	0.00000050	0.3621	0.00000477	0.0800	0.0	1.2300	0.00003259	0.0671	0.00001569	762	0.0	0.0240	0.0	0.0530	0.0
Diesel	0	1970	224	448	0.9900	0.00005270	0.9110	0.00004849	0.9900	0.00005270	18.7743	0.00031246	0.0700	0.0	5.6300	0.00111573	1.6900	0.00005887	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1970	1972	224	448	0.8400	0.00004479	0.7730	0.00004121	0.8400	0.00004479	17.4333	0.00028966	0.0700	0.0	5.6300	0.00111573	1.4100	0.00004908	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1972	1979	224	448	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	16.0923	0.00026820	0.0700	0.0	5.6300	0.00111573	1.2700	0.00004439	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1979	1980	224	448	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	16.0923	0.00026820	0.0700	0.0	5.6300	0.00111573	1.2700	0.00004439	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1980	1985	224	448	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	14.7512	0.00024541	0.0700	0.0	5.6300	0.00111573	1.2100	0.00004211	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1985	1988	224	448	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	14.7512	0.00024541	0.0700	0.0	5.4982	0.00108891	1.1300	0.00003929	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1988	1996	224	448	0.5100	0.00002709	0.4690	0.00002492	0.5100	0.00002709	10.9561	0.00018238	0.0700	0.0	3.6200	0.00007174	0.9100	0.00003178	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1996	1997	224	448	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00013947	0.0700	0.0	1.2300	0.00002441	0.4300	0.00001502	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	1997	2001	224	448	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00013947	0.0700	0.0	1.2300	0.00002441	0.4300	0.00001502	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2001	2002	224	448	0.1600	0.00000873	0.1470	0.00000803	0.1600	0.00000873	6.6381	0.00009843	0.0700	0.0	1.2300	0.00002441	0.2548	0.00002615	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2002	2003	224	448	0.1500	0.00000809	0.1380	0.00000744	0.1500	0.00000809	6.0480	0.00008475	0.0700	0.0	1.2300	0.00002441	0.1900	0.00002977	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2003	2005	224	448	0.1500	0.00000776	0.1380	0.00000714	0.1500	0.00000776	5.7500	0.00007791	0.0700	0.0	1.2300	0.00002441	0.1600	0.00003165	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2005	2006	224	448	0.1500	0.00000744	0.1380	0.00000685	0.1500	0.00000744	5.3600	0.00007107	0.0700	0.0	1.2300	0.00002441	0.1300	0.00003353	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2006	2011	224	448	0.1500	0.00000744	0.1380	0.00000685	0.1500	0.00000744	3.2855	0.00004264	0.0700	0.0	1.2300	0.00002441	0.1300	0.00003353	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2011	2014	224	448	0.0134	0.00000050	0.0120	0.00000046	0.0134	0.00000050	1.8238	0.00002374	0.0700	0.0	1.2300	0.00002441	0.0939	0.00002454	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	2014	2040	224	448	0.0134	0.00000050	0.0120	0.00000046	0.0134	0.00000050	0.3621	0.00000477	0.0700	0.0	1.2300	0.00002441	0.0671	0.00001569	762	0.0	0.0200	0.0	0.0470	0.0
Diesel	0	1970	448	560	0.9900	0.00005270	0.9110	0.00004849	0.9900	0.00005270	18.7743	0.00031246	0.0700	0.0	5.6300	0.00111573	1.6900	0.00005887	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1970	1972	448	560	0.8400	0.00004479	0.7730	0.00004121	0.8400	0.00004479	16.0923	0.00028966	0.0700	0.0	5.6300	0.00111573	1.4100	0.00004908	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1972	1979	448	560	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	16.0923	0.00026820	0.0700	0.0	5.6300	0.00111573	1.2700	0.00004439	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1979	1980	448	560	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	16.0923	0.00026820	0.0700	0.0	5.6300	0.00111573	1.2700	0.00004439	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1980	1985	448	560	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	14.7512	0.00024541	0.0700	0.0	5.6300	0.00111573	1.2100	0.00004211	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1985	1988	448	560	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	14.7512	0.00024541	0.0700	0.0	5.4982	0.00108891	1.1300	0.00003929	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1988	1996	448	560	0.5096	0.00002709	0.4690	0.00002492	0.5096	0.00002709	10.9561	0.00018238	0.0700	0.0	3.6200	0.00007174	0.9119	0.00003178	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1996	1999	448	560	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00013947	0.0700	0.0	1.2300	0.00002441	0.4291	0.00001502	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1999	2002	448	560	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00013947	0.0700	0.0	1.2300	0.00002441	0.4300	0.00001502	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2002	2003	448	560	0.1600	0.00000873	0.1470	0.00000803	0.1600	0.00000873	6.6381	0.00009843	0.0700	0.0	1.2300	0.00002441	0.2548	0.00002615	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2003	2004	448	560	0.1500	0.00000809	0.1380	0.00000744	0.1500	0.00000809	6.0480	0.00008475	0.0700	0.0	1.2300	0.00002441	0.1900	0.00002977	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2004	2006	448	560	0.1500	0.00000776	0.1380	0.00000714	0.1500	0.00000776	5.7500	0.00007791	0.0700	0.0	1.2300	0.00002441	0.1600	0.00003165	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2006	2011	448	560	0.1500	0.00000744	0.1380	0.00000685	0.1500	0.00000744	3.2855	0.00004264	0.0700	0.0	1.2300	0.00002441	0.1300	0.00003353	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2011	2014	448	560	0.0134	0.00000050	0.0120	0.00000046	0.0134	0.00000050	1.8238	0.00002374	0.0700	0.0	1.2300	0.00002441	0.0939	0.00002454	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2014	2040	448	560	0.0134	0.00000050	0.0120	0.00000046	0.0134	0.00000050	0.3621	0.00000477	0.0700	0.0	1.2300	0.00002441	0.0671	0.00001569	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	0	1970	560	999	0.9900	0.00005270	0.9110	0.00004849	0.9900	0.00005270	18.7743	0.00031246	0.0720	0.0	5.6300	0.00111573	1.6900	0.00005887	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1970	1972	560	999	0.8400	0.00004479	0.7730	0.00004121	0.8400	0.00004479	17.4333	0.00028966	0.0720	0.0	5.6300	0.00111573	1.4100	0.00004908	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1972	1979	560	999	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	16.0923	0.00026820	0.0720	0.0	5.6300	0.00111573	1.2700	0.00004439	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1979	1980	560	999	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	16.0923	0.00026820	0.0720	0.0	5.6300	0.00111573	1.2700	0.00004439	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1980	1985	560	999	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	14.7512	0.00024541	0.0720	0.0	5.6300	0.00111573	1.2100	0.00004211	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1985	1988	560	999	0.7100	0.00003768	0.6530	0.00003467	0.7100	0.00003768	14.7512	0.00024541	0.0720	0.0	5.4982	0.00108891	1.1300	0.00003929	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	1988	2000	560	999	0.5100	0.00000271	0.4690	0.00000249	0.5100	0.00002271	10.9561	0.00018238	0.0720	0.0	3.6200	0.00007174	0.9100	0.00001502	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2000	2006	560	999	0.2000	0.00001067	0.1840	0.00000982	0.2000	0.00001067	8.3800	0.00013947	0.0720	0.0	1.2300	0.00002441	0.4300	0.00001502	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2006	2007	560	999	0.1600	0.00000873	0.1470	0.00000803	0.1600	0.00000873	6.6381	0.00009843	0.0720	0.0	1.2300	0.00002441	0.2548	0.00002615	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2007	2008	560	999	0.1500	0.00000809	0.1380	0.00000744	0.1500	0.00000809	6.0480	0.00008475	0.0720	0.0	1.2300	0.00002441	0.1900	0.00002977	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2008	2010	560	999	0.1500	0.00000776	0.1380	0.00000714	0.1500	0.00000776	5.7500	0.00007791	0.0720	0.0	1.2300	0.00002441	0.1600	0.00003165	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2010	2011	560	999	0.1475	0.00000744	0.1360	0.00000685	0.1475	0.00000744	5.4714	0.00007107	0.0720	0.0	1.2300	0.00002441	0.1300	0.00003353	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2011	2015	560	999	0.0800	0.00000373	0.0740	0.00000343	0.0800	0.00000373	3.1600	0.00004104	0.0720	0.0	1.2300	0.00002441	0.1300	0.00003353	762	0.0	0.0210	0.0	0.0480	0.0
Diesel	2015	2040	560	999	0.0268	0.00000149	0.0250	0.00000137	0.0268	0.00000149	3.1600	0.00004104	0.0720	0.0	1.2300	0.00002441	0.0671	0.00001569	762	0.0	0.0210	0.0	0.0480	0.0
Gasoline	0	1996	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	10.7400	0.00010000	0.0100	0.0	120.5600	0.00740000	5.0400	0.00060000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	1996	2001	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	10.7400	0.00010000	0.0100	0.0	120.5600	0.00740000	5.0400	0.00060000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	2001	2002	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	9.2700	0.00020000	0.0100	0.0	104.7200	0.02700000	3.9700	0.00050000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	2002	2003	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	7.4000	0.00040000	0.0100	0.0	109.6700	0.02640000	3.1400	0.00050000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	2003	2004	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	6.0600	0.00050000	0.0100	0.0	95.2500	0.02590000	2.1700	0.00040000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	2004	2007	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	1.7800	0.00060000	0.0100	0.0	51.2100	0.02550000	0.9500	0.00020000	1050	0.0	0.0340	0.0	0.0760	0.0

Engine Type	Engine Year min	max	Power (kW) min	max	PM ZH	PM DR	PM₂.₅ ZH	PM₂.₅ DR	DPM ZH	DPM DR	NOₓ ZH	NOₓ DR	SO₂ ZH	SO₂ DR	CO ZH	CO DR	HC ZH	HC DR	CO₂ ZH	CO₂ DR	N₂O ZH	N₂O DR	CH₄ ZH	CH₄ DR
Gasoline	2007	2010	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	2.2000	0.00020000	0.0100	0.0	12.7900	0.00370000	0.7000	0.00070000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	2010	2050	0	38	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	1.3000	0.00020000	0.0100	0.0	12.7900	0.00660000	0.5900	0.00060000	1050	0.0	0.0340	0.0	0.0760	0.0
Gasoline	0	1996	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	15.8800	0.00010000	0.0100	0.0	58.7400	0.00390000	3.5300	0.00040000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	1996	2001	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	15.8800	0.00010000	0.0100	0.0	58.7400	0.00390000	3.5300	0.00040000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2001	2002	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	12.8500	0.00020000	0.0100	0.0	55.0900	0.00540000	2.7900	0.00030000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2002	2003	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	9.8200	0.00040000	0.0100	0.0	53.2700	0.00610000	2.0700	0.00030000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2003	2004	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	6.7900	0.00050000	0.0100	0.0	51.4400	0.00680000	1.3300	0.00030000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2004	2007	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	2.3900	0.00030000	0.0100	0.0	11.7500	0.00760000	0.3500	0.00010000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2007	2010	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	1.5700	0.00010000	0.0100	0.0	3.1800	0.00010000	0.1700	0.00010000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2010	2050	38	90	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	0.4700	0.00000000	0.0100	0.0	3.1800	0.00350000	0.0400	0.00000000	1039	0.0	0.0270	0.0	0.0600	0.0
Gasoline	0	1996	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	17.3500	0.00020000	0.0100	0.0	27.8900	0.00110000	2.1600	0.00010000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	1996	2001	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	17.3500	0.00020000	0.0100	0.0	27.8900	0.00110000	2.1600	0.00010000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2001	2002	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	13.8000	0.00010000	0.0100	0.0	27.8900	0.00110000	1.7800	0.00010000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2002	2003	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	10.2500	0.00010000	0.0100	0.0	27.8900	0.00110000	1.4200	0.00010000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2003	2004	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	6.6800	0.00010000	0.0100	0.0	27.8900	0.00110000	1.0500	0.00000000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2004	2007	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	2.6000	0.00040000	0.0100	0.0	27.8900	0.00110000	0.2100	0.00010000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2007	2010	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	1.5700	0.00010000	0.0100	0.0	3.1800	0.00000000	0.1700	0.00010000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2010	2050	90	131	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	0.4700	0.00000000	0.0100	0.0	3.1800	0.00350000	0.0400	0.00000000	1010	0.0	0.0270	0.0	0.0600	0.0
Gasoline	0	1996	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	17.3500	0.00020000	0.0100	0.0	27.8900	0.00110000	2.1600	0.00010000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	1996	2001	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	17.3500	0.00020000	0.0100	0.0	27.8900	0.00110000	2.1600	0.00010000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2001	2002	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	13.8000	0.00010000	0.0100	0.0	27.8900	0.00110000	1.7800	0.00010000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2002	2003	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	10.2500	0.00010000	0.0100	0.0	27.8900	0.00110000	1.4200	0.00010000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2003	2004	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	6.6800	0.00010000	0.0100	0.0	27.8900	0.00110000	1.0500	0.00000000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2004	2007	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	2.6000	0.00040000	0.0100	0.0	27.8900	0.00110000	0.2100	0.00010000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2007	2010	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	1.5700	0.00010000	0.0100	0.0	3.1800	0.00000000	0.1700	0.00010000	982	0.0	0.0270	0.0	0.0600	0.0
Gasoline	2010	2050	131	9999	0.0800	0.00000000	0.0700	0.00000000	0.0000	0.00000000	0.4700	0.00000000	0.0100	0.0	3.1800	0.00350000	0.0400	0.00000000	982	0.0	0.0270	0.0	0.0600	0.0
LNG	2004	2007	0	999	0.0000	0.00000000	0.0000	0.00000000	0.0000	0.00000000	3.5500	0.00000000	0.0000	0.0	0.0900	0.00000000	2.9400	0.00000000	662	0.0	0.0000	0.0	0.0000	0.0
On Road Diesel	0	1970	76	131	0.7228	0.00005257	0.6650	0.00004836	0.7228	0.00005257	8.2607	0.00019118	0.0800	0.0	5.9005	0.00015556	0.5841	0.00002704	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1970	1972	76	131	0.6196	0.00004506	0.5700	0.00004145	0.6196	0.00004506	7.6706	0.00017760	0.0800	0.0	5.9005	0.00015556	0.4868	0.00002253	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1972	1979	76	131	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	7.0806	0.00016403	0.0800	0.0	5.9005	0.00015556	0.4425	0.00002049	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1979	1980	76	131	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	7.0806	0.00016403	0.0800	0.0	5.9005	0.00015556	0.4425	0.00002049	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1980	1985	76	131	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	6.4905	0.00014987	0.0800	0.0	5.7664	0.00015288	0.4160	0.00001925	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1985	1988	76	131	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	6.4905	0.00014987	0.0800	0.0	5.6323	0.00014885	0.3894	0.00001801	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1988	1997	76	131	0.3567	0.00002591	0.3280	0.00002384	0.3567	0.00002591	4.8207	0.00011152	0.0800	0.0	3.6208	0.00009575	0.3009	0.00001394	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1997	2003	76	131	0.3567	0.00002591	0.3280	0.00002384	0.3567	0.00002591	4.0713	0.00009441	0.0800	0.0	3.6208	0.00009575	0.3009	0.00001394	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2003	2004	76	131	0.2253	0.00001596	0.2070	0.00001468	0.2253	0.00001596	3.1037	0.00005688	0.0800	0.0	3.6208	0.00009575	0.1460	0.00001235	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2004	2005	76	131	0.1784	0.00001267	0.1640	0.00001166	0.1784	0.00001267	2.7850	0.00004437	0.0800	0.0	3.6208	0.00009575	0.0974	0.00001164	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2005	2007	76	131	0.1502	0.00001108	0.1380	0.00001019	0.1502	0.00001108	2.6198	0.00003812	0.0800	0.0	3.6208	0.00009575	0.0708	0.00001137	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2007	2012	76	131	0.0131	0.00000094	0.0120	0.00000086	0.0131	0.00000094	1.3799	0.00001802	0.0800	0.0	3.6208	0.00009575	0.0443	0.00001106	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2012	2015	76	131	0.0090	0.00000042	0.0080	0.00000039	0.0090	0.00000042	0.3957	0.00000516	0.0800	0.0	3.6208	0.00009575	0.0398	0.00000960	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2015	2040	76	131	0.0090	0.00000042	0.0080	0.00000039	0.0090	0.00000042	0.2426	0.00000320	0.0800	0.0	3.6208	0.00009575	0.0221	0.00000518	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	0	1970	131	224	0.7228	0.00005257	0.6650	0.00004836	0.7228	0.00005257	8.2607	0.00019118	0.0800	0.0	5.9005	0.00015556	0.5841	0.00002704	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1970	1972	131	224	0.6196	0.00004506	0.5700	0.00004145	0.6196	0.00004506	7.6706	0.00017760	0.0800	0.0	5.9005	0.00015556	0.4868	0.00002253	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1972	1979	131	224	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	7.0806	0.00016403	0.0800	0.0	5.9005	0.00015556	0.4425	0.00002049	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1979	1980	131	224	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	7.0806	0.00016403	0.0800	0.0	5.9005	0.00015556	0.4425	0.00002049	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1980	1985	131	224	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	6.4905	0.00014987	0.0800	0.0	5.7664	0.00015288	0.4160	0.00001925	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1985	1988	131	224	0.5163	0.00003755	0.4750	0.00003454	0.5163	0.00003755	6.4905	0.00014987	0.0800	0.0	5.6323	0.00014885	0.3894	0.00001801	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1988	1996	131	224	0.3567	0.00002591	0.3280	0.00002384	0.3567	0.00002591	4.8207	0.00011152	0.0800	0.0	3.6208	0.00009575	0.3009	0.00001394	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1996	1997	131	224	0.1408	0.00000747	0.1300	0.00000687	0.1408	0.00000747	3.6878	0.00008556	0.0800	0.0	1.2337	0.00003259	0.1416	0.00000655	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	1997	2003	131	224	0.1408	0.00000747	0.1300	0.00000687	0.1408	0.00000747	3.6878	0.00008556	0.0800	0.0	1.2337	0.00003259	0.1416	0.00000655	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2003	2004	131	224	0.1126	0.00000611	0.1040	0.00000562	0.1126	0.00000611	2.9502	0.00005340	0.0800	0.0	1.2337	0.00003259	0.0841	0.00000925	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2004	2005	131	224	0.1033	0.00000566	0.0950	0.00000521	0.1033	0.00000566	2.7024	0.00004266	0.0800	0.0	1.2337	0.00003259	0.0620	0.00001018	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2005	2007	131	224	0.1033	0.00000544	0.0950	0.00000500	0.1033	0.00000544	2.5844	0.00003735	0.0800	0.0	1.2337	0.00003259	0.0531	0.00001062	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2007	2011	131	224	0.0103	0.00000052	0.0090	0.00000048	0.0103	0.00000052	1.3799	0.00001791	0.0800	0.0	1.2337	0.00003259	0.0443	0.00001106	762	0.0	0.0106	0.0	0.0175	0.0

Engine Type	Engine Year		Power (kW)		Zero Hour Emission Factor (g/kW-hr) and Deterioration Rate (gm/kW-hr²)																	
	min	max	min	max	PM ZH	PM DR	PM₂.₅ ZH	PM₂.₅ DR	DPM ZH	DPM DR	NOₓ ZH	NOₓ DR	SO₂ ZH	SO₂ DR	CO ZH	CO DR	HC ZH	HC DR	CO₂ ZH	CO₂ DR	N₂O ZH	N₂O DR	CH₄ ZH	CH₄ DR
On Road Diesel	2011	2014	131	224	0.0090	0.00000033	0.0080	0.00000031	0.0090	0.00000033	0.2371	0.00000309	0.0800	0.0	1.2337	0.00003259	0.0310	0.00000810	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	2014	2040	131	224	0.0090	0.00000033	0.0080	0.00000031	0.0090	0.00000033	0.2426	0.00000320	0.0800	0.0	1.2337	0.00003259	0.0221	0.00000518	762	0.0	0.0106	0.0	0.0175	0.0
On Road Diesel	0	1970	224	448	0.6946	0.00003689	0.6390	0.00003394	0.6946	0.00003689	8.2607	0.00013748	0.0700	0.0	5.6323	0.00111573	0.5576	0.00001943	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1970	1972	224	448	0.5914	0.00003135	0.5440	0.00002884	0.5914	0.00003135	7.6706	0.00012745	0.0700	0.0	5.6323	0.00111573	0.4647	0.00001620	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1972	1979	224	448	0.4975	0.00002638	0.4580	0.00002427	0.4975	0.00002638	7.0806	0.00011801	0.0700	0.0	5.6323	0.00111573	0.4204	0.00001465	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1979	1980	224	448	0.4975	0.00002638	0.4580	0.00002427	0.4975	0.00002638	7.0806	0.00011801	0.0700	0.0	5.6323	0.00111573	0.4204	0.00001465	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1980	1985	224	448	0.4975	0.00002638	0.4580	0.00002427	0.4975	0.00002638	6.4905	0.00010798	0.0700	0.0	5.6323	0.00111573	0.3983	0.00001390	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1985	1988	224	448	0.4975	0.00002638	0.4580	0.00002427	0.4975	0.00002638	6.4905	0.00010798	0.0700	0.0	5.4982	0.00108891	0.3717	0.00001297	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1988	1996	224	448	0.3567	0.00001896	0.3280	0.00001745	0.3567	0.00001896	4.8207	0.00008025	0.0700	0.0	3.6208	0.00007174	0.3009	0.00001049	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1996	1997	224	448	0.1408	0.00000747	0.1300	0.00000687	0.1408	0.00000747	3.6878	0.00006137	0.0700	0.0	1.2337	0.00002441	0.1416	0.00000496	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	1997	2001	224	448	0.1408	0.00000747	0.1300	0.00000687	0.1408	0.00000747	3.6878	0.00006137	0.0700	0.0	1.2337	0.00002441	0.1416	0.00000496	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2001	2002	224	448	0.1126	0.00000611	0.1040	0.00000562	0.1126	0.00000611	2.9207	0.00004331	0.0700	0.0	1.2337	0.00002441	0.0841	0.00000863	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2002	2003	224	448	0.1033	0.00000566	0.0950	0.00000521	0.1033	0.00000566	2.6611	0.00003729	0.0700	0.0	1.2337	0.00002441	0.0620	0.00000982	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2003	2005	224	448	0.1033	0.00000544	0.0950	0.00000500	0.1033	0.00000544	2.5313	0.00003428	0.0700	0.0	1.2337	0.00002441	0.0531	0.00001044	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2005	2006	224	448	0.1033	0.00000521	0.0950	0.00000479	0.1033	0.00000521	2.3602	0.00003127	0.0700	0.0	1.2337	0.00002441	0.0443	0.00001106	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2006	2011	224	448	0.1033	0.00000521	0.0950	0.00000479	0.1033	0.00000521	2.2670	0.00002942	0.0700	0.0	1.2337	0.00002441	0.0443	0.00001106	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2011	2014	224	448	0.0090	0.00000033	0.0080	0.00000031	0.0090	0.00000033	0.2371	0.00000309	0.0700	0.0	1.2337	0.00002441	0.0310	0.00000810	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	2014	2040	224	448	0.0090	0.00000033	0.0080	0.00000031	0.0090	0.00000033	0.2426	0.00000320	0.0700	0.0	1.2337	0.00002441	0.0221	0.00000518	762	0.0	0.0088	0.0	0.0155	0.0
On Road Diesel	0	1970	448	560	0.6944	0.00003697	0.6390	0.00003401	0.6944	0.00003697	8.2574	0.00013743	0.0700	0.0	5.6300	0.00111573	0.5574	0.00001942	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1970	1972	448	560	0.5912	0.00003152	0.5440	0.00002900	0.5912	0.00003152	7.6676	0.00013802	0.0700	0.0	5.6300	0.00111573	0.4645	0.00001617	762	0.0	0.0100	0.0	0.0158	0.0
On Road Diesel	1972	1979	448	560	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	7.0777	0.00011796	0.0700	0.0	5.6300	0.00111573	0.4202	0.00001469	762	0.0	0.0092	0.0	0.0159	0.0
On Road Diesel	1979	1980	448	560	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	7.0777	0.00011796	0.0700	0.0	5.6300	0.00111573	0.4202	0.00001469	762	0.0	0.0092	0.0	0.0159	0.0
On Road Diesel	1980	1985	448	560	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	6.4879	0.00010794	0.0700	0.0	5.6300	0.00111573	0.3981	0.00001385	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1985	1988	448	560	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	6.4879	0.00010794	0.0700	0.0	5.4900	0.00108729	0.3716	0.00001292	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1988	1996	448	560	0.3566	0.00001896	0.3280	0.00001744	0.3566	0.00001896	4.8188	0.00008022	0.0700	0.0	3.6200	0.00007174	0.3008	0.00001048	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1996	1999	448	560	0.1408	0.00000751	0.1300	0.00000691	0.1408	0.00000751	3.6863	0.00006135	0.0700	0.0	1.2300	0.00002441	0.1416	0.00000496	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1999	2002	448	560	0.1408	0.00000751	0.1300	0.00000691	0.1408	0.00000751	3.6863	0.00006135	0.0700	0.0	1.2300	0.00002441	0.1416	0.00000495	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	2002	2003	448	560	0.1126	0.00000614	0.1040	0.00000565	0.1126	0.00000614	2.9196	0.00004329	0.0700	0.0	1.2300	0.00002441	0.0840	0.00000862	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	2003	2004	448	560	0.1032	0.00000556	0.0950	0.00000512	0.1032	0.00000556	2.6601	0.00003728	0.0700	0.0	1.2300	0.00002441	0.0619	0.00000970	762	0.0	0.0092	0.0	0.0156	0.0
On Road Diesel	2004	2006	448	560	0.1032	0.00000534	0.0950	0.00000491	0.1032	0.00000534	2.5303	0.00003429	0.0700	0.0	1.2300	0.00002441	0.0531	0.00001050	762	0.0	0.0092	0.0	0.0159	0.0
On Road Diesel	2006	2011	448	560	0.1032	0.00000512	0.0950	0.00000471	0.1032	0.00000512	1.4450	0.00001876	0.0700	0.0	1.2300	0.00002441	0.0442	0.00001140	762	0.0	0.0092	0.0	0.0163	0.0
On Road Diesel	2011	2014	448	560	0.0099	0.00000037	0.0090	0.00000034	0.0099	0.00000037	1.4450	0.00001881	0.0700	0.0	1.2300	0.00002441	0.0310	0.00000810	762	0.0	0.0166	0.0	0.0159	0.0
On Road Diesel	2014	2040	448	560	0.0099	0.00000037	0.0090	0.00000034	0.0099	0.00000037	1.4450	0.00001905	0.0700	0.0	1.2300	0.00002441	0.0221	0.00000517	762	0.0	0.0838	0.0	0.0158	0.0
On Road Diesel	0	1970	560	999	0.6944	0.00003697	0.6390	0.00003401	0.6944	0.00003697	8.2574	0.00013743	0.0720	0.0	5.6300	0.00111573	0.5574	0.00001942	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1970	1972	560	999	0.5912	0.00003152	0.5440	0.00002900	0.5912	0.00003152	7.6676	0.00012740	0.0720	0.0	5.6300	0.00111573	0.4645	0.00001617	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1972	1979	560	999	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	7.0777	0.00011796	0.0720	0.0	5.6300	0.00111573	0.4202	0.00001469	762	0.0	0.0092	0.0	0.0159	0.0
On Road Diesel	1979	1980	560	999	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	7.0777	0.00011796	0.0720	0.0	5.6300	0.00111573	0.4202	0.00001469	762	0.0	0.0092	0.0	0.0159	0.0
On Road Diesel	1980	1985	560	999	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	6.4879	0.00010794	0.0720	0.0	5.6300	0.00111573	0.3981	0.00001385	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1985	1988	560	999	0.4973	0.00002639	0.4580	0.00002428	0.4973	0.00002639	6.4879	0.00010794	0.0720	0.0	5.4900	0.00108729	0.3716	0.00001292	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	1988	2000	560	999	0.3566	0.00000189	0.3280	0.00000174	0.3566	0.00000189	4.8188	0.00008022	0.0720	0.0	3.6200	0.00007174	0.3008	0.00000496	762	0.0	0.0092	0.0	0.0159	0.0
On Road Diesel	2000	2006	560	999	0.1408	0.00000751	0.1300	0.00000691	0.1408	0.00000751	3.6863	0.00006135	0.0720	0.0	1.2300	0.00002441	0.1416	0.00000495	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	2006	2007	560	999	0.1126	0.00000614	0.1040	0.00000565	0.1126	0.00000614	2.9196	0.00004329	0.0720	0.0	1.2300	0.00002441	0.0840	0.00000862	762	0.0	0.0092	0.0	0.0158	0.0
On Road Diesel	2007	2008	560	999	0.0099	0.00000053	0.0090	0.00000049	0.0099	0.00000053	1.5477	0.00002169	0.0720	0.0	1.2300	0.00002441	0.0619	0.00000970	762	0.0	0.0054	0.0	0.0156	0.0
On Road Diesel	2008	2010	560	999	0.0099	0.00000051	0.0090	0.00000047	0.0099	0.00000051	1.4722	0.00001995	0.0720	0.0	1.2300	0.00002441	0.0531	0.00001050	762	0.0	0.0054	0.0	0.0159	0.0
On Road Diesel	2010	2011	560	999	0.0099	0.00000050	0.0090	0.00000046	0.0099	0.00000046	0.2352	0.00000306	0.0720	0.0	1.2300	0.00002441	0.0442	0.00001140	762	0.0	0.0009	0.0	0.0163	0.0
On Road Diesel	2011	2015	560	999	0.0099	0.00000046	0.0090	0.00000042	0.0099	0.00000046	0.2352	0.00000305	0.0720	0.0	1.2300	0.00002441	0.0442	0.00001140	762	0.0	0.0016	0.0	0.0163	0.0
On Road Diesel	2015	2040	560	999	0.0038	0.00000021	0.0030	0.00000019	0.0038	0.00000021	0.2352	0.00000305	0.0720	0.0	1.2300	0.00002441	0.0221	0.00000517	762	0.0	0.0016	0.0	0.0158	0.0
On Road LNG	2007	2010	0	999	0.0000	0.00000000	0.0000	0.00000000	0.0000	0.00000000	2.1300	0.00000000	0.0000	0.0	0.0900	0.00000000	2.9400	0.00000000	662	0.0	0.0000	0.0	0.0000	0.0
On Road LNG	2010	2040	0	999	0.0000	0.00000000	0.0000	0.00000000	0.0000	0.00000000	0.3550	0.00000000	0.0000	0.0	0.0900	0.00000000	2.9400	0.00000000	662	0.0	0.0000	0.0	0.0000	0.0
Propane	0	1983	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	17.4300	0.00009000	0.0000	0.0	9.4100	0.00064000	1.8500	0.00020000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1983	1984	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	17.4300	0.00009000	0.0000	0.0	9.4100	0.00064000	1.8500	0.00020000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1984	2001	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	17.4300	0.00009000	0.0000	0.0	9.4100	0.00064000	1.8500	0.00020000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2001	2002	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	13.9500	0.00021000	0.0000	0.0	9.4100	0.00064000	1.5600	0.00021000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2002	2003	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	10.4500	0.00033000	0.0000	0.0	9.4100	0.00064000	1.2500	0.00022000	905	0.0	0.0000	0.0	0.0000	0.0

Engine Type	Engine Year min	max	Engine Power (kW) min	max	PM ZH	PM DR	PM$_{2.5}$ ZH	PM$_{2.5}$ DR	DPM ZH	DPM DR	NO$_x$ ZH	NO$_x$ DR	SO$_2$ ZH	SO$_2$ DR	CO ZH	CO DR	HC ZH	HC DR	CO$_2$ ZH	CO$_2$ DR	N$_2$O ZH	N$_2$O DR	CH$_4$ ZH	CH$_4$ DR
Propane	2003	2004	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	6.9600	0.00045000	0.0000	0.0	9.4100	0.00064000	0.9500	0.00023000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2004	2007	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	2.6100	0.00037000	0.0000	0.0	9.4100	0.00064000	0.1900	0.00014000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2007	2010	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	2.3300	0.00093000	0.0000	0.0	3.1800	0.00002000	0.1500	0.00008000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2010	2050	0	38	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	1.5300	0.00095000	0.0000	0.0	9.4100	0.00064000	0.0700	0.00004000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	0	1983	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.1200	0.00007000	0.0000	0.0	26.4400	0.00180000	2.0800	0.00023000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1983	1984	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.1200	0.00007000	0.0000	0.0	26.4400	0.00180000	2.0800	0.00023000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1984	2001	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.1200	0.00007000	0.0000	0.0	26.4400	0.00180000	2.0800	0.00023000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2001	2002	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	11.4500	0.00020000	0.0000	0.0	26.4400	0.00180000	1.7200	0.00023000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2002	2003	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	8.8000	0.00032000	0.0000	0.0	26.4400	0.00180000	1.3700	0.00023000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2003	2004	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	6.1300	0.00044000	0.0000	0.0	26.4400	0.00180000	1.0100	0.00024000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2004	2007	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	2.1200	0.00047000	0.0000	0.0	26.4400	0.00180000	0.2100	0.00014000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2007	2010	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	1.3900	0.00002000	0.0000	0.0	3.1800	0.00002000	0.1300	0.00006000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2010	2050	38	91	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	0.4200	0.00005000	0.0000	0.0	3.1800	0.00349000	0.0400	0.00002000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	0	1983	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1983	1984	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1984	2001	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2001	2002	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	11.4400	0.00012000	0.0000	0.0	22.0900	0.00116000	1.5600	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2002	2003	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	8.7700	0.00010000	0.0000	0.0	22.0900	0.00116000	1.2600	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2003	2004	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	6.1200	0.00009000	0.0000	0.0	22.0900	0.00116000	0.9500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2004	2007	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	2.1200	0.00035000	0.0000	0.0	22.0900	0.00116000	0.1900	0.00014000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2007	2010	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	1.3900	0.00002000	0.0000	0.0	3.1800	0.00002000	0.1300	0.00006000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2010	2050	91	131	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	0.4200	0.00005000	0.0000	0.0	3.1800	0.00349000	0.0400	0.00002000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	0	1983	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1983	1984	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1984	2001	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2001	2002	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	11.4400	0.00012000	0.0000	0.0	22.0900	0.00116000	1.5600	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2002	2003	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	8.7700	0.00010000	0.0000	0.0	22.0900	0.00116000	1.2600	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2003	2004	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	6.1200	0.00009000	0.0000	0.0	22.0900	0.00116000	0.9500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2004	2007	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	2.1200	0.00035000	0.0000	0.0	22.0900	0.00116000	0.1900	0.00014000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2007	2010	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	1.3900	0.00002000	0.0000	0.0	3.1800	0.00002000	0.1300	0.00006000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2010	2050	131	187	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	0.4200	0.00005000	0.0000	0.0	3.1800	0.00349000	0.0400	0.00002000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	0	1983	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1983	1984	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	1984	2001	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	14.0900	0.00014000	0.0000	0.0	22.0900	0.00116000	1.8500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2001	2002	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	11.4400	0.00012000	0.0000	0.0	22.0900	0.00116000	1.5600	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2002	2003	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	8.7700	0.00010000	0.0000	0.0	22.0900	0.00116000	1.2600	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2003	2004	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	6.1200	0.00009000	0.0000	0.0	22.0900	0.00116000	0.9500	0.00005000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2004	2007	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	2.1200	0.00035000	0.0000	0.0	22.0900	0.00116000	0.1900	0.00014000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2007	2010	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	1.3900	0.00002000	0.0000	0.0	3.1800	0.00002000	0.1300	0.00006000	905	0.0	0.0000	0.0	0.0000	0.0
Propane	2010	2050	187	999	0.0800	0.00000000	0.0800	0.00000000	0.0000	0.00000000	0.4200	0.00005000	0.0000	0.0	3.1800	0.00349000	0.0400	0.00002000	905	0.0	0.0000	0.0	0.0000	0.0

Zero Hour Emission Factor (g/kW-hr) and Deterioration Rate (gm/kW-hr^2)