Port of Oakland
2017 Seaport Air Emissions Inventory
Final Report

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GLOSSARY

AIS (Automatic Identification System): A U.S. Coast Guard system for managing vessel traffic that provides data on vessel location, speed, heading, and other identifying information via automated radio links.

AMP (Alternative Maritime Power): A source of electrical power (typically from the local electrical grid) available to vessels while at berth which eliminates the need to run on-board generators powered by the vessel's auxiliary engines; also known as shore power or "cold ironing".

Adjustment factors: Used to adjust emissions or engine load or other situations for non-standard conditions.

ARB (Air Resources Board): California Air Resources Board, the state of California's regulatory agency for air pollution (see also CARB).

Assist mode: Period when a tugboat is engaged in assisting a ship to/from the harbor and to/from its berth.

Auxiliary engine: Used to drive on-board electrical generators to provide electric power or to operate equipment on board the vessel.

Auxiliary power: Electric power generated via the auxiliary engines or supplied by shore power and used for non-propulsion equipment.

Barge: A flat-bottomed craft built mainly for water transport of heavy goods and, in this report, dredged material. Most barges are not self-propelled and need to be moved by tugboats towing or towboats pushing them.

Buoy: Sea Buoy, North ('November'), South ('Sierra'), and West ('Whiskey') used to designate shipping lanes to enter the San Francisco Bay.

Bollard pull class: A power measure of the tug's capacity to push or pull ships.

BSFC (Brake-Specific Fuel Consumption): This is the measure of the engines efficiency in terms of the fuel consumption rate (weight of fuel burned per hour) divided by the engine load or output (e.g. kilowatts). For marine engines, a different term, standard fuel oil consumption (SFOC), is sometimes used to describe the identical efficiency measure.

CARB (California Air Resources Board): California Air Resources Board, the state of California's regulatory agency for air pollution (see also ARB).

CHE (Cargo Handling Equipment): Equipment used to transfer cargo or containers. Cargo handling equipment is used to move containers from one mode of transportation to another (e.g. from a storage area to a truck chassis) or to reposition containers within a marine terminal or rail yard. Typical cargo handling equipment at the Port of Oakland include yard trucks, RTG cranes, top and side picks, forklifts, and other general industrial equipment.

Clamshell dredge: Equipment used to scoop, lift, and release sediment from berths and channels. It hangs from an onboard crane, or is carried by a hydraulic arm, or is mounted like on a dragline.

CH_4: methane. It is a hydrocarbon species that has a global warming potential.

CO: carbon monoxide

CO_2: carbon dioxide

CO_2e: greenhouse gas carbon dioxide equivalent, a metric used to estimate combined emissions of various greenhouse gases based upon their global warming potential relative to carbon dioxide.

CO: carbon monoxide.

Cruise modes: The vessel operation while traveling in the open ocean or in an area without speed restrictions.

DWT (Dead Weight Tonnage): Weight of the ship, all her stores and fuel, pumps and boilers, crew's quarters with crew and the cargo. In other words, the amount of water the vessel displaces when fully loaded.

Deep draft marine vessel: Deep draft vessels are larger vessels typically with draft in excess of 14 feet measured at the highest waterline and the bottom of the vessel. Other works describe this type of vessel as only Ocean-Going Vessels (OGV), but deep draft is used in this report to distinguish and avoid confusion between these larger vessels and smaller ocean-going tugs, supply vessels, and fishing vessels that could also be considered "ocean-going vessels."

DPF (Diesel Particulate Filter): filters or traps used to filter particulate matter from engine exhaust.

DPM (Diesel Particulate Matter): particulate matter of all sizes present in diesel engine exhaust

Drayage Truck: An on-road truck used to transport marine and rail intermodal freight (primarily shipping containers) to and from terminals.

Dredging: An excavation activity or operation carried out underwater typically for the purpose of the removal of accreted materials or sediments from the bottom of channels and berths to allow vessels with deep drafts.

ECA (Emission Control Area): Coastal region within which enhanced restrictions on vessel emissions as determined by the International Maritime Organization apply.

Emission estimation: Method by which the quantity of a particular pollutant emission is estimated.

Emission factor: The average emission rate of a given pollutant for a given source, relative to a unit of activity. For example, grams per kilowatt of actual power or grams per hour of engine operation.

Emissions inventory: A listing of all the pollutant emissions included in the study.

g/kW-hr: This is the unit for reporting emission or fuel consumption factors, and means the grams per kilowatt-hour of work performed. Work and energy are used synonymously in this context.

GGB: Golden Gate Bridge

GHG (Greenhouse Gas): includes CO_2, methane (CH_4), and nitrous oxide (N_2O).

G&T (Generation and Transmission): electricity generation and transmission.

GWP (**Global Warming Potential):** A measure of the relative greenhouse gas effect of a specific GHG such as methane as compared to CO_2.

Harbor Craft: Tug boats and other smaller vessels used for support operations

HC: hydrocarbon emissions

Hotelling: On-board activities while a ship is in port and at its berth with similar electrical and other demands when anchored nearby.

IMO (International Maritime Organization): An agency of the United Nations responsible for regulating international shipping.

Installed power: The engine power available on the vessel. The term most often refers only to the propulsion power available on the vessel, but could incorporate auxiliary engine power as well.

Intermodal site: Terminal or site where cargo is transferred from one form of transportation to another, for example between trucks and an ocean-going vessel or a railroad car.

Knot: A nautical unit of speed meaning one nautical mile per hour and is equal to about 1.15 statute miles per hour.

Lift: Movement of a shipping container (box) on or off a vessel, truck, or rail car.

Link: A defined portion of a vessel's, train's, or truck's travel. For example, a link was established extending from the November Buoy to the location where the pilot boards the vessel. A series of links defines all of the movements within a defined area or a trip.

LOA (Length Overall): total length of a vessel from bow to stern.

Load: The actual power output of the vessel's engines or generator. The load is typically the rated maximum power of the engine multiplied by the load factor if not measured directly.

Load factor: Average engine load expressed as a fraction or percentage of rated power.

LPG (Liquid Petroleum Gas): a hydrocarbon fuel which may contain one or more hydrocarbons (propane, butane, isobutane) that is held under pressure to keep it liquid.

MAQIP: Port's Maritime Air Quality Improvement Plan[1]

Maximum power: A power rating usually provided by the engine manufacturer that states the maximum continuous power available for an engine.

Medium speed engine: A 4-stroke engine used for auxiliary power and rarely, for propulsion. Medium speed engines typically have rated speeds of greater than 250 revolutions per minute.

Mode: Defines a specific set of activities, for example, a tug's transit mode includes travel time to/from a port berth while escorting a vessel.

NOx: nitrogen oxides. Includes all types of nitrogen oxide compounds.

[1] http://www.portofoakland.com/community/environmental-stewardship/maritime-air-quality-improvement-plan/

N_2O: nitrous oxide. A nitrogen oxide that has a global warming potential.

OAB (Oakland Army Base): The Port area formerly operated as the Oakland Army Base.

OIG (Oakland Intermodal Gateway): railyard operated by BNSF Railway.

OGV (Ocean-Going Vessel): Vessels equipped for travel across the open oceans. These do not include the vessels used exclusively in the harbor, which are covered in this report under commercial harbor craft. In this report OGV are restricted to the deep draft vessels that carry containers.

Off-Road activity: Activity that occurs off of established roadways. Activity within a marine terminal yard is considered off-road activity.

OGRE (Oakland Global Rail Enterprise): operator of the Outer Harbor Intermodal Terminal

OHIT (Outer Harbor Intermodal Terminal): railyard operated by Oakland Global Rail Enterprise

OICT (Oakland International Container Terminal): Marine terminal containing Berths 55 through 59

On-road activity: Activity that occurs on established roadways.

Operation mode: the current mode of operation for a ship – cruise, reduced speed zone (RSZ), maneuver, or berth.

O&M: Operation and Maintenance.

PM_{10}: particulate matter emissions less than 10 micrometers in diameter.

$PM_{2.5}$: particulate matter emissions less than 2.5 micrometers in diameter, and a subset of PM_{10}.

Port of Call: A specified port where a ship docks.

Port berth: A location in a port or harbor used specifically for mooring vessels.

Propulsion engine: Shipboard engine used to propel the ship.

Propulsion power demand: Power used to drive the propeller and the ship.

Rated power: A guideline set by the manufacturer as a maximum power that the engine can produce continuously.

Reefer plug: Plug allowing a refrigerator container to plug into an outlet connected to the ship's power generation or the landside grid.

RNA (Regulated Navigation Area): a portion of navigable waters for which the U.S. Coast Guard regional District Commander has established special rules (typically speed limits).

ROG (Reactive Organic Gases): all hydrocarbon compounds that participate in the production of ozone (smog); includes HC plus aldehyde and alcohol compounds except methane.

Roll-on/roll-off (RORO) vessels: Ships designed to carry wheeled cargo such as automobiles, trailers, or railway carriages that drive or are pulled onto the vessels.

RSZ (Reduced Speed Zone): Area of OGV travel within prescribed lanes at reduced speeds extending from the Sea Buoy to the Bay Bridge.

RTG (Rubber Tired Gantry) Crane: sometimes called a straddle crane because the crane 'straddles' a row of containers stored in the terminal yard as it drives up and down the row selecting and repositioning containers or loading them onto truck chassis.

Sea (Pilot) Buoy: used to mark a maritime administrative area to allow boats and ships to navigate safely where the Bay pilot boards and disembarks the ship. This location is 10 nautical miles from the Golden Gate and more than 15 nautical miles from the Port.

SFMX (San Francisco Marine Exchange): maritime service organization for the San Francisco Bay Area

Shoaling: Shoaling is term used in this report to describe subsidence of the shore or other filling of the navigation channel near shore.

Shore Power: Electric power supplied to ships while at berth in place of power generated by the ships' on-board auxiliary diesel engines.

SO_2: Sulfur dioxide.

SOx: Oxides of sulfur. Interchangeable term with sulfur dioxide but include some other minor forms of sulfur oxides.

Spatial allocation: Areas on a map allocating a specific set of activities.

Spatial scope: A specified area on a map that defines the area covered in study.

Slow speed engine: Typically a 2-stroke engine or an engine that run below 250 rpms.

SF-DODS (San Francisco Deep Ocean Disposal Site): a location in the Pacific Ocean offshore of San Francisco designated for disposal of dredge spoils.

SFOC (Standard Fuel Oil Consumption): See brake specific fuel consumption (BSFC).

Steam boiler: Boiler used to create steam or hot water using external combustion.

Steam turbines: A mechanical device that extracts thermal energy from pressurized steam, and converts it into useful mechanical work.

STEP (Secure Truck Enrollment Program): Port of Oakland registry for drayage trucks

Survey boat: A small marine vessel used during dredging to survey the berth and channel depths.

Tender: a utility vessel used to service another type of vessel, for example, to service a clamshell dredge.

TEU (Twenty Foot Equivalent Unit): A measure of cargo volume; a 20 foot long container = 1 TEU and a 40 foot long container = 2 TEUs.

THC (Total Hydrocarbon): A category of air pollutant primarily composed of ROG but includes methane and excludes oxygenated compounds such as formaldehyde.

Time in mode: The amount of time a vessel remains in a specified mode, for example the amount of time a ship spends in the reduced speed zone.

Tons: Represents short tons (2,000 lbs) unless otherwise noted.

Tonnes: Metric tons (1,000 kg)

Transit mode: The time a tug spends traveling to/from its berth to the pick-up location.

TRU (Transport Refrigeration Unit): Diesel or gasoline powered refrigeration devices attached to containers or trucks used to cool perishable products; TRUs can also run on electrical power where available, typically while onboard ship and in temporary storage at intermodal container facilities.

Tug class: A tugboat's Bollard pull class designation.

Two-stroke engine: Engine designed so that it completes the four processes of internal combustion (intake, compression, power, exhaust) in only two strokes of the piston.

ULSD: ultra-low sulfur diesel.

USACE: United States Army Corps of Engineers.

VMT (Vehicle Miles Traveled): Miles traveled by vehicles, equal to length of trip times number of vehicle-trips driven.

EXECUTIVE SUMMARY

The Port of Oakland 2017 Seaport Air Emissions Inventory identifies and quantifies air emissions from the Port's maritime activities, organized into six major source categories:

- Deep-Draft Ocean-Going Vessels (OGV),
- Commercial Harbor Craft (dredging and assist tugs),
- Cargo Handling Equipment (CHE),
- Trucks (container movements),
- Locomotives, and
- Other Off-road Equipment.

This is the fourth Seaport Air Emissions Inventory prepared by the Port. The Port's 2005, 2012, and 2015 inventories are available on the Port's website.[2] This calendar year 2017 emissions inventory highlights the Port's continued progress towards meeting its goal of reducing total diesel particulate matter (DPM) emissions 85% and nitrogen oxide (NOx) emissions from on-and near-shore sources 34% below 2005 levels by 2020. This goal is stated in the Port Maritime Air Quality Policy Statement adopted by the Board of Port Commissioners in March 2008.

The purpose of this voluntary inventory is to better understand emissions from maritime-related business activities at the Port and thus allow the Port to better address the related air quality impacts.

Geographic Scope

This is an inventory of the air emissions generated by routine and construction activities occurring at the Port of Oakland seaport during 2017. Most of these activities are conducted by Port tenants, commercial marine vessels, drayage trucks, and locomotives. On the water side, the spatial domain of the inventory includes Port-related marine vessel transits to and from dockside out through the Golden Gate Bridge, to the first outer buoys beyond the Sea Buoy, approximately 30 miles west of the Port. On the landside, the spatial scope of the inventory includes four active marine terminals, two rail yards, several off-dock cargo handling facilities, and on-road truck traffic between those facilities and the nearest freeway interchanges. The Seaport area was defined approximately by the boundaries of I-80, I-880, and Howard Terminal (Berths 67 and 68) adjacent to Jack London Square. Within this defined geographic domain, operations in three areas were specifically excluded: the privately-owned Schnitzer Steel terminal and Union Pacific rail yard, and the City of Oakland's portion of the former Oakland Army Base located along West Burma Road. The remaining portion of the former Oakland Army Base, which is overseen by the Port, is included, including the Outer Harbor Intermodal Terminal (OHIT) and associated distribution facilities located between Maritime Street and

[2] https://www.portofoakland.com/community/environmental-stewardship/seaport-air-emissions-inventory-2005/

I-880. Figures 1-1, 2-1, and 2-2 in the body of the report illustrate the spatial scope of the inventory.

Pollutants

Emission estimates are reported in tons per year for five "criteria" air pollutants which are regulated by the U.S. Environmental Protection Agency and the California Air Resources Board:

- Reactive organic gases (ROG) which are closely related to volatile organic compounds (VOCs),
- Carbon monoxide (CO),
- Nitrogen oxides (NOx),
- Particulate matter (PM) including diesel particulate matter (DPM), and
- Sulfur oxides (SOx).

PM emissions are reported in two size ranges: PM_{10} (particles with aerodynamic diameter 10 µm or less) and $PM_{2.5}$ (particles with aerodynamic diameter 2.5 µm or less). $PM_{2.5}$ particles take longer to settle out of the atmosphere and can lodge more deeply in the lung due to their smaller size.[3] As most of the sources included in the inventory are diesel engines, PM emissions presented in this report primarily represent particles of all sizes emitted in diesel engine exhaust. This is commonly referred to as diesel particulate matter

Diesel Particulate Matter

Particulate matter (PM) emissions in diesel engine exhaust are classified as diesel particulate matter (DPM). PM emissions from other sources such as boilers and gasoline or LPG-powered engines are not classified as DPM. In particular, PM emissions from diesel-fired boilers are not DPM. The table below shows which source categories may emit diesel particulate matter as it is defined by the California ARB (CARB), along with the corresponding fuel sulfur content (% S). Use of lower sulfur fuel results in lower emissions of both PM and SOx.

Summary of Potential for DPM Emissions and Fuel Sulfur Content by Source Category.

Category	Potential to Emit DPM?	Diesel Fuel Sulfur Content[a]
Ocean-Going Vessels – Motor Vessels	Yes (main and auxiliary engines)	Marine Diesel Oil: 0.1% S
Ocean-Going Vessels – Steamships	Yes (auxiliary engines)	Marine Diesel Oil: 0.1% S
Harbor Craft	Yes (main and auxiliary engines)	CARB Diesel: 0.0015% S
Cargo Handling Equipment	Yes (diesel-fueled equipment only)	CARB Diesel: 0.0015% S
On-Road Heavy-Duty Trucks	Yes	CARB Diesel: 0.0015% S
Locomotives	Yes	CARB Diesel: 0.0015% S
Other Off-Road Equipment	Yes (diesel-fueled equipment only)	CARB Diesel: 0.0015% S

[a]Values listed here are regulatory limits used to calculate conservative estimates of emissions as per CARB methodology; actual average fuel sulfur content typically falls below these values.

[3] A micrometer, or micron (µm), is equal to one millionth of a meter. By way of comparison, the thickness of a human hair averages about 75 µm and a human red blood cell is about 5 µm in diameter.

(DPM). DPM has been designated a toxic air contaminant by the California Air Resources Board (ARB).

This inventory also includes data on emissions of the three major greenhouse gases (GHGs) emitted by vehicles and equipment associated with Seaport operations: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Since a given amount of CH_4 or N_2O has a far more powerful greenhouse gas effect than an equivalent amount of CO_2, total GHG emissions are reported in terms of CO_2 equivalent (CO_2e) emissions. CO_2e is equal to the weighted sum of the individual GHGs with weights equal to the relative global warming potential (GWP) of each GHG. CO_2 has a GWP of 1, while CH_4 and N_2O have been assigned GWPs of 25 and 298, respectively.

Emissions Inventory Results for 2017

Port of Oakland seaport emissions for 2017 are summarized in Table ES-1a (for criteria pollutants) and Table ES-1b (for GHG emissions).

As shown in Table ES-1a, the 2017 Emissions Inventory shows an 81% reduction in emissions of DPM and a 31% reduction in emissions of NOx since 2005. These reductions occurred despite a 6.5% increase in container throughput at the Port over this same period.

Table ES-1a. Summary of 2017 Seaport emissions: criteria pollutants (tons).

	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx
OGV	177	219	2,345	49.5	45.9	42.2	129
Harbor Craft: Dredge & OGV assist	19	81	152	6.1	5.9	6.1	<0.5
CHE	19	162	173	1.7	1.6	1.6	<0.5
Trucks	5	24	80	0.9	0.5	0.3	<0.5
Locomotives	0.8	1	17	0.3	0.2	0.3	<0.5
Other	0.8	40	11	0.3	0.3	0.3	<0.5
Total	**221**	**527**	**2,777**	**58.8**	**54.4**	**50.7**	**130**
2005 Total	**248**	**886**	**4,005**	**272.4**	**250.6**	**260.9**	**1,427**
% Reduction from 2005	**11%**	**40%**	**31%**	**78%**	**78%**	**81%**	**91%**

Sum of individual values may not equal indicated totals due to rounding

Table ES-1b. Summary of 2017 Seaport emissions: GHGs (tons).

	CO_2	CH_4	N_2O	CO_2e[a]
OGV	122,542	13.1	3.0	123,775
Harbor Craft: Dredge & OGV assist	16,369	1.9	0.4	16,548
CHE	35,398	1.4	0.3	35,520
Trucks	18,992	0.2	2.7	19,805
Locomotives	697	0.04	0.02	703
Other	1,602	0.4	2.2	2,228
Total	**195,600**	**17.2**	**8.6**	**198,579**

[a]CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (25), and N_2O (298).
Sum of individual values may not equal indicated totals due to rounding

Results in Table ES-1a show that OGVs accounted for the largest fraction of DPM (83%) and NOx (84%) emissions in 2017. Figure ES-1 shows that berthing accounted for 21% (9 tons) of the OGV DPM, and thus represents 17% of Seaport total DPM emissions in 2017. Harbor craft accounted for the next largest fraction of 2017 DPM emissions (12%). Harbor craft emissions are expected to decrease in the future as older engines are replaced by newer models with lower emissions.

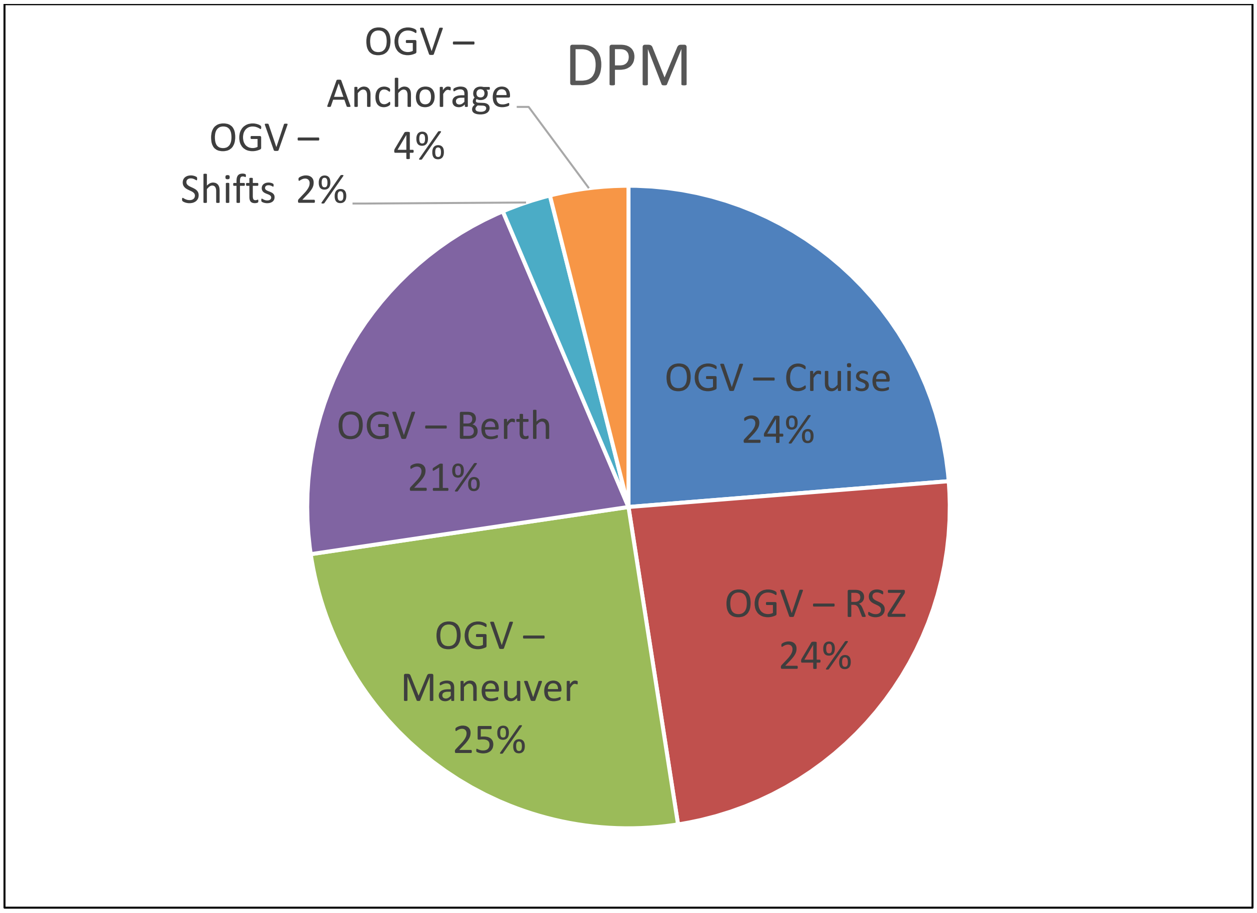


Figure ES-1. DPM emissions associated with OGV operating modes in 2017.

Port Activity Levels in 2017

Activity at the Port during 2017 included operations at four marine terminals (TraPac, Everport, Oakland International Container Terminal, and Matson) and two rail yards (BNSF and OGRE). Total TEU (Twenty Foot Equivalent Unit) throughput for 2017 was 2,420,837, which represents a 6.5% increase over 2005. Cargo vessels made a total of 1,596 visits to the Port in 2017 which is 15% lower than in 2005 as increasing average vessel size has reduced the number of visits despite the increase in TEU throughput. A total of 2,081,932 one way drayage truck trips (0.86 trips/TEU) are estimated to have occurred in 2017 based on gate counts provided by terminal operators. This is lower than the 2,620,483 trips (1.15 trips/TEU) estimated for 2005 and is an indication in efficiency improvements at the Port, although uncertainties in inferring trip totals from reported gate counts may have contributed to some of the difference. In contrast to 2005, when many older trucks operated at the Port, the 2017 drayage truck fleet consisted exclusively of trucks with 2007 or newer (or equivalent) engines, with 51% of the fleet comprised of trucks with 2010 or newer engines that meet lower emission standards.

All of the 1,596 ship visits to the Port of Oakland in 2017 were by deep-draft vessels designed as container ships. Port maritime terminals operated as intermodal sites where cargo handling equipment transfers containers to and from vessels to truck or rail transportation. In addition, several other off-dock businesses operate at the Port as transloading facilities where cargo is repackaged and transferred between containers, trucks or trains.

Methods

The emissions inventory was assembled by analyzing the time-in-mode, load or speed, and engine characteristics of marine vessels and other equipment used to transport cargo. Assigning emissions by time-in-mode allowed for emissions to be defined by approximate location. Equipment and activity data were obtained from ship call records, surveys of terminal operators and tenants, and other sources. Additional data, including emission factors and engine load factors, were obtained from previous studies, literature reviews, and emission models developed by the California Air Resources Board (ARB). Assumptions and methods used to develop the inventory are consistent with ARB methodologies.

Comparison of 2017 with Prior Year Inventories

This inventory was developed using methods consistent with the approach used by the ARB for each source category. Procedures and assumptions for estimating air emissions have evolved over time as new information becomes available. However, to provide for meaningful comparisons with Seaport inventories from prior years, the methods used for the 2017 have been kept as similar as possible to those used to develop the 2005, 2012, and 2015 inventories.[4] In this way, the main factor responsible for year-to-year differences in reported emissions is the amount of activity of various types occurring at the Port and the evolving characteristics of the equipment (ships, cargo handling equipment, trucks, etc.) used to carry out those activities. Emission reductions have been realized over the years mostly as a result of the introduction of cleaner new or retrofit equipment (such as newer trucks or harbor craft that have been retrofitted with newer, cleaner engines) and the adoption of new procedures such as use of shore power by vessels while at berth.

Results of this Port of Oakland 2017 Seaport Emissions Inventory update are compared with the 2005, 2012, and 2015 inventories in Tables ES-2a and ES-2b.[5,6] Figures ES-2 and ES-3 show the reductions over time in each source category for DPM and NOx emissions, respectively.

Emissions shown for 2017 in Tables ES-1 and ES-2 and Figures ES-1, ES-2, and ES-3 are based on methods and assumptions that are generally consistent with methods and assumptions used to develop the 2005, 2012, and 2015 inventories. In particular, OGV emissions in Tables ES-1 and ES-2 are based on the same assumptions about vessel speeds and engine load adjustment factors used in the prior year inventories. Also, the 2017 commercial harbor craft emissions in these tables do not include emissions from bunkering operations as bunkering was not included in the prior year inventories. Bunkering operations accounted for 16% (1.2 tons) of total commercial harbor craft DPM emissions in 2017, and bunkering volume levels were higher in 2005 although their emissions were not quantified. Emissions from bunkering are discussed further in Section 3.

Note that the 2005 inventory did not distinguish between PM_{10} and $PM_{2.5}$; only total PM and DPM emissions were reported. For emission sources found at the Port, total PM in the 2005 inventory can be considered equivalent to PM_{10}.

For <u>OGVs</u>, both NOx and DPM emissions were lower for 2017 as compared with three previous inventories.[7] NOx emission reductions resulted both from the use of shore power and fleet turnover to newer ship engines designed to meet lower NOx emission standards. DPM reductions since 2005 are primarily attributable to increased use of low sulfur fuel and the use of shore power.

<u>Harbor craft</u> emissions declined between 2005 and 2017 as vessel fleets turned over to incorporate lower emitting engines. Port records indicate bunkering volume levels were higher

[4] Although methods used to develop the 2017 inventory have been kept mostly the same, as in previous inventories the most recent available version of ARB's EMFAC on-road vehicle emission factor model (in this case EMFAC2017) was used.
[5] Note that an inadvertent double counting of the on-road portion of each truck trip included in the originally published 2012 and 2015 inventories has been corrected in these tables.
[6] GHG emissions were not originally included in the 2005 inventory but were added as part of this study.
[7] Direct comparison with the 2015 inventory is not representative, as there was an unusual amount of berthing, shifts, and anchorage activity in 2015 due to a slow down at the beginning of the year.

in 2005 as compared to 2017, so including bunkering in the comparison would probably have led to a larger calculated emissions reduction.

Cargo handling equipment emissions have declined as the CHE fleet has turned over to lower emitting engines. DPM emissions have decreased by 93% and NOx emissions by 77% since 2005.

On-road heavy-duty truck NOx and DPM emissions in 2017 were sharply reduced from 2005. Changes in emissions from year to year are a result of 1) changes in the number of estimated truck trips, 2) modernization of the truck fleet due to the introduction of restrictions on older trucks and fleet turnover, and 3) revisions to emission rates associated with updates to ARB's EMFAC model. Modernization of the drayage truck fleet was the overwhelming factor responsible for DPM emission reductions of 91% between 2005 and 2012, and another 83% between 2012 and 2015. Differences in drayage truck emission rates between ARB's EMFAC2014 model (which was used to prepare the 2015 inventory) and the updated EMFAC2017 model (used to prepare the 2017 inventory) are responsible for the calculated 5% DPM emission increase between 2015 and 2017. Overall, DPM emissions from trucks decreased by 98% between 2005 and 2017. Similarly, NOx emissions decreased 72% between 2005 and 2012, 5% between 2012 and 2015, and 12% between 2015 and 2017 for an overall 2005 – 2017 NOx emission reduction of 76%.

Year to year changes in locomotive emissions reflect the gradual introduction of newer and retrofitted locomotives with lower emissions and idle reduction measures as well as changes in the amount of cargo moved by rail instead of trucks. Locomotive emissions in 2017 were 15% (DPM) and 22% (NOx) higher than in 2015 due at least in part to the added activity in the OGRE yard. Overall, locomotive DPM emissions at the Port have decreased by 87% and NOx emissions by 78% from 2005 levels.

As shown in Table ES-2b, emissions of GHGs (as CO_2e) from sources included in the Seaport inventory declined 7% between 2005 and 2017, despite the 6.5% growth in TEU throughput. Some of this decrease is attributable to the use of shore power by OGVs while at berth in 2017 that is less carbon intensive than combustion of diesel in the auxiliary engines; shore power was not available in 2005. GHG emissions from generation and transmission (G&T) of electricity used for shore power in 2017 (9,905 tons CO_2e) were estimated based on electricity consumption records.[8] G&T emissions were not estimated for 2012 or 2015. The decline in GHG emissions is also partially attributable to greater efficiencies achieved by increases in OGV TEU capacities which resulted in fewer vessel calls and reduced assist tug usage in 2017.

[8] Examination of shore power usage records for 2017 indicates 23,735,379 kW-hours of electricity consumption. Based on the 2017 state-wide average electricity generation and transmission carbon intensity of 105.16 g CO_2e/MJ (378.58 g CO_2e/kW-hr), electricity for shore power use in 2017 produced 9,905 tons CO_2e (see details in Section 2).

Although emissions for 2017 described in this Executive Summary were calculated using methods and procedures similar to those used in previous inventories as described above, some new data sources and calculation procedures have recently become available which provided opportunities to improve the accuracy of the 2017 inventory and are consistent with the use of “best practice” inventory methods. In light of this, the Port decided to also present refined 2017 emission estimates based on these new data and methods alongside the “traditional” estimates. Improvements focused on using more accurate data on OGV speeds inside and outside the Bay, more realistic OGV emission factors under low load (i.e., low speed) operation, and including emission estimates for bunkering activities and off-dock distribution facilities that were in operation during 2017 and had not been included in prior inventories. Applicable data and procedures are detailed in the body of this report and a summary of the refined emission estimates is presented in Section 8. These results indicate that using more accurate data on OGV speeds and low load emission factors results in a lower estimate of OGV emissions overall, thus reducing the Port total emissions.

Table ES-2a. Comparisons of 2017 with prior year Port inventories: criteria pollutants in tons per year.

2017 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going vessels	177	219	2,345	49.5	45.9	42.2	129
Harbor craft	19	81	152	6.1	5.9	6.1	0
CHE	19	162	173	1.7	1.6	1.6	0
Truck	5	24	80	0.9	0.5	0.3	0
Locomotive	1	1	17	0.3	0.2	0.3	0
Other Offroad Equipment	1	40	11	0.3	0.3	0.3	0
Total	221	527	2,777	58.8	54.4	50.7	130
% Reduction from 2005	11%	40%	31%	78%	78%	81%	91%
2015 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going vessels	182	259	2,715	58.7	54.3	51.8	141
Harbor craft	23	97	166	6.6	6.4	6.2	0
CHE	43	253	332	3.9	3.6	3.7	1
Truck[a]	5	16	91	0.8	0.4	0.2	0
Locomotive	0	2	14	0.2	0.2	0.2	0
Other Offroad Equipment	1	12	11	0.6	0.5	0.6	0
Total	254	639	3,328	70.8	65.5	62.8	142
2012 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going vessels	176	232	2,591	66.9	62.1	57.4	289
Harbor craft	25	95	235	9.3	9.0	9.3	0
CHE	35	207	413	8.0	7.4	7.9	1
Truck[a]	11	43	95	2.1	1.6	1.5	0
Locomotive	1	2	19	0.5	0.4	0.5	0
Other Offroad Equipment	1	4	4	0.3	0.3	0.3	0
Total	249	584	3,358	87.2	80.8	76.9	290
2005 Inventory	**ROG**	**CO**	**NOx**	**PM**	**$PM_{2.5}$[b]**	**DPM**	**SOx**
Ocean-going vessels	117	235	2,484	219.5	201.9	208.5	1,413
Harbor craft	22	83	344.75	13.4	12.3	13.4	3
CHE	53	408	766	21.7	19.9	21.2	7
Truck	49	149	334	15.9	14.6	15.9	2
Locomotive	7	11	76	2.0	1.8	2.0	2
Total	**248**	**886**	**4,005**	**272.4**	**250.6**	**260.9**	**1,427**

[a]Corrected to account for double counting of on-road portion of each trip.
[b]Not included in 2005 inventory; estimated here based on assumption that 92% of PM by mass is $PM_{2.5}$.

Table ES-2b. Comparisons of 2017 with prior year Port inventories: GHGs (tons).

2017 Inventory	CO_2	CH_4	N_2O	CO_2e[a]
Ocean-going vessels[b]	122,542	13.1	3.0	133,680[c]
Harbor craft	16,369	1.9	0.4	16,548
CHE	35,398	1.4	0.3	35,520
Truck	18,992	0.2	2.7	19,805
Locomotive	697	0.0	0.0	703
Other Offroad Equipment	1,602	0.4	2.1	2,228
Total	**195,600**	**17.2**	**8.6**	**208,484**
% Reduction from 2005	**11%**	**52%**	**9%**	**7%**
2015 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[a]**
Ocean-going vessels[b]	168,745	18.0	4.1	170,405
Harbor craft	16,837	2.1	0.5	17,039
CHE	32,606	4.3	0.0	32,713
Truck[d]	18,596	0.3	0.5	18,761
Locomotive	639	0.0	0.0	645
Other Offroad Equipment	1,155	0.0	0.1	1,191
Total	**238,578**	**24.7**	**5.2**	**240,754**
2012 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[e]**
Ocean-going vessels[b]	133,005	14.2	3.3	134,332
Harbor craft	20,134	3.6	0.5	20,377
CHE	38,556	5.3	0.0	38,667
Truck[d]	20517.17	0.6	0.6	20,701
Locomotive	926	0.1	0.0	935
Other Offroad Equipment	368	0.1	0.0	370
Total	**213,505**	**23.8**	**4.4**	**215,384**
2005 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[e]**
Ocean-going vessels[b]	141,191	24.5	7.9	144,141
Harbor craft	19,795	2.0	0.7	20,053
CHE	37,238	7.7	0.3	37,486
Truck	21,460	1.7	0.6	21,676
Locomotive	1,216	0.0	0.0	1,220
Total	**220,900**	**36.0**	**9.4**	**224,576**

[a]CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (25), and N_2O (298).
[b]Auxiliary engine emissions while berthing based on ARB default 18% load assumption in all years although actual power draw during use of shore power is about one-half the value implied by the ARB default assumption (based on 2017 shore power records).
[c]Shore power CO_2e emissions of 9,905 tons from electricity generation and transmission in CO_2e are added here based on recorded shore power electricity consumption.
[d]Corrected to account for double counting of on-road portion of each trip.
[e]CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (21), and N_2O (310).

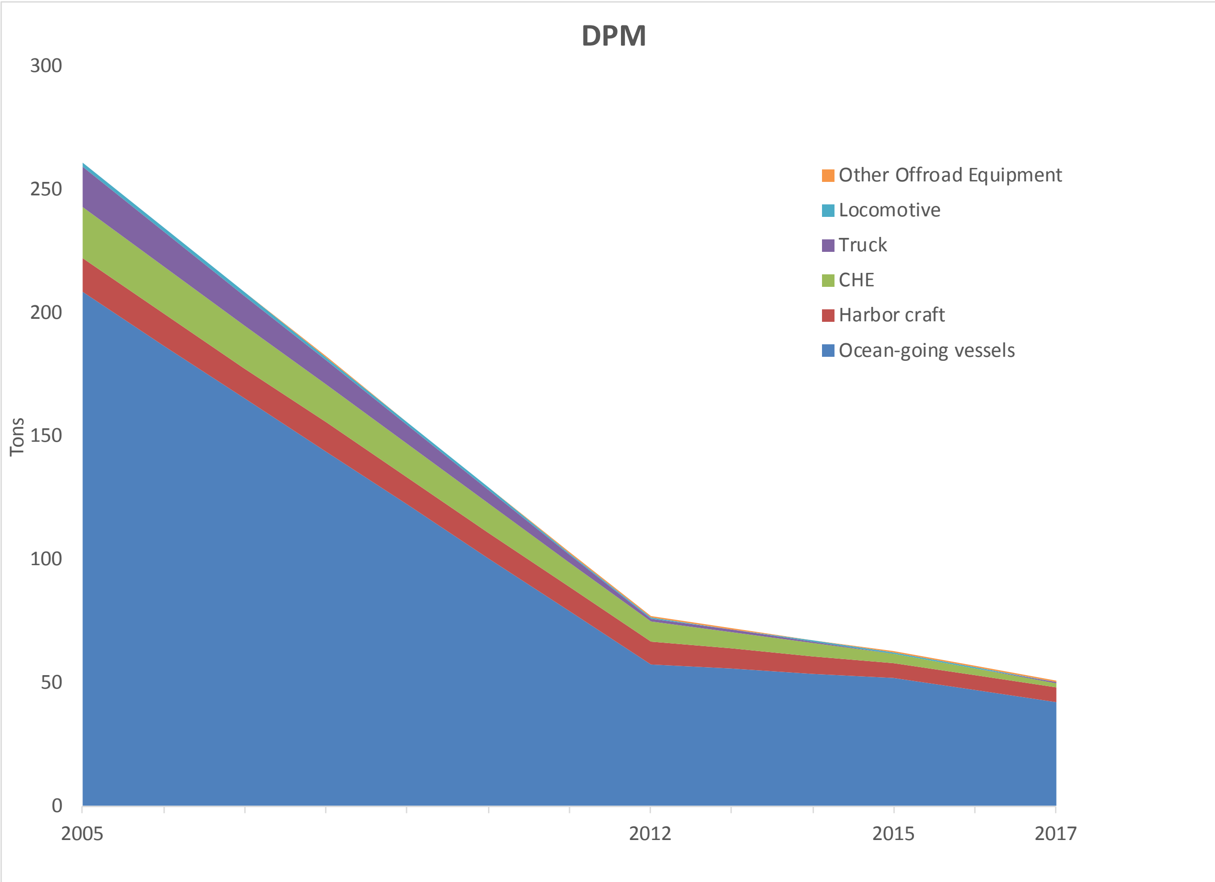


Figure ES-2. Seaport diesel particulate matter (DPM) emissions (tons).

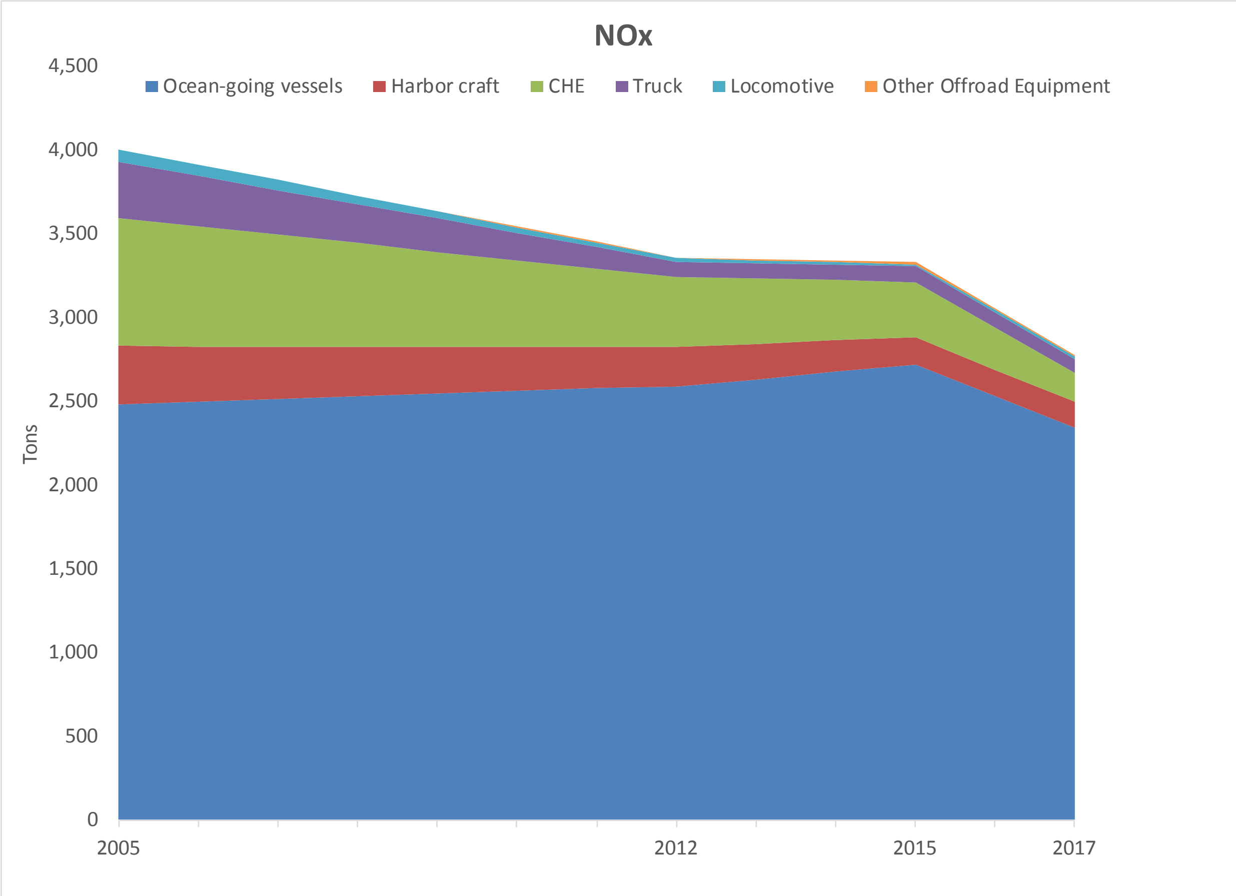


Figure ES-3. Seaport NOx emissions (tons).

1.0 INTRODUCTION

1.1 Purpose and Background

The Port of Oakland (Port) has prepared this 2017 Seaport Air Emissions Inventory (emissions inventory) for the purpose of identifying and quantifying the air quality impacts from the maritime operations of the Port and its tenants. This emissions inventory updates the 2005, 2012, and 2015 Seaport Air Emissions Inventories (ENVIRON, 2008a, 2013; Ramboll Environ, 2016) for the major categories of maritime equipment:

- Deep-Draft Ocean-Going Vessels (OGV);
- Harbor Craft (dredging and assist tugs);
- Cargo Handling Equipment (CHE);
- Trucks (container movements);
- Locomotives; and
- Other Off-Road Equipment.

The Port voluntarily chose to prepare the original 2005 inventory and periodic inventory updates to help in air quality planning and to meet its commitment to develop and implement an air emissions reduction program. Because annual emissions from operations vary over time due to changes in cargo volume, implementation of regulations, and other factors, this study was undertaken to provide an updated inventory for 2017 for comparison with the calendar year 2005 baseline inventory.

This emissions inventory highlights the Port's commitment to improve understanding of the nature, location, and magnitude of emissions from its maritime-related operations. An emissions inventory is best understood as an estimate of the quantity of pollutants that a group of sources produce in a given area (or domain), over a prescribed period of time. Emissions inventories should be used in context with proper interpretation and in conjunction with other information and tools to evaluate and assess air quality problems.

1.2 Considerations When Using Emissions Inventories

Emissions inventories are used for multiple purposes: to analyze air quality, to develop pollutant control strategies or plans, and to track and communicate progress toward air quality goals. Emissions inventories are essential tools, but they have some inherent shortcomings that are often overlooked and lead to misconceptions about their use and value. The term "inventory" is something of a misnomer because it implies greater precision in "counting" emissions than is really the case. An emissions inventory is better understood as an estimate of the quantity of pollutants that a group of sources produce in a given area, over a prescribed period of time. The methods of making estimates are usually very technical in nature, a characteristic that makes the limitations of emissions inventories less transparent to the general public.

The accuracy of emissions estimates varies due to a number of factors. Even a well-conducted, detailed and carefully constructed inventory, such as this one, does not have access to direct emissions measurements from the specific, individual sources being studied. As a result, it is necessary to rely on surrogate information to characterize sources, describe source activities, and specify pollutant emission rates.

Emissions estimation methodologies are continuously in flux, changing and evolving over time as better and more accurate information becomes available. Historically, emissions inventory updates have revealed previously overlooked information about sources and source activity that has substantially changed overall emissions estimates. As a result, emissions inventories conducted even a few years apart may not be directly comparable.

Another important consideration in interpreting emissions inventories is the somewhat counter-intuitive fact that there can be a poor correlation between the magnitude of emissions and an air quality impact. The importance of a given ton of emissions may differ from another ton because of the location at which it is emitted, because of the meteorological conditions that affect its dispersion, and in some cases because of the chemical reactions that occur in the atmosphere. Emissions inventories should be used with care and in conjunction with other information and tools to evaluate and assess air quality problems.

1.3 Important Features of the Port of Oakland Seaport Air Emissions Inventory

Some key features of the Port emissions inventory that should be kept in mind when reviewing this report are described below.

1.3.1 Scope

This inventory estimates emissions from the Port's tenants' maritime-related operations, including operations by ocean-going vessels visiting the Port that occurred in the calendar year 2017. Port tenants for which emissions were estimated include marine terminal and off-dock (e.g., transload) terminal operators, and rail yard operators. Non-tenant maritime operations which are part of this inventory include sources for which the Port has no direct leasing arrangements; these emissions sources include shipping lines, trucks, dredges and other assist vessels, and some of the construction equipment emissions. For consistency and to allow comparison across years, the geographic scope of the inventory is the same as in prior (2005, 2012, 2015) inventories.

1.3.2 Sources

Source categories included in this inventory are ocean-going vessels, harbor craft assisting those vessels, harbor craft performing or assisting in dredging, cargo handling equipment at marine terminals and the Oakland International Gateway (OIG) and the Outer Harbor Intermodal Terminal (OHIT) rail yards and off-dock transload facilities, locomotives and trucks engaged in transport of maritime cargo containers, and construction and maintenance equipment. Nearly all sources are powered by diesel engines. The inventory does not address other smaller sources, such as transport refrigeration units (TRUs) or gasoline-powered light-duty vehicles, that operated at the Port. Within the context of this inventory, gasoline-powered light-duty vehicles are not a significant source of air contaminants. While TRUs occasionally operate on power from diesel generators while containers are being moved, TRUs are estimated to spend nearly all of their time while at the Port plugged into shore (i.e., grid) power at what are called reefer plugs or reefer racks, of which there are at least 3,500 at the Port. Given the estimated minimal contribution to emissions from TRUs within the domain of this inventory and the lack of reliable data on average number of hours TRUs might operate at the Port when not plugged in (especially in light of the moderate average ambient temperatures experienced at the Port), emissions from TRUs are not included in this inventory.

1.4 Criteria Air Pollutants

The inventory provides estimates for emissions of five "criteria" air pollutants described here, reported as tons per year.[9]

Reactive Organic Gases (ROG)	Generally colorless gases that are emitted during combustion or through evaporation. They react with other chemicals in the ambient air to form ozone or particulate matter, both of which can have adverse health effects at higher concentrations.
Carbon Monoxide (CO)	Colorless gas that is a product of incomplete combustion; has an adverse health effect at higher concentrations.
Nitrogen Oxides (NOx)	Nitrogen oxides include nitric oxide and nitrogen dioxide. Nitrogen dioxide is a light brown gas formed during combustion from reactions with nitrogen in the fuel or the combustion air. Nitrogen dioxide has adverse health effects at higher concentrations. Both nitrogen dioxide and nitric oxide participate in the formation of ozone and particulate matter in the ambient air.
Particulate Matter (PM)	Solid or liquid particles that form from a variety of chemical reactions during the combustion process. Solid particulate matter may also be emitted from activities that involve abrasion or friction, such as brake and tire wear. Have adverse health effects at higher concentrations. Particulates are divided into those less than 10 microns in aerodynamic diameter, PM_{10}, and those less than 2.5 microns in aerodynamic diameter, $PM_{2.5}$. Diesel particulate matter (DPM) is defined as particulate matter from diesel engine exhaust.
Sulfur Oxides (SOx)	Sulfur bearing gases, primarily sulfur dioxide (SO_2), that form during combustion of a fuel that contains sulfur. Has adverse health effects at higher concentrations and participates in the formation of sulfate particulate matter in the ambient air.

[9] The term "criteria" pollutant is applied to pollutants for which an ambient air quality standard has been set, or which are chemical precursors to pollutants for which an ambient air quality standard has been set.

1.4.1 Particulate Matter

The particulate matter (PM) estimated in this report is primarily diesel particulate matter (DPM) emitted from diesel engines. the California Air Resources Board (ARB) regulates DPM as a toxic air contaminant. Some, primarily older, ocean-going vessels calling at the Port were designed to use boilers to supply steam power for propulsion engines, and all vessels operate auxiliary boilers for heating water and other uses on board. PM emissions from boilers are not classified as DPM by the ARB. In addition, some particulate matter emissions were from non-diesel gasoline or LPG-fueled cargo handling equipment, as noted in Section 4. Particulate matter emissions were estimated from emission factors as PM_{10}; $PM_{2.5}$ was calculated as a fraction of PM_{10} which varies by source category.

1.5 Greenhouse Gases

The greenhouse gas (GHG) emission inventory includes estimates of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from each source category. Fuel combustion is the source of CO_2, while CH_4 results from incomplete combustion and N_2O is generated during the high temperature combustion. A combined carbon dioxide equivalent (CO_2e) estimate was prepared by adding 25 times the CH_4 and 298 times N_2O emissions to the CO_2 emissions to account for the greater global warming potential (GWP)of these two species (IPCC, 2007).

1.6 Technical Approach

This report outlines the maritime emissions inventory from mobile sources at the Port of Oakland in 2017 and includes the input data and methodology used in estimating emissions. The emissions inventory includes the following major source categories:

- Deep-Draft Ocean-Going Vessels (OGV);
- Commercial Harbor Craft (dredging and assist tugs);
- Cargo Handling Equipment (CHE);
- Trucks (container movements);
- Locomotives; and
- Other Off-road Equipment.

This is an inventory of the air emissions generated by maritime activities conducted by the Port of Oakland's tenants and seaport customers. On the water side, the spatial domain of the inventory includes Port-related marine vessel transit from dockside out through the Golden Gate Bridge, to the first outer buoys beyond the Sea Buoy approximately 30 miles away from the Port. On the landside, the spatial scope of the inventory includes five marine terminals, two rail yards, and the road traffic between those facilities and the nearest freeway interchanges. The Port area was defined approximately by the boundaries of I-80, I-880, and the Howard Terminal (Berths 67 and 68) adjacent to Jack London Square, although the Howard Terminal was lightly used during 2017. Within this defined geographic domain, two areas were specifically excluded: the Schnitzer Steel terminal and the Union Pacific rail yard. As in previous inventory years, these two areas were not controlled or operated by the Port of Oakland in 2017 and are therefore not included in this update. Construction activities at the new Cool Port Oakland facility are included in the inventory. Figures 1-1 and 2-1 illustrate the spatial scope of the inventory.

Figure 1-1. Port of Oakland maritime facilities – 2017 (dashed magenta line indicates landside boundaries of the emissions inventory).

Ramboll prepared this inventory by analyzing all maritime activity in 2017 including the time in different modes of operation, the load or speed, and the engine characteristics of all equipment and vessels used in the Port's maritime operations. To obtain these data, Port, State, and terminal and rail operator records were used. Previous studies and literature reviews and ARB input data or model estimates were used when more precise estimates could not be generated during the period of this study.

Emissions estimates included in this report are based on ARB inputs and methodologies except as specifically noted.

1.7 Report Organization

This emissions inventory report is organized into an Executive Summary, nine sections, and two appendices.

- The Executive Summary briefly describes the methodologies used to estimate air emissions for all Port activities and includes a summary of the results (Tables ES-1 and ES-2).
- Section 1 contains this introduction to the report.
- Section 2 describes deep-draft ocean-going marine vessel emissions.
- Section 3 describes emissions from harbor craft used for operation and maintenance dredging activity, bunkering operations, and tug assists.
- Section 4 describes emissions from cargo handling equipment.
- Section 5 describes emissions from Port of Oakland on-road truck activity associated with container movements.
- Section 6 describes locomotive emissions.
- Section 7 describes other off-road equipment emissions.
- Section 8 contains the summary and results of the report and comparisons with the 2005, 2012, and 2015 seaport emission inventories.
- Section 9 provides the references used in developing the emissions inventory.
- A glossary defines the technical terms used in the report.
- Appendix A: OGV Speed Distributions.
- Appendix B: Low-load Adjustment Factors.

2.0 OCEAN-GOING VESSELS

In 2017, the Port purchased Automated Identification System (AIS) data for June to December to allow the use of real-time vessel transit data to evaluate vessel speed. For purposes of consistency with prior inventories, this emissions inventory presents an emissions estimation scenario that is consistent with the vessel speed assumptions used in the 2005, 2012, and 2015 emissions inventories and a new emissions estimation scenario that uses actual speeds derived from the AIS data. Also, in response to changes in the application of vessel engine low load adjustment factors in similar inventories developed for the Ports of Los Angeles and Long Beach, two alternative emission estimates are presented here: one with and one without the application of low load adjustment factors.

2.1 Vessel Activity and Inventory Description

This section documents the activity, emission inventory methods, and results for larger deep-draft ocean-going vessels (OGVs) calling to the Port of Oakland terminals in 2017. Ramboll followed the latest ARB emission estimation methodology for ocean-going vessels.[10] (ARB, 2011a, 2016)

OGVs calling at the Port of Oakland in 2017 were exclusively container ships including some with capability to handle roll on/roll off cargo. No OGVs calling at the Port of Oakland in 2017 made calls to other San Francisco Bay (SF Bay) ports during their visits.

OGV use propulsion engines for transiting, auxiliary engines for on-board electrical power, and small boilers to meet steam and hot water needs. Each vessel has unique characteristics of design speed, engine type, and power that affect estimates of engine load for each vessel call.

In the following sections, we describe the input activity and characterization data, operational estimates, and other inputs as well as the emission estimation methodology including emission factors and other considerations. Lastly, total emissions by mode and pollutant are reported together with a sensitivity analysis based on uncertainties in certain input parameters.

2.2 Input Data and Use

The basic input data for calculating emissions from OGVs include a list of all vessel voyages in 2017, installed power and design speed estimates for each vessel that called in 2017, and actual (or assumed) speeds during portions of the vessel trips included in the inventory. Input data include:

1) Vessel Activities
    a) San Francisco Marine Exchange (SFMX) voyage data
        i) Date/Time Stamp at key waypoints (new in second half of 2017)
        ii) Time at Berth (First line on, Last line off)
        iii) Time at Anchor

[10] Personal communication from Corey Palmer, ARB, April 4, 2018.

      iv) Shifts between berths
   b) Shore power berth location and connect/disconnect date and time stamps
2) Vessel Characteristics (from 2018 IHS Fairplay Database)
   a) Build date (keel laid date)
   b) Vessel Installed propulsion power (kW)
   c) Cruise speed (knots)
   d) Auxiliary power (kW)
3) AIS[11] data samples for actual vessel speed profiles (time by speed bin)

Each ship movement was recorded just outside and within the SF Bay providing a basis for estimating total activity. Times at berth or at anchor were provided by the date and time stamps at the beginning and end of each movement. Ship speeds at various locations were both assumed the same as in prior Port maritime inventories (for sake of consistency) and, as an alternative, based on AIS data provided by the SF Marine Exchange for June – December, 2017.

2.2.1 Vessel Voyages

Data on vessel characteristics (identifying data, size, age, engine characteristics, etc.) were obtained from IHS Fairplay which maintains a worldwide database of all OGVs (IHS Fairplay, 2018). Data on vessel calls to Port of Oakland berths were provided by the Marine Exchange of the San Francisco Bay Region (SFMX, 2018) and included the berth and date and time stamps at the beginning and end of each movement, allowing a calculation of time at berth and at anchor. SFMX identified each vessel by the International Maritime Organization (IMO) identification number, allowing for cross reference to the vessel characteristics in the IHS Fairplay Database.

SFMX assigned a voyage number to each time a vessel entered the SF Bay, thus providing a way to track each visit. However, a vessel may have shifted between berths at the Port or between anchorage and a berth at the Port and those multiple berthings are counted as multiple calls. As a result, the number of voyages in the SFMX data was less than the number of calls at the Port; multiple calls per voyage are included in the emission estimates presented here. Voyages count the number of transit trips inbound and outbound, while calls count the number of berthing events. Therefore, we report the number of voyages rather than the number of calls.

Ramboll excluded from this inventory the 26 voyages in 2017 for ships calling at the privately owned Schnitzer Steel facility. Although this facility lies between two Port of Oakland terminals, it is not located on Port property. Schnitzer Steel receives only bulk carriers calling for scrap steel. Emissions from vessel voyages associated with calls at Schnitzer Steel are not included in the Port's maritime inventory because the Schnitzer facility is not owned or controlled by the Port of Oakland.

[11] AIS (Automatic Identification System) data for June – December 2017 indicating vessel location and speed over ground at various key waypoints were provided by the SF Marine Exchange.

Two calls to the Port's Berth 67/68 were made in 2017 for the purposes of long term (greater than one week) cold ironing, and those vessels later shifted to other Port Berths thereby initiating a new vessel call record, which were included in the inventory as shifts. No auxiliary engines or boilers were assumed to be in use during the time spent at Berth 67/68 for these calls because the vessels were not expected to be staffed or loading or unloading cargo during this period.

After eliminating the ships calling Schnitzer Steel, there were 1,596 vessel voyages to the Port of Oakland in 2017. We describe the voyages by ship characteristics in terms of size, frequency, and age. Ship sizes were defined by three different methods:

- Dead weight tonnage (DWT),
- Container capacity in twenty-foot equivalent units (TEU), or
- Length overall (LOA).

Each of these size measurements may affect one emission source or another, but usually implicitly in that larger ships typically have higher propulsion and auxiliary engine rated power. Table 2-1 describes general ship characteristics using three size measurements for vessels calling at the Port of Oakland in 2017. As was the case in 2015, some of the ships calling in 2017 are significantly larger than in prior years including vessels exceeding 1,100 feet length overall and with carrying capacity over 12,000 TEUs.

Table 2-1. Ocean-Going Vessels – 2017 Port of Oakland vessel calls by three different ship size measures.

Dead Weight Tonnage	Voyages	TEU	Voyages	Length Overall	Voyages
<20,000	17	<1,000	0	<750 feet	172
<40,000	230	- <2,000	141	750 – 1100	1,187
<60,000	199	- <3,000	74	>1100	237
<80,000	444	- <4,000	88		
<100,000	231	- <5,000	339		
<120,000	319	- <6,000	100		
<140,000	65	- <7,000	239		
140,000+	91	- <8,000	63		
		- <10,000	347		
		- <12,000	107		
		12,000+[a]	98		
All	1,596	All	1,596	All	1,596

[a]The largest vessels calling at the Port in 2017 were 14,500 TEUs.

Vessels undertake voyages within the SF Bay at both regular and irregular frequencies. Many vessels follow regular routes and schedules while others make infrequent calls to the Bay. Vessels calling between 4 and 10 times in 2017 accounted for 66% of total calls, and 15% of calls were from vessels calling 11 or more times during 2017. Table 2-2 lists the distribution of Port of Oakland voyage counts (some voyages resulted in more than one call) by individual ships in 2017.

Table 2-2. Ocean-Going Vessel - Port of Oakland vessel voyages counts in 2017.

Number of Voyages in 2017	Ship Count	Cumulative Voyages		Number of Voyages in 2017	Ship Count	Cumulative Voyages
1	63	63		13	4	1,450
2	61	185		14	0	1,450
3	40	305		15	0	1,450
4	14	361		16	0	1,450
5	29	506		17	0	1,450
6	35	716		18	2	1,486
7	23	877		19	2	1,524
8	18	1,021		20	0	1,524
9	17	1,174		21	0	1,524
10	18	1,354		22	0	1,524
11	4	1,398		23	0	1,524
12	0	1,398		24	3	1,596

The age distribution of the vessels calling at the Port in 2017 is shown in Table 2-3. Most were relatively new with 85% of voyages by vessels built since 2000, but there were several frequently calling vessels older than 35 years. The call-weighted median age of vessels calling at the Port in 2017 was 9 years. The age distribution is important because the international emission standards limit NOx emissions from newer marine engines: Tier I emission standards started with model year 2000 vessels, Tier II started with model year 2011. In 2017, 23% of calls were by vessels required to comply with Tier II standards while 62% of calls were by vessels required to comply with Tier I standards. Tier I and Tier II standards apply globally. Tier III standards took effect for ships operating within the North American Emission Control Area (ECA)[12] with model year 2016, but no such modern ships called at the Port in 2017. The Ports of Los Angeles and Long Beach found that over 1,200 keels were laid in 2015, 106 of them for container ships, to allow for Tier II engines, not Tier III, while in 2016 only 99 total keels were laid.[13] The spike in 2015 keels laid will delay the introduction of Tier III container ships to North America.

Steamships (ships powered by propulsion boilers) are among the oldest vessels calling at the Port. Steamships that were not originally designed for operation on marine distillate fuel or natural gas are exempt from the North American ECA fuel sulfur requirements until 2020 as per International Maritime Organization resolution MEPC.202(62).[14] Steamship propulsion boilers were exempt from the ARB fuel sulfur requirements. Auxiliary boilers, however, are not exempt from the ARB fuel requirements. NO_x emission limits from the IMO emission standards

[12] Emission Control Areas (ECAs) cover certain coastal waters defined by the International Maritime Organization (IMO) within which certain additional restrictions on emissions apply.
[13] https://www.portoflosangeles.org/pdf/CAAP_Vessel_Tier_Forecasts_2015-2050-Final.pdf
[14] http://www.imo.org/en/MediaCentre/HotTopics/GHG/Documents/FAQ_2020_English.pdf

do not affect steamship propulsion boilers which have low NOx emission rates even without any additional controls.

Table 2-3. Ocean-Going Vessels – Port of Oakland vessel age distribution in 2017.

Model Year[a] – Tier Level	Count of Voyages	Individual % of Voyages		Model Year	Count of Voyages	Individual % of Voyages
2015 – Tier II	20	1%		1992	0	0%
2014 – Tier II	98	6%		1991	0	0%
2013 – Tier II	95	6%		1990	0	0%
2012 – Tier II	84	5%		1989	0	0%
2011 – Tier II	65	4%		1988	0	0%
2010 – Tier I	156	10%		1987	0	0%
2009 – Tier I	112	7%		1986	0	0%
2008 – Tier I	141	9%		1985	0	0%
2007 – Tier I	227	14%		1984	0	0%
2006 – Tier I	108	7%		1983	0	0%
2005 – Tier I	65	4%		1982	0	0%
2004 – Tier I	32	2%		1981	20	1%
2003 – Tier I	11	1%		1980	18	1%
2002 – Tier I	55	3%		1979	0	0%
2001 – Tier I	47	3%		1978	29	2%
2000 – Tier I	40	3%		1977	66	4%
1999	11	1%		1976	0	0%
1998	11	1%		1975	0	0%
1997	19	1%		1974	0	0%
1996	2	0%		1973	19	1%
1995	35	2%		1972	0	0%
1994	9	1%		1971	0	0%
1993	0	0%		1970	1	0%

[a]No 2016 or later model year vessels called at the Port in 2017.
Source: Marine Exchange of the San Francisco Bay Region (2018) and IHS Fairplay (2018)

2.2.2 Vessel Characteristics

Propulsion and auxiliary engine loads during voyages within the geographic scope of this emission inventory were assessed based on each engine's rated power and the vessel speed relative to the design speed (for propulsion engine load). The vessel build date was used to estimate the regulatory emission standard for each installed engine. Vessel characteristics were obtained from the IHS Fairplay database (2018). Vessel voyages were matched to the vessel characteristics based on each vessel's unique IMO number.

2.2.3 OGV Operating Modes

Vessel operating modes include transiting and hotelling modes. Transiting occurs at different speeds depending upon the navigational challenges as the ship maneuvers within the Bay and near berth. The ship speeds and distance for transit links are important to understanding the propulsion engine loads and time in mode. The time for the hotelling modes is critical to estimating the auxiliary engine emissions.

2.2.3.1 OGV Operating Modes and Previous Seaport Emission Inventory Speed Estimates

Previous emissions inventories for the Port for years 2005, 2012, and 2015 used average speed estimates by transiting link to estimate engine load. These average speeds were estimated based on discussions with the SFMX (2006, 2013),[15] and San Francisco (SF) Bar Pilots (2006).[16] A schematic description of the transit activity for vessels calling at the Port of Oakland is shown in Table 2-4. Entries in Table 2-4 correspond to the schematic link descriptions shown in Figures 2-1 and 2-2. Links listed in Table 2-4 were used to specify activity applicable to each portion of the vessel's transit.

Figure 2-1 shows the Precautionary zone (indicated by the partial circle of dashed magenta line centered on the Sea Buoy) and the inbound and outbound routes to and from the Bay. Transiting in the shipping lanes outside of the Precautionary zone were not included in the emission inventory. On entering the precautionary zone, the ship transits toward the Sea Buoy and slows to allow the Bar Pilot to board. After the Bar Pilot boards and takes command of the vessel, the ship proceeds toward the Golden Gate passing the line between Mile Rocks and Point Bonita near the San Francisco shoreline where a speed limit of 15 knots takes effect. The outbound trip follows the same modes in reverse order.

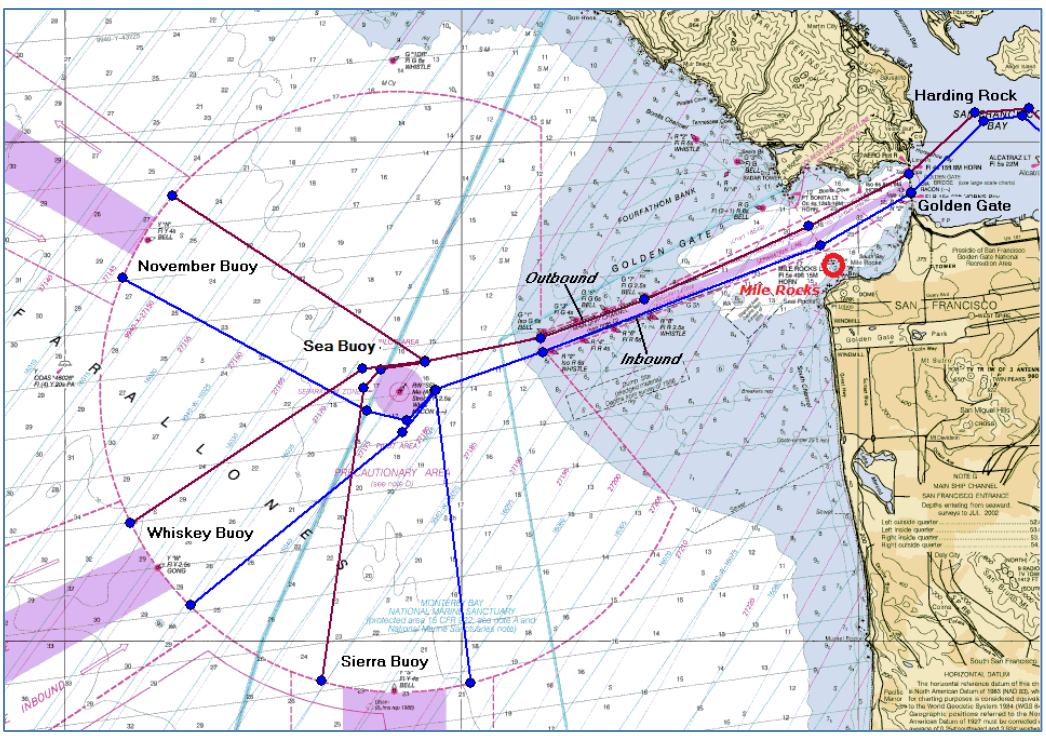


Figure 2-1. Link descriptions outside of the Golden Gate.

[15] Personal communication, Allen Steinbrugge 2006, Chris Hicks 2013, San Francisco Marine Exchange, 2013.
[16] Personal communication, San Francisco Bar Pilots, Ken Levin 2006.

There are two potential transit routes between the Golden Gate and Bay Bridge shown in Figure 2-2. Ships follow one route or the other depending on a number of factors including weather and scheduling of public events in the Bay. The SF Bar Pilots (2013) indicated that the primary or exclusive in-bound transit route between the Golden Gate and Bay Bridges is south of Alcatraz unless the vessel is drawing more than 45 feet in which case it should use the deep water route north of Harding Rock. Only three vessels exceeding a draft of 45 feet called on the Port; the maximum draft was 46.5 feet. The northern route may also occasionally be used by other vessels under unusual weather conditions or if public events interfere with the southern route. Because insufficient data were available to describe each call's specific route for the 2005, 2012, and 2015 inventories, the typical (and shorter) route south of Alcatraz was assumed for all inbound transits. The outbound transit must use the deep water route north of Harding Rock if the vessel draft exceeds 28 feet, and the southern route may not be available due to traffic concerns. Because more than 90% of ships outbound from Oakland draw more than 28 feet and the route south of Alcatraz is rarely available for outbound transit, in the 2017 inventory all vessels were assumed to use the route north of Harding Rock for outbound transit. Alternative inbound and outbound transit routes are shown and described in Figure 2-2 and Table 2-4, but these alternatives were not used in the emission estimation.

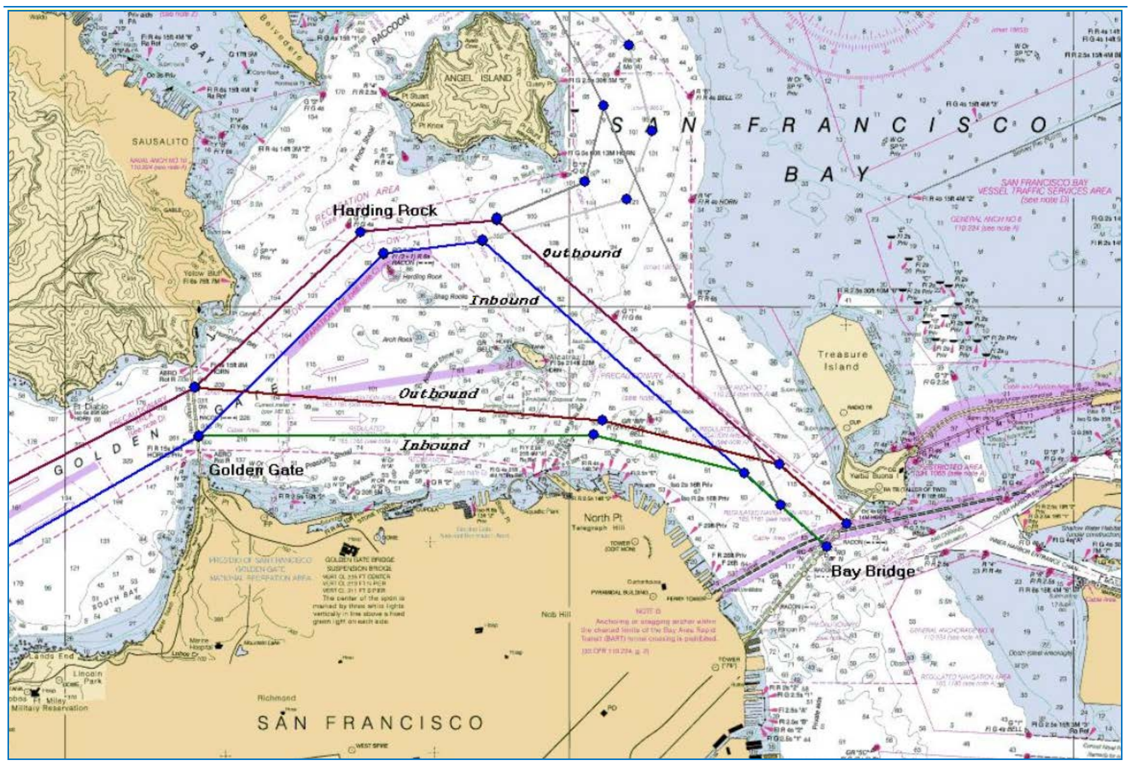


Figure 2-2. Transit link descriptions in San Francisco Bay (direct route primarily used inbound and less direct route outbound).

Vessels were assumed to be in maneuvering mode while moving between the Bay Bridge and the berths. This mode consists of a short low speed transit, turn at the berth or in the turning basin, and propulsion engine start and stop at the berth with tug assist. Based on the SF Bar Pilots' (2013) best judgment, the maneuvering time was assumed longer for the Inner Harbor berths and for larger vessels, defined here as two types of longer vessels, one greater than 750 feet LOA and another greater than 1,100 feet LOA. The larger ships require more time to turn and can only turn in prescribed areas, specifically the Inner Harbor and Outer Harbor turning basins. Therefore, as shown in Table 2-4, the SF Bar Pilots (2013) estimated the maneuvering time for larger ships to be longer than for smaller ships. Also, maneuvering time is shorter for the Outer Harbor terminal calls (i.e. Berths 24 through 37) than the Inner Harbor terminal calls (i.e. Berths 55 through 68) because of the shorter distance from the Bay Bridge and proximity of the Outer Harbor turning basin to the Outer Harbor berths.

Generally, vessel activity was classified into four modes of operation: cruise, reduced speed zone (RSZ), maneuvering, and hotelling at berth as follows:

- Cruise mode occurs in the open ocean where there are fewer navigational challenges and where ships typically operate at their design speed. The cruise mode occurs before the Pilot boards or after the Pilot departs the ship near the Sea Buoy.
- RSZ mode occurs where ships are required to slow down and stay within prescribed lanes as shown on Figures 2-1 and 2-2. For ships arriving in the SF Bay, the RSZ mode occurs after a SF bar pilot boards and takes command of the vessel at the Sea Buoy until the vessel slows to a very low maneuvering speed near the Port, defined for the purposes of this inventory as starting at the Bay Bridge. The RSZ mode for departing ships is the inverse of that for arriving ships.
- Maneuvering mode is defined as occurring between the Bay Bridge and the berth and shifts between berths.
- Hotelling or 'at berth' mode occurs when the vessel is stopped at berth or lying at anchor south of the Bay Bridge.
    - Anchorage occurs if a ship lies at anchor in one of the anchorage areas south of the Bay Bridge and is similar to berthing such that the propulsion engine is not running and only auxiliary hotelling loads are demanded.

The two additional modes, shifts and anchorage, were infrequent and did not occur for every vessel visit to the Port. These modes were added to account for all potential ship activity within the Bay. Shifts were included with other maneuvering activity and anchorage was estimated as a separate mode (though similar to berthing, ships at anchor are not able to use shore power and therefore must use their auxiliary engines).

The time in mode and load for propulsion engines needed to estimate emissions was calculated two ways for the 2017 inventory:

1. Time in mode and propulsion engine loads were estimated in a manner consistent with the approach used in the 2005, 2012, and 2015 inventories, that is, based on vessel speed and the distance (length) of each transit mode. The SF Bar Pilots (2013) estimated the RSZ average speed and typical maneuvering mode times as listed in Table 2-4. An average RSZ mode speed of 13.5 knots was chosen to account for an average compliance margin relative to the legal requirement for vessels to “Not exceed a speed of 15 knots through the water” in the regulated navigation areas (RNAs) included in Coast Guard regulations within the line between Mile Rocks and Point Bonita. The cruise speed was designated as the design speed reported for each vessel in the IHS Fairplay (2018) database. The time in mode derived from the speed and distance along each link was used to estimate the propulsion and auxiliary engine activity for cruise and RSZ modes.

2. Position and speed over ground from AIS data collected in 2017 were used to estimate emissions as discussed in Section 2.2.3.2.

The SFMX provided vessel call data for the Port of Oakland which included date and time stamps for the ‘first line on’ to the port and ‘last line off’ records and the beginning and end times for each shift.

Table 2-4. Ocean Going Vessels – Transit link descriptions.

Transit into Port				
Direction	**Link Start**	**Link End**	**Distance (nautical miles)**	**Speed (knots)**
In – All	Precautionary Zone Outer Edge	Pilot Boards	6.8[3]	Cruise
In – All	Pilot Boards	Sea Buoy	1.5[2]	9
In – All	Sea Buoy	Golden Gate	8.7	13.5
In – All (alternative route) [1]	Golden Gate[1]	Harding Rock	2.0	13.5
In – All (alternative route) [1]	Harding Rock[1]	Bay Bridge	4.5	13.5
In – All [1]	Golden Gate	Bay Bridge	5.3	13.5
Maneuvering Modes				
Direction	**Link Start**	**Link End**	**Time (hrs)**	**Load**
In/Out – Inner Harbor Terminals (<= 750 foot Ships)	Bay Bridge	Dock	0.833 / 0.833	2%
In/Out – Inner Harbor Terminals (>1100 or >750 foot Ships – Turning Basin)	Bay Bridge	Dock	2.09 or 1.42 / 0.833	2%
In/Out – Outer Harbor Terminals (<= 750 foot Ships)	Bay Bridge	Dock	0.75 / 0.75	2%
In/Out – Outer Harbor Terminals (>750 feet Ships – Turning Basin)	Bay Bridge	Dock	1.33 / 0.75	2%
Shifts (small number of calls have shifts from one terminal to another)	Oakland	Oakland	0.75	2%
Transit Out of Port				
Direction	**Link Start**	**Link End**	**Distance (nautical miles)**	**Speed (knots)**
Out – All [1]	Bay Bridge[1]	Harding Rock	4.8	13.5
Out – All [1]	Harding Rock[1]	Golden Gate	1.8	13.5
Out – All (alternative route) [1]	Bay Bridge[1]	Golden Gate	5.5	13.5
Out – All	Golden Gate	Sea Buoy	8.9	13.5
Out – All	Sea Buoy	Pilot Departs	1.5[2]	9
Out – All	Pilot Departs	Precautionary Zone Outer Edge	6.8[3]	Cruise

[1] SF Bar Pilots (2013) reported that ships with drafts greater than 45 feet must use the Deep Water Traffic Lane north of the Harding Rock Buoy, though other ships under certain conditions (such as occurrence of special events) may also take northern route. For transit out of the Bay, ships with drafts greater than 28 feet must use the Deep Water Traffic Lane.

[2] Assumed 10 minutes at 9 knots for the pilot to board and depart safely. Distance in this mode was subtracted from the cruise mode. Distances were measured from east of Sea Buoy.

[3] In previous inventory years, the incoming and outgoing directions (north, west, or south) for vessels transiting to or from the Sea Buoy was easily determined based on the data provided by the SF Marine Exchange. Direction-specific inbound distances varied from 6.0 to 7.4 nautical miles (inbound) and 6.1 to 7.3 nautical miles (outbound). For the 2017 inventory, voyage data on incoming and outgoing directions were not readily available so an average distance of 6.8 nautical miles was used.

2.2.3.2 2017 Inventory Estimates Based on AIS Vessel Speeds

Automatic Identification Systems (AIS) began to be widely installed on ships in 2003 primarily to promote safe navigation. Records of AIS activity provide a wealth of information about ship speed and routes. Archived AIS data has become more widely available to investigators allowing average ship speed profiles to be estimated. Beginning in 2017, the Port contracted with SFMX to collect AIS ship speed data, which Ramboll used to estimate typical ship speed profiles for different transiting modes within the scope of this emissions inventory. AIS represents a more robust and accurate estimate of ship speeds rather than relying on estimated average speeds based on interviews with pilots or on regulatory speed limits.

The AIS data was segregated into spatial zones as shown in Figure 2-3. These zones cover the same spatial scope as the transit links outlined in Table 2-4 but have individually different modes. For example, the Precautionary Zone includes the previous cruise, pilot boarding/disembarking, and a portion of the link from the Sea Buoy (at the center of the Precautionary zone) to the Golden Gate. A new region has been defined outside of the line between Mile Rocks and Point Bonita which includes the HS (high speed) Outer GGB (Golden Gate Bridge) and Precautionary Zone, in which the 15 knot speed limit is not in effect. All other zones within the SF Bay (i.e., inside of the line between Mile Rocks and Point Bonita), are covered by the 15 knot speed limit although the SF Bar Pilot has control of the ship so actual speeds are at the pilot’s discretion.

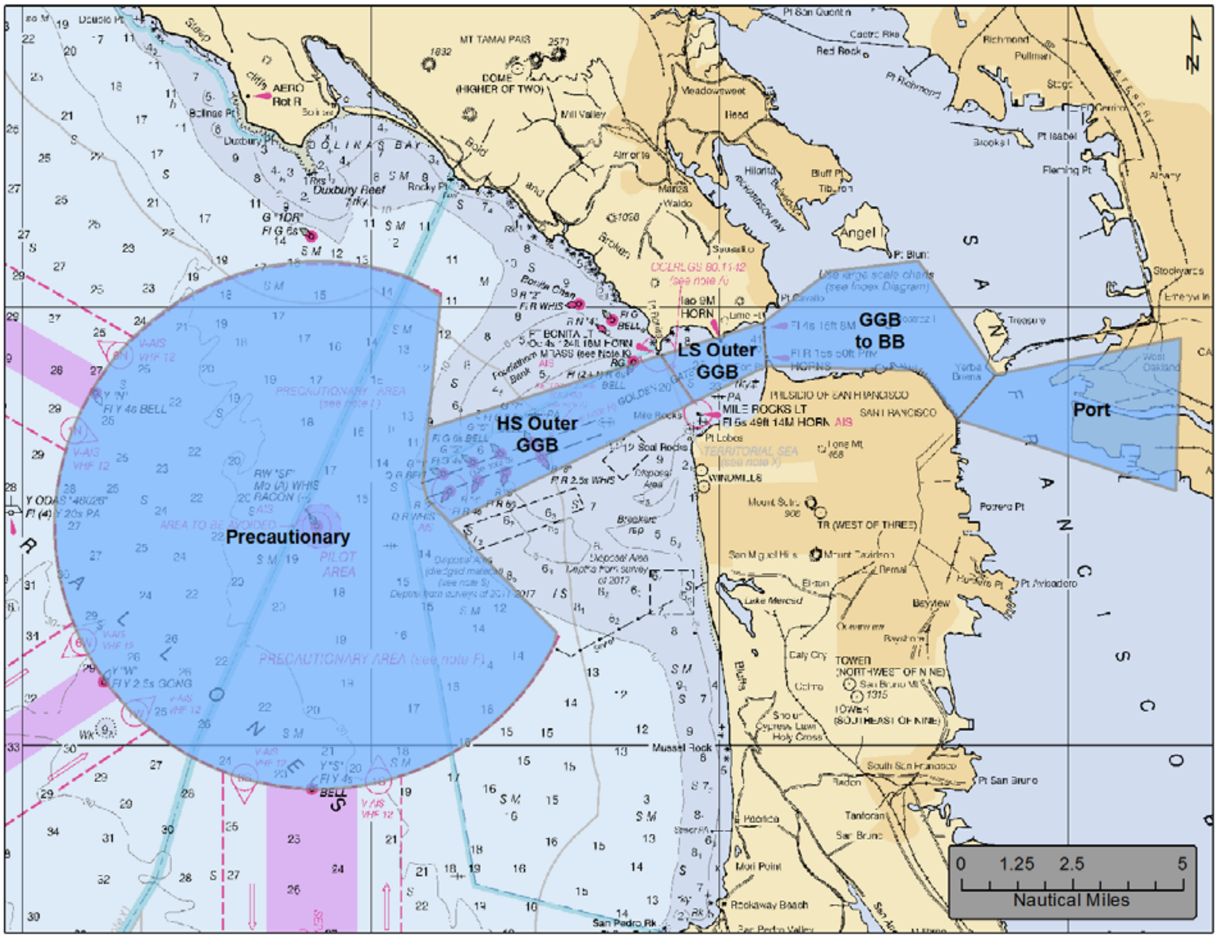


Figure 2-3. Mode descriptions in San Francisco Bay (with AIS data).

Using the AIS data, Ramboll developed time-by-speed-bin profiles for each zone shown in Figure 2-3. An example of these profiles is shown in Figure 2-4 for the Precautionary zone; profiles for the other zones are provided in Appendix A. As shown in Figure 2-4, outbound speeds are generally higher than inbound speeds. This same pattern is also observed for the other zones. For the Precautionary zone, the ship must slow to at least 10 knots to allow the pilot to transfer between the ship and the pilot boat, so a significant amount of time is spent below 10 knots. Once the Pilot no longer has command of the vessel there is no speed restriction, which explains the higher speeds for outbound trips.

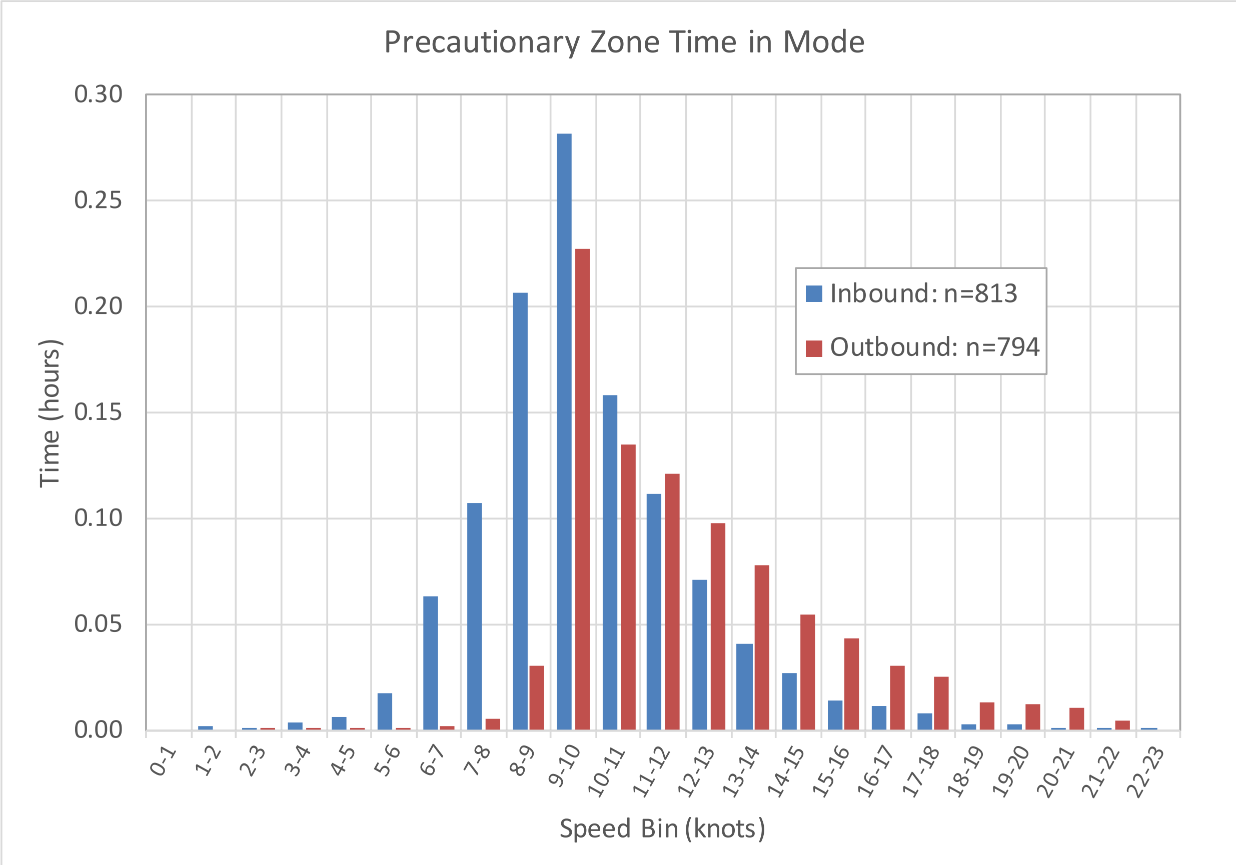


Figure 2-4. Precautionary zone speed profiles (from AIS data samples).

Ship speed profiles provide a more accurate representation of ship activity within the study area. Emission calculations performed using these profiles are included as an update to the methodology. Because ship engine loads have a highly nonlinear relationship with vessel speed, the times in each speed bin for each zone are used rather than the average speed by zone to more accurately assess emissions.

2.3 General Emission Estimation Methodology

2.3.1 Emission Factors and Emission Estimation

Emissions were determined for each link or mode using the equation below, accounting for the engine rated power, typical load factor, and time at that load. The rated power is the maximum power that the engine can produce. The load factor is the fraction of the actual to the rated power that the engine operates for a given mode. Emissions were calculated separately for propulsion and auxiliary engines, and for boilers, using emission factors from ARB (2011a).

Emissions per vessel/mode = (Rated Power) x (Load Factor) x (Time) x (Emission Factor)

Emissions total = Σ {All vessel calls and modes}

The time in each link was calculated from the link length and estimated speed. The load factor was calculated on the basis of the vessel's maximum speed and the actual vessel speed in each mode (either using the average speed by mode approach or the AIS time in speed bin profiles) as described in Section 2.2.3.

Emission factors depend on the type of engine and fuel used in the vessel for propulsion or auxiliary engines. Three types of engines are commonly used for propulsion power on cargo ships: slow speed engines (2-stroke and typically lower than 200 rpm), medium speed engines (4-stroke), and steam turbines coupled with steam boilers. Ramboll determined from the IHS Fairplay 2018 data that the most common propulsion engines used on vessels calling at the Port of Oakland in 2017 were slow speed engines (1,481 vessel voyages) with steam engines powered by boilers accounting for the remainder (115 vessel voyages). No medium speed propulsion engines were found in the 2017 calls. Emission factors for these engines are shown in Table 2-5 (ARB 2011a; ARB 2016).

Table 2-5. Ocean Going Vessels – Emission factors (g/kW-hr) for Precontrol (<2000), Tier I (2000 – 2010), Tier II (2011 – 2015), and Tier III (2016+) engines as noted. (Source: ARB 2016).

Engine Type	Fuel Type	ROG	CO	NOx	PM_{10}	$PM_{2.5}$
Slow Speed	Marine Distillate (0.1% S)	0.78	1.10	17.0 Pre-controlled 17.0 Tier I 14.4 Tier II 3.4 Tier III	0.25	0.23
Medium Speed	Marine Distillate (0.1% S)	0.65	1.10	13.2 Pre-controlled 13.2 Tier I 10.9 Tier II 2.7 Tier III[a]	0.25	0.23
Steam	Marine Distillate (2.7% S)	0.11	0.2	2.1	0.80	0.78
Auxiliary	Marine Distillate (0.1% S)	0.52	1.10	13.9 Pre-controlled 11.54 Tier I 9.20 Tier II 2.31 Tier III[a]	0.25	0.23
Auxiliary Boiler	Marine Distillate (0.1% S)	0.11	0.2	1.995	0.133	0.130

[a]No vessels with Tier III engines visited the Port of Oakland in 2017.

NOx emissions from marine engines are regulated by model year with Tier I beginning with the 2000 model year, Tier II beginning with model year 2011, and Tier III beginning with model year 2016 (for vessels operating in the North American Emission Control Area). Minimum marine engine emission standards for foreign flagged vessels are specified in MARPOL Annex 13 which defines the model year as the year in which "keels … are laid or which are at a similar stage of construction." Though not all of the ships have 'keel laid' as an entry in the Fairplay database, all ships have a date of build listed. This date was used together with the average time from the keel laid to the listed date of build for container ships calling at the Port for which both dates were provided (240 days) to estimate the model year of the vessel. Tier I, II, and III NO_x emission rates were derived from ARB (2016).

Emission rates assuming 0.1% fuel sulfur content were used based on the ARB fuel regulation except for steamships for which 2.7% sulfur content was used. The fuel sulfur level and the fuel consumption of the engines and boilers were used to estimate SOx emissions assuming all sulfur is emitted as SO_2.

2.3.2 Propulsion Power

Propulsion power during each operating mode was estimated based on vessel installed power, design speed, and the actual speed during the transiting mode.

Propulsion power and vessel design speed were derived from the IHS Fairplay (2018) database, which reports design features for each vessel. To obtain estimates of maximum power and speed, main engine power and vessel design speed from the IHS Fairplay data were used directly, consistent with ARB's methodology (ARB, 2011a).

Load factors for the propulsion power over any given link were determined from the classic Stokes Law cubic relationship for speed and load. The proportional relationship of load to the vessel speed can be expressed as

$$\textit{Load Factor} = (\textit{Vessel Speed} / \textit{Vessel Maximum Speed})^3,$$

where the 100% load factor would correspond to the vessel operating at its maximum speed.

The design speed of the vessel was estimated to be 93.7% of the maximum speed. The vessel design speed was assumed to be equal to the cruise speed. Thus the load factor at the cruise speed is 0.823. For other transiting modes the load was calculated from the equation shown above and is unique to each vessel's reported design speed.

2.3.2.1 Low Load Adjustment Factors

Emission factors for OGV engines were derived from data collected at high operational loads. Adjustment factors are applied to obtain emission factors applicable to operation at very low loads where the engine does not operate as efficiently. Low load adjustment factors previously recommended by ARB (see ENVIRON, 2008a), for propulsion engines were applied (see Table 2-6); these adjustment factors are consistent with those used in the calendar year 2008 Port of Los Angeles emission inventory (Starcrest, 2009) for HC, CO, NOx and SOx. Low load adjustment factors for PM listed in Table 2-6 are from ARB (2006a).

Table 2-6. Ocean Going Vessels – Low load adjustment factors for propulsion engines.

Load %	HC	CO	NOx	SOx	PM
1	N/A	N/A	N/A	N/A	9.82
2	21.18	9.68	4.63	1.00	5.60
3	11.68	6.46	2.92	1.00	4.03
4	7.71	4.86	2.21	1.00	3.19
5	5.61	3.89	1.83	1.00	2.66
6	4.35	3.25	1.60	1.00	2.29
7	3.52	2.79	1.45	1.00	2.02
8	2.95	2.45	1.35	1.00	1.82
9	2.52	2.18	1.27	1.00	1.65
10	2.18	1.96	1.22	1.00	1.52
11	1.96	1.79	1.17	1.00	1.40
12	1.76	1.64	1.14	1.00	1.31
13	1.60	1.52	1.11	1.00	1.22
14	1.47	1.41	1.08	1.00	1.15
15	1.36	1.32	1.06	1.00	1.09
16	1.26	1.24	1.05	1.00	1.03
17	1.18	1.17	1.03	1.00	1.00
18	1.11	1.11	1.02	1.00	1.00
19	1.05	1.05	1.01	1.00	1.00
20	1	1	1	1	1

Source: Table 3.8 from Starcrest (2009) except PM.

For the emission inventory generated using average link speeds and not AIS data, a 2% average propulsion engine load was assumed for the maneuvering mode (accounting for activity between the Bay Bridge and berth). For the RSZ mode (between the Bay Bridge and the Sea Buoy), a load factor was calculated specifically for each vessel as the cube root of the ratio of the assumed RSZ mode speed (13.5 knots) to the maximum speed of the vessel. Of all vessels calling at Oakland, the maximum speed of the fastest vessel was estimated to be 30 knots, so the load factor was as low as 9% within the RSZ mode with other vessels operating at slightly higher loads.

For the emission inventory generated using speed profiles derived from the AIS data, the calculated engine load was different for each speed bin to account for the variability in speeds throughout the link. A 2% average propulsion engine load was assumed for the vessel shift activities within the Port zone, which addressed vessel movement between anchorage and berths.

There have been recent reassessments of the low load adjustment factors for propulsion engines. Starcrest (2015) provided alternative load adjustment factors to be applied to emission factors for slide-valve and non-slide-valve MAN 2-stroke slow speed engines.[17] These alternative load adjustment factors are provided in Appendix B. The ARB[18] has indicated that the agency plans to use the new Starcrest low load adjustment factors for MAN engines with

[17] MAN refers to engines manufactured by MAN SE, a European Company.
[18] Personal communication from Corey Palmer, ARB, April 4, 2018.

slide valves, and apply the new Starcrest low load adjustment factors for MAN engines without slide valves to all other propulsion engines. As a sensitivity assessment, these alternative low load adjustment factors were used to generate an alternative set of emission estimates for the Port of Oakland 2017 vessel activity (see Section 2.4.1).

Given the two different low-load factor assumptions and two different methods for estimating propulsion engine loads described above, emission estimate for three different cases are presented below to reflect the different emission methodologies. The first case uses the same methodology used since the 2005 Port of Oakland Seaport Emissions Inventory, which assumes a single average speed on each transit link for every ship and applies the historical low-load adjustment factors that have been used since 2005. The second case employs the AIS-generated average speed distribution results on each transit link to better reflect the actual operating conditions in combination with the historical low-load adjustment factors. The third case uses the revised low-load adjustment factors applied to emission factors derived from the transit speed distributions used in the second case. Emission estimates for all three cases are presented in Section 2.4.

2.3.2.1.1 Transiting

Each voyage represented one inbound and one outbound trip through the Golden Gate. The vessel speed and time for each mode (based on distance using either the average speeds by leg method or the new method based on time in speed bin from AIS data) were used to estimate the propulsion and auxiliary engine(s) and boiler load and total work (kW-hrs) which were then combined with the appropriate emissions factor to calculate emissions.

2.3.2.1.2 Shifts and Maneuvering

A shift occurs when a ship moves from one berth or anchorage to another and is considered an additional maneuvering mode for those calls. For 2017, there were 115 shifts representing movement between berths or to or from the anchorage and the Port. The time from the beginning to the end of the maneuvering mode was provided by the SFMX data to which 15 minutes was added to account for propulsion engine start up and shut down. The 0.75 hours per shift from anchorage to berth (or vice versa) was also included in the shift activity and emissions estimates.

2.3.3 Auxiliary Power

As described in Port of Oakland Seaport Emissions Inventory for 2005, vessel auxiliary power was primarily derived from auxiliary generator capacity taken from the IHS Fairplay database. For vessels with missing IHS data (51 of the 333 ships), auxiliary power was estimated by finding sister ships (vessels with the same size and owner) for which data were available in IHS or using information from older databases.

The auxiliary engine load factors shown in Table 2-7 represent vessel activity for Port of Oakland calls by container ships. These load factors were taken from ARB (2011a).

Table 2-7. Ocean Going Vessels – Auxiliary engine load factors assumptions.

Ship-Type	Cruise	Reduced Speed Zone (RSZ)	Maneuvering	Hotel
Container Ship	13%	13%	50%	18%

Source: ARB, 2011a.

For each vessel call, the time when the auxiliary engine was running was estimated and used in the emission calculations. For those calls without shoreside power, the hotelling time was set equal to the time at berth.

2.3.3.1 Transiting

The transiting time described above was multiplied by the auxiliary generator capacity and the load factor to estimate the total work during each mode.

2.3.3.2 At Berth

The at-berth time was determined from the SFMX berth report 'first line on' and 'last line off' date and time stamps. The average berthing time in 2017 was 25 hours per call, which is lower than the 44 hours in 2015, but higher than the average of 21 hours per call in 2012 and 2005.

2.3.3.3 Shore Power Benefits

Emissions avoided as a result of alternative marine power (AMP, also known as shore power) usage were addressed in the calculation of hotelling emissions by subtracting the time when shore power was used from the berthing time. The Port of Oakland provided shore power data. There were over 1,000 calls averaging 18.5 hours on shore power per call during 2017. This represents a greater than 50% reduction in auxiliary engine operating hours at berth overall.

Data on shore power usage during 2017 also provide a comparison of the auxiliary engine load with the default 18% load factor assumed by ARB used to develop the emission estimates presented in this report. When shore power is connected, the kW-hr billed and connection time (hours) are recorded, thus affording an estimate of average load demanded. Data from the Port of Oakland for shore power calls in 2017 indicate that the average in-use power demanded was 10.5% of the auxiliary generator capacity for the significant shore power connections made (ignoring unusually short or low load connections), which is 42% lower than the default 18% load factor estimate. Figure 2-5 shows the comparison of the predicted and measured auxiliary load for each connection. Because the auxiliary load does not correlate with auxiliary generator capacity, applying the average load of 1,147 +/- 21 kW (95% confidence interval) to each call regardless of auxiliary engine generator capacity would better represent the actual berthing load than assuming 18% of generator capacity as per the ARB methodology. However, further investigation will be required before this approach can be recommended.

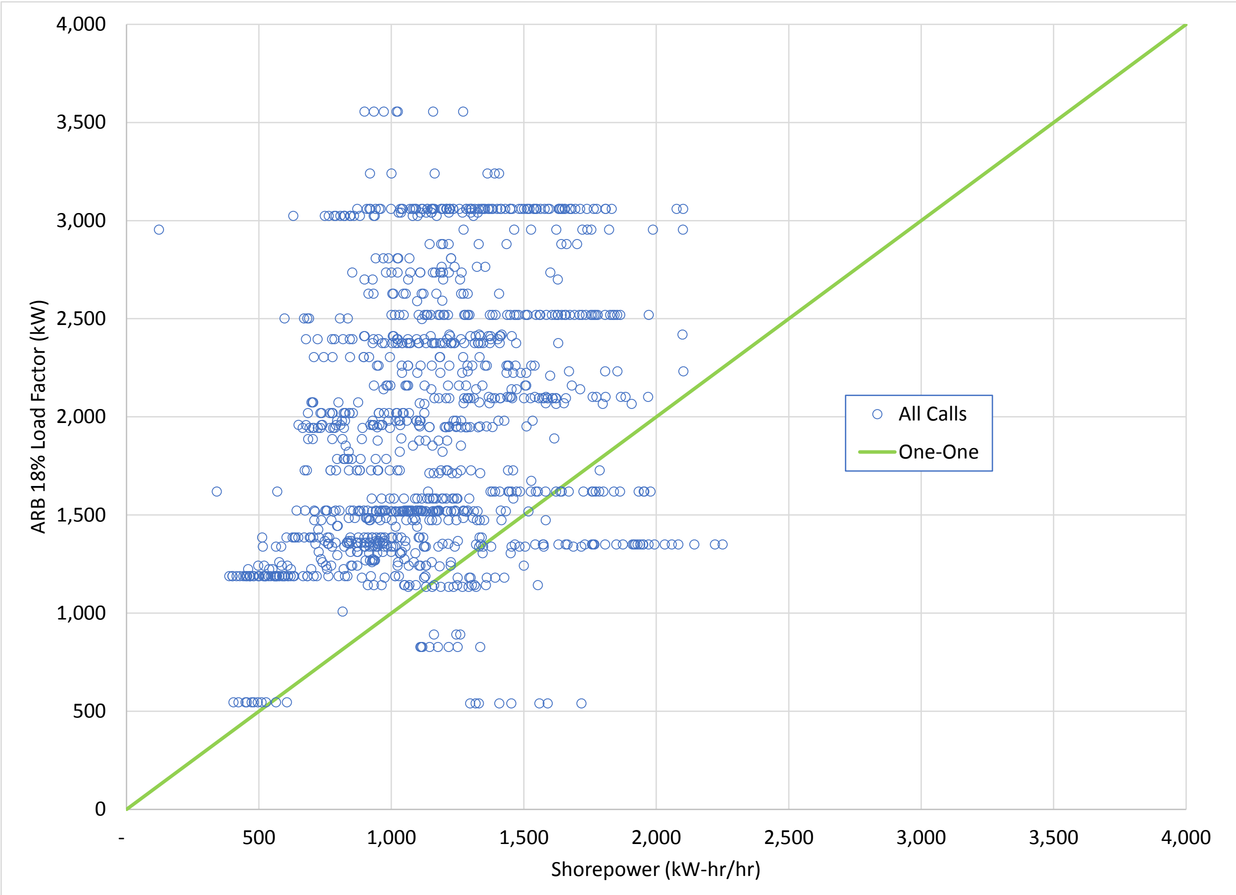


Figure 2-5. Actual shore power demand compared with auxiliary generator capacity assuming 18% auxiliary engine load. Vessel calls shown above the green line would have overestimated emissions using the 18% load assumption rather than actual auxiliary shore power demand.

2.3.3.4 At Anchor

For 2017, there were 149 calls averaging 27 hours each at anchorage either before or after calling at a Port berth. There was one vessel that accounted for nearly 35% of all anchorage time in 2017. According to the SFMX, this vessel was delayed at the Port of Oakland for nearly two months on a Captain of the Port hold due to engine issues. Table 2-8 shows the historic trend in anchorage of ships calling the Port.

Table 2-8. Historic Anchorage Activity.

Calendar Year:	2017	2015	2012	2005
Calls	149	307	37	99
Average Time (hours)	27.0	57.2	13.9	15.2
Total Time (hours)	4,023	17,560	514	1,505

2.3.4 Boilers

In-use boiler power estimates of 506 kW for container ships were assumed based on ARB modeling (2013).[19] Boiler emission factors shown in Table 2-9 were used; these are consistent with emission factors used in ARB (2011a). Boilers were assumed to be in use during transiting, berthing, shifting and anchorage.

Table 2-9. Auxiliary boiler emission rates (g/kW-hr).

Fuel Type	ROG	CO	NOx	PM_{10}	SOx	CO_2	CH_4	N_2O
0.1% Sulfur	0.11	0.20	1.995	0.133	0.58	921.5	0.032	0.013

Source: ARB, 2011a

2.4 Summary of OGV Emission Results

Emission totals from propulsion engines, auxiliary engines, and auxiliary boilers were assessed for OGVs using three different approaches:

1) average ("static") leg speeds and historic low load adjustment factors as in previous Port inventories,
2) AIS-based speed profiles and historic low load adjustment factors, and
3) AIS-based speed profiles with revised low-load adjustment factors.

Emissions by operating mode calculated by each method are provided in Tables 2-10, 2-11, and 2-12. Table 2-10 shows emissions from OGVs using static leg speeds and historic low load adjustment factors which is the same methodology used in the 2005, 2012, and 2015 emission inventories. Table 2-11 shows emissions from OGVs using speed profiles developed using AIS-based speed profiles based on AIS data from June – December 2017. Table 2-12 shows emissions from OGVs using the AIS-based speed profiles and the revised load adjustment factors that were used in the Port of Los Angeles 2014 and subsequent inventories.

Total DPM emissions from the main and auxiliary diesel engines are provided in all three tables. Propulsion steam and auxiliary boiler particulate matter emissions are not included in the DPM total because they are not generated by diesel engines. Shore power emission reductions shown in these tables represent the berthing emissions avoided due to the use of shore power.

As noted in Section 2.3.3.3 above, the use of shore power represents greater than 50% reduction in auxiliary engine operating hours at berth overall and resulted in 40-50% reduction in emissions for all pollutants (berthing emission percent reductions vary by pollutant because auxiliary boilers are unaffected by the use of shore power). Emissions of GHGs shown in Tables 2-10, 2-11, and 2-12 do not account for GHG emissions from generation and transmission (G&T) of electricity used for shore power. GHG emissions from electricity G&T for shore power are estimated to have been 9,905 tons CO_2e in 2017 based on electricity consumption records and

[19] Ocean Going Vessels, Marine Emissions Model v2.3L, https://www.arb.ca.gov/msei/ordiesel.htm

ARB methods for estimating emissions from grid electricity (ARB 2018).[20] When this is added to the 2017 berthing CO_2e from Tables 2-10, 2-11 or 2-12, the CO_2e emissions avoided due to shore power use are reduced to 21,813 tons CO_2e and the corresponding berthing percent reduction is 28% rather than 41%. However, as noted in Section 2.3.3.3 above, in keeping with ARB methodology the auxiliary engine berthing emissions used to generate the results shown in these tables are based on an assumed 18% engine load factor and this implies an average 74% greater power demand by vessels at berth than indicated by the shore power electricity consumption records. If auxiliary engine loads used for the emission calculations were adjusted accordingly, the shore power CO_2e benefit with electricity G&T included would be approximately 15%.

Table 2-10. Emissions totals for OGV calling at the Port of Oakland in 2017 by mode for main and auxiliary engines and boilers – tons. Static (average) Speeds and Historic Load Adjustment Factors.

2017 Inventory	**Criteria Air Pollutants**							**Greenhouse Gas[a] CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O**			
	ROG	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**	**CO_2**	**CH_4**	**N_2O**	**CO_2e**
OGV – Cruise	31.17	44.49	651.45	11.37	10.53	10.01	41.25	25,734	3.21	0.76	26,040
OGV – RSZ	39.11	52.83	592.27	11.78	10.93	10.05	42.46	24,769	2.90	0.69	25,046
OGV – Maneuver	74.75	64.47	526.35	11.47	10.60	10.60	13.14	18,740	2.26	0.48	18,938
OGV – Berth	20.83	43.33	444.05	11.80	11.02	8.84	27.02	44,867	3.89	0.93	45,240
OGV – Shifts	7.53	6.38	52.01	1.08	1.00	1.04	1.11	1,779	0.21	0.05	1,798
OGV – Anchorage	3.70	7.76	78.44	1.96	1.82	1.66	3.96	6,653	0.67	0.15	6,714
OGV Subtotal	**177.10**	**219.26**	**2,344.58**	**49.46**	**45.90**	**42.21**	**128.92**	**122,542**	**13.14**	**3.04**	**123,775**
Emissions avoided due to shore power (tons)	23.64	50.01	493.58	11.37	10.46	11.37	18.19	31,372	4.09	0.82	31,718
Berthing % reduction	53%	54%	53%	49%	49%	56%	40%	41%	51%	47%	41%

[a]Excludes GHG emissions from electricity generation and transmission for shore power (see text).

[20] Examination of shore power usage records for 2017 indicates 23,735,379 kW-hours of electricity consumption. The 2017 state-wide average electricity generation and transmission carbon intensity is 105.16 gCO_2e/MJ (378.58 $gCO_2e/kW\text{-}hr$) based on emission factor ELC001 (ARB, 2018). Thus, the generation and transmission of electricity for shore power use in 2017 produced 9,905 tons CO_2e.

Table 2-11. Emissions totals for OGV calling at the Port of Oakland in 2017 by mode for main and auxiliary engines and boilers – tons. AIS Time in Speed Bin and Historic Load Adjustment Factors.

2017 Inventory	Criteria Air Pollutants							Greenhouse Gas[a] CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
OGV – Cruise	38.28	43.49	406.61	8.87	8.23	7.69	24.59	15,325	1.77	0.42	15,494
OGV – RSZ	45.84	61.01	724.04	14.29	13.26	12.15	53.03	30,059	3.55	0.84	30,398
OGV – Maneuver	25.16	30.93	275.77	6.36	5.87	5.87	10.76	14,003	1.68	0.35	14,150
OGV – Berth	20.83	43.33	444.05	11.80	11.02	8.84	27.02	44,867	3.89	0.93	45,240
OGV – Shifts	7.53	6.38	52.01	1.08	1.00	1.04	1.10	1,779	0.21	0.05	1,798
OGV – Anchorage	3.70	7.76	78.44	1.96	1.82	1.66	3.96	6,653	0.67	0.15	6,714
OGV Subtotal	**141.34**	**192.90**	**1,980.93**	**44.36**	**41.20**	**37.24**	**120.46**	**112,686**	**11.77**	**2.73**	**113,793**
Emissions avoided due to shore power (tons)	23.64	50.01	493.58	11.37	10.46	11.37	18.19	31,372	4.09	0.82	31,718
Berthing % reduction	53%	54%	53%	49%	49%	56%	40%	41%	51%	47%	41%

[a]Excludes GHG emissions from electricity generation and transmission for shore power (see text).

Table 2-12. Emissions totals for OGV calling at the Port of Oakland in 2017 by mode for main and auxiliary engines and boilers – tons. AIS Time in Speed Bin and revised Load Adjustment Factors.

2017 Inventory	Criteria Air Pollutants							Greenhouse Gas[a] CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
OGV – Cruise	17.90	21.50	429.33	4.78	4.46	3.60	24.92	15,868	2.02	0.54	16,079
OGV – RSZ	33.23	54.64	832.03	9.36	8.73	7.22	53.60	30,985	3.64	1.01	31,378
OGV – Maneuver	11.48	19.44	249.83	4.78	4.42	4.29	10.84	14,134	1.77	0.39	14,293
OGV – Berth	20.83	43.33	444.05	11.80	11.02	8.84	27.02	44,867	3.89	0.93	45,240
OGV – Shifts	1.55	2.41	34.23	0.58	0.54	0.54	1.12	1,802	0.23	0.05	1,823
OGV – Anchorage	3.70	7.76	78.44	1.96	1.82	1.66	3.96	6,653	0.67	0.15	6,714
OGV Subtotal	**88.69**	**149.08**	**2,067.90**	**33.26**	**30.99**	**26.14**	**121.45**	**114,308**	**12.22**	**3.06**	**115,527**
Emissions avoided due to shore power (tons)	23.64	50.01	493.58	11.37	10.46	11.37	18.19	31,372	4.09	0.82	31,718
Berthing % reduction	53%	54%	53%	49%	49%	56%	40%	41%	51%	47%	41%

[a]Excludes GHG emissions from electricity generation and transmission for shore power (see text).

2.4.1 Comparison of OGV Emission Calculation Methodologies

A comparison of NOx and DPM emissions for 2017 across the three different calculation methodologies is provided in Figures 2-6 and 2-7. The Port's 2009 Maritime Air Quality Improvement Plan (MAQIP) set goals for NOx and DPM to be achieved by 2020.

2.4.1.1 Average Leg Speeds vs. Speed Profiles

Emissions calculated using AIS-based speed profiles instead of average (static) leg speeds are lower than those estimated using the historical method, as shown in Table 2-10 and 2-11. The speed profiles provide the ability to assess the variability in speed as vessels approach and depart the Port. This leads to a more accurate representation of propulsion engine loads and vessel emissions. For example, the emissions in the "cruise" or precautionary zone are generally lower when calculated using the speed profiles, which suggests the speed profile for this zone captures vessel speeds that are lower than the average speed scenario, which assumes a constant cruise speed for all vessels.

On the other hand, emissions in the reduced speed zone are higher when calculated using the speed profiles. The average speed scenario for the RSZ used an average speed of 13.5 knots for all legs in the RSZ, which implied only minimal low load adjustments for engine loads. In contrast, speeds below 13.5 knots are present in the speed profiles for the areas included in the RSZ, which leads to lower engine loads, but higher low load adjustment factors with the net result being higher emissions.

The emission calculations performed using speed profiles also result in significantly reduced emissions during maneuvering. In previous inventories, an average time of maneuvering based on vessel length overall and an engine load of 2% was used to determine emissions in this zone. The AIS data provided within the "Port" zone captured these maneuvering movements, which allowed for development of a speed profile for this area. This speed profile provides more representative data on time of movements and engine loads within this zone.

2.4.1.2 Historic Low Load Adjustment Factors vs. Revised Low Load Adjustment Factors

The influence of applying the revised Starcrest (2015) low-load adjustment factors discussed in Section 2.3.2.1 above instead of the factors listed in Table 2-6 is quantified in Tables 2-11 and 2-12 and shown for NOx and DPM in Figures 2-6 and 2-7. The applicable (either MAN slide valve or non-slide valve) revised low load adjustment factors listed in Appendix B were applied to all diesel propulsion engines; the historic low load adjustment factors listed in Table 2-6 were retained for application to steam propulsion engines (which accounted for 115 voyages in 2017). The MAN 2-stroke engines accounted for 988 of the 1,596 vessel voyages (62%) in 2017, while non-MAN 2-stroke engines (Wartsila/Sulzer manufactured engines) accounted for 493 voyages (31%).

Total emissions calculated using the revised low load adjustment factors are lower for some pollutants (ROG, CO, PM_{10}, $PM_{2.5}$, and DPM) while other pollutants show increased emissions (NOx, SOx, N_2O, CH_4, and CO_2). In general, the revised low load adjustment factors for the pollutants which result in lower emissions are lower than the historic low load adjustment factors. For NOx, the revised adjustment factors at low loads (up to 5%) were significantly lower than the historic factors at the respective loads; however, beyond 5% load, the revised adjustment factors are greater than historic factors, leading to overall higher NOx emissions for the entire 2017 inventory. In addition, emissions of SOx, N_2O, CH_4, and CO_2 are higher using the revised load adjustment factors because these emissions were not adjusted at all when using the historic low load adjustment factors.

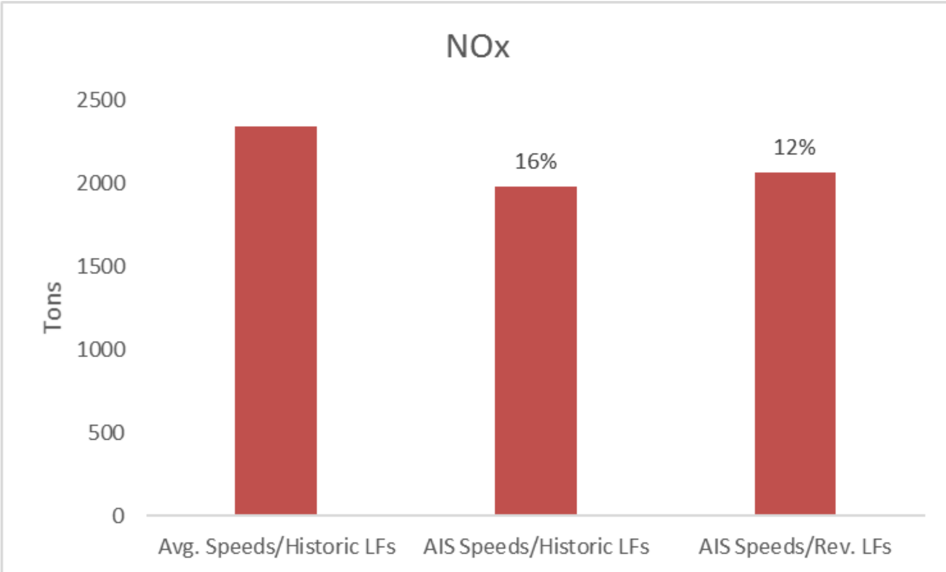


Figure 2-6. Comparison of NOx emissions calculated via different methodologies (LF = Emission adjustment by load factor; percentage values show reductions relative to the Avg. Speeds/Historic LFs case).

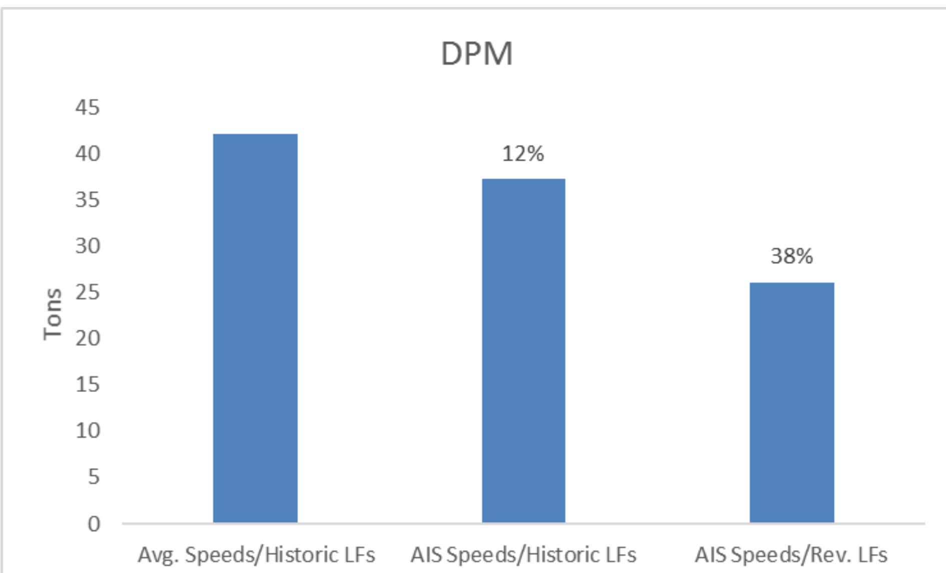


Figure 2-7. Comparison of DPM emissions calculated via different methodologies (LF = Emission adjustment by load factor; percentage values show reductions relative to the Avg. Speeds/Historic LFs case).

2.4.2 Comparisons with Prior Year Inventories

Changes in the OGV DPM and NOx emissions from past inventories are compared with emissions from Table 2-10 in Figure 2-8. Emissions in tables 2-11 and 2-12 cannot be compared directly with prior year inventories due to the differences in methodology noted above. Both NOx and DPM emissions are lower for 2017 as compared with three previous inventories.[21] NOx emission reductions resulted both from the use of shore power and fleet turnover to newer ship engines designed to meet lower NOx emission standards. DPM reductions may be attributed to increased use of low sulfur fuel and the use of shore power.

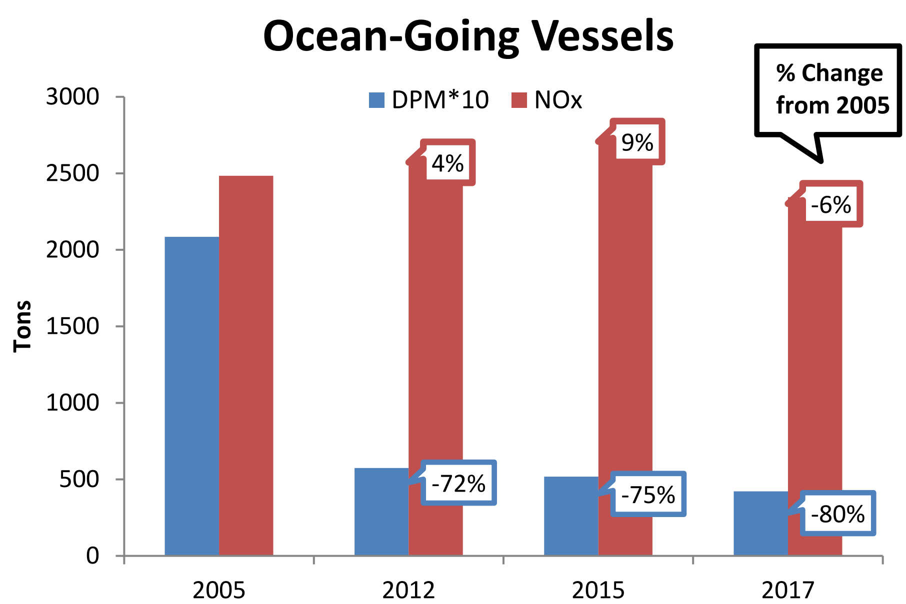


Figure 2-8. Yearly change in OGV DPM and NOx emissions.

[21] Direct comparison with only the 2015 inventory is not representative, as there was an unusual amount of berthing, shifts, and anchorage activity in 2015 due to a slow down at the beginning of the year.

3.0 COMMERCIAL HARBOR CRAFT

This section describes emissions estimation methodologies and results for three regularly occurring activities at the Port of Oakland: 1) operation and maintenance dredging in the channels and at berths and disposal of dredged material, 2) container ship assist tugs, and 3) tug trips and fuel pumping from fuel barges towed from Richmond to refuel ships' bunkers at the Port. The bunker refueling activity has been added to the harbor craft emission inventory for 2017; this activity was not part of the prior Port maritime inventories because refueling data were not available. Other than a few small work boats that assist dredging operations and the dredges themselves, tugs are the primary category of commercial harbor craft in the Port's maritime emissions inventory. This inventory does not include dredging and vessel assist activities at the privately owned Schnitzer Steel bulk cargo terminal berths or emissions from boats based in San Francisco used by the San Francisco Bar Pilots.

3.1 Operation and Maintenance Dredging and Disposal

3.1.1 Background and Limitation

Operation and maintenance (O&M) dredging is conducted annually at the Port of Oakland to maintain the depth of channels and berths and to ensure safe navigation. O&M dredging removes material that is deposited into the Bay by stream and urban runoff throughout the Sacramento-San Joaquin River Delta area extending east to the Sierras, and eliminates shallow areas created by the redistribution of bottom sediments through a process known as "shoaling." The channel dredging was conducted from August 2017 into February 2018, while berth dredging was conducted in August, October, and the first two weeks of November 2017.

The Port and the US Army Corps of Engineers (USACE) contract separately for O&M dredging at the Port's berths and in the Federal channels serving the Port, respectively. During 2017, dredging was conducted by a diesel-powered derrick barge (clamshell) dredge, accompanied by tender tugs and work boats.

Dredged material was transferred into scows (barges) which were towed by a diesel-powered tug to a disposal site. After the barge was emptied, the tug returned with the empty barge to pick up a new load.

The contractor working for both the Port in 2017 and the USACE in 2017 removed 89,000 cubic yards of material from the Port's berths and 559,000 cubic yards of material from the channel in 2017 (Dutra, 2018). All of the material excavated from the channels and Port berths was disposed of at the San Francisco Deep Ocean Disposal Site (SF-DODS). SF-DODS is an open water site located approximately 49 nautical miles (nm) west of the Golden Gate.

3.1.2 Dredging Emissions Methodology

O&M dredging and disposal activities were treated as two separate activities: 1) dredging (operation of the clamshell dredge and associated support vessels), and 2) disposal (transport of dredge materials from the dredging area to disposal sites). Emissions from these activities were summed to form the final total emissions estimate.

3.1.2.1 Dredger and Dredging Support Vessels

Dutra Construction, the contractor responsible for the 2017 POAK berth dredging project and the 2017 calendar year federal channel dredging, provided a list of equipment used for O&M and channel deepening dredging; they include:

- A clamshell dredge on a dredge barge
    - Main and auxiliary diesel engines
- Dredge tenders and work boats
    - Two main propulsion diesel engines
    - One or two auxiliary engines

The basic equation used to calculate emissions from each of the engines involved in dredging is:

$$Equip_{Emiss} = \frac{EF \times Time_{hrs} \times Engine_{bhp} \times LF_{wt}}{(453.6 \times 2000)}$$

Where:

$Equip_{Emiss}$ is the engine's emissions in tons per year,
EF is the engine emission factor in grams per brake horsepower-hour,
$Time_{hrs}$ is the annual operating hours,
$Engine_{bhp}$ is the brake horsepower rating of the engine,
LF_{wt} is the time weighted engine load factor (fraction of full load), based on different engine operating modes during a round trip, and
(453.6 x 2000) is the conversion factor from grams to tons.

3.1.2.2 Dredge Material Disposal

In 2017 all dredged material was disposed of by removing it to an offsite disposal area. In a typical operation, a diesel-powered tug pushes or tows the loaded scow to its destination and, after unloading, pushes or tows the empty barge back to the dredge. The tow boat tug has two main propulsion engines and one or two auxiliary engines.

The basic equation used to calculate main propulsion and auxiliary engine emissions from the tug is:

$$Tug_{emiss} = \frac{EF \times Engine_{bhp} \times Time_{hrs} \times LF_{wt} \times Trips}{(453.6 \times 2000)}$$

Where:

Tug_{emiss} is the tug emissions in tons per year,

EF is the tug main propulsion or auxiliary engine emission factor in grams per brake horsepower-hour,
$Engine_{bhp}$ is the combined brake horsepower rating of a tug's main propulsion engines and the brake horsepower rating of the auxiliary engines,
$Time_{hrs}$ is the tug operating time per round trip in hours,
LF_{wt} is the time weighted engine load factor (fraction of full load), based on different engine operating modes during a round trip,
Trips is the annual number of round trips per tug, and
(453.6 x 2000) is the conversion factor from grams to tons.

Once it reaches the disposal area, a barge or scow is unloaded either by gravity or mechanically. Unloading at the ocean disposal site SF-DODS was accomplished by gravity - that is, by opening the bottom of the scow and allowing material to flow out.

Dredging performed by the USACE in the federal channel serving the Port during 2017 was all associated with annual maintenance activity and is therefore included in the Port's 2017 emission inventory.

3.1.3 Dredging Input Data and Emissions

Key input data for estimating dredging emissions include the physical characteristics of the vessels and equipment used by the Port and USACE contractor, equipment emission factors, engine load factors, the volume of material removed, and the hours of operation. The dredging contractor Dutra (2018) provided the engine characteristic data and activity in hours of use. ARB vessel emission, deterioration, fuel correction, and load factors were used to estimate emissions for all engines used on the dredging and support vessels. (ARB 2011b)

The 2017 berth dredging at the Port occurred in August and October, and the USACE dredging occurred from August 2017 through February 2018. Dredged material from both projects was sent to the deep ocean disposal site, SF-DODS. Dutra (2018) provided the collected dredging volume and tug and barge trip log data. Because the SF-DODS disposal site is outside the geographic scope of the Port of Oakland emission inventory, only the portion of the USACE disposal trips between the Bay Bridge and the West Buoy near the Farallon Islands (see Fig. 2-1) was included in the inventory calculations; this one-way distance measures approximately 22.2 nautical miles. Dutra estimated 8 knots as a representative average speed for the tug and barge trips.

The tug *Sarah Reed* was reported to be the primary tug to tow the materials dredged from the Port berth and channel maintenance dredging in 2017.

Dredging was accomplished using barge mounted derricks which were positioned using the tender tugs *Becky T* and *Jeannette C*. The Dutra dredgers resemble clamshell excavators or cranes and are not on self-propelled barges.

3.1.3.1 Dredgers and Support Vessels

Input data and assumptions for dredging are summarized in Table 3-1(a), and emission factors associated with each type of equipment are summarized in Table 3-1(b). Emission factors for dredgers were derived from the OFFROAD model incorporating the model year and age of equipment in 2017, while the diesel engines used in tugs and tenders used the load, zero-hour emission factors, and deterioration factors available in the ARB (2011b) harbor craft emission inventory database tool. The zero-hour emission factors in Table 3-2 were adjusted for deterioration, so that the in-use emissions increase with engine age and a downward fuel correction is applied for cleaner California diesel.

Table 3-1(a).Operation & maintenance dredging - key data and variables.

Vessel/Equipment	Use	Engine(s)	Model Year	Power (hp)	Load Factor	Hours	
						POAK	USACE
DB Beaver	Dredge	Main	1999	210	0.42	792	1392
DB Beaver	Dredge	Aux.	2002	810	0.31	792	1392
DB Beaver	Dredge	Aux.	1999	210	0.31	792	1392
Barge 24	Dredge	Main	2002	425	0.42	144	2568
Barge 24	Dredge	Main	2007	300	0.42	144	2568
Barge 24	Dredge	Main	2007	300	0.42	144	2568
Barge 24	Dredge	Main	2007	127	0.42	144	2568
Barge 24	Dredge	Aux.	2006	325	0.31	144	2568
Becky T [2]	Tender	Main (2)	2000	302	0.45	256	600
	Tender	Aux.	2001	150	0.43	256	600
	Tender	Aux.	2002	25	0.43	256	600
Jeannette C [2]	Tender	Main (2)	1983	460	0.45	48	688
	Tender	Aux.	1983	96	0.43	48	688

[1] Main engines assumed to be dredge cranes and auxiliary hoist swing winch
[2] The tender boats use twin diesel engines, Load Factors from ARB Estimate for Work Boats

Table 3-1(b).Operation & maintenance dredging – zero-hour emission factors.

Vessel	Type	Emission Factors in g/bhp-hr							
		ROG	CO	NOx	PM_{10}	$PM_{2.5}$	CO_2	CH_4	N_2O
DB Beaver	Main	0.19	0.92	5.527	0.167	0.162	1011	0.082	0.000
	Aux.	0.32	0.92	6.199	0.146	0.142	1174	0.112	0.000
	Aux.	0.32	0.92	5.958	0.185	0.179	526	0.200	0.000
Barge 24	Main	0.14	0.92	5.276	0.108	0.105	525	0.414	0.000
Barge 24	Main	0.10	0.92	2.807	0.121	0.116	526	0.016	0.000
Barge 24	Main	0.10	0.92	2.807	0.121	0.116	526	0.016	0.000
Barge 24	Main	0.10	0.92	2.856	0.171	0.166	528	0.084	0.000
Barge 24	Aux.	0.10	2.70	4.041	0.104	0.101	524	0.023	0.000
Becky T	Main	0.82	3.07	7.310	0.361	0.350	587	0.074	0.02
Becky T	Aux.	0.81	2.78	7.310	0.319	0.309	587	0.073	0.02
Becky T	Aux.	0.81	2.78	7.310	0.319	0.309	587	0.073	0.02
Jeannette C	Main	1.15	3.07	14.160	0.504	0.489	587	0.104	0.02
Jeannette C	Aux.	1.19	4.53	12.000	0.462	0.448	587	0.107	0.02

Table 3-2. Operation & maintenance dredging emissions - 2017 (tons/yr).[a]

	Equipment	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
POAK	Dredger	0.16	0.53	2.86	0.08	0.08	0.08	0.00	414	0.06	0.00	416
	Tenders	0.17	0.40	1.35	0.07	0.07	0.07	0.00	85	0.02	0.00	86
	Annual Tons	***0.34***	***0.93***	***4.21***	***0.15***	***0.14***	***0.15***	***0.01***	***499***	***0.07***	***0.00***	***502***
USACE	Dredger	1.65	3.72	13.61	0.57	0.56	0.57	0.01	1,495	0.31	0.00	1,501
	Tenders	0.95	2.19	8.19	0.39	0.38	0.39	0.00	370	0.09	0.01	376
	Annual Tons	***2.60***	***5.91***	***21.79***	***0.96***	***0.94***	***0.96***	***0.02***	***1,865***	***0.40***	***0.01***	***1,879***
Total		**2.93**	**6.83**	**26.00**	**1.11**	**1.08**	**1.11**	**1.11**	**2,365**	**0.47**	**0.02**	**2,381**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.

3.1.3.2 Dredge Materials Disposal Vessels

Tables 3-3 and 3-4 summarize the key input data and assumptions used to calculate emissions from dredge materials disposal activities. The load factor for tow boats was used. Emissions are summarized in Table 3-5.

Table 3-3. Dredged material transport tug engine characteristics and emission (Sarah Reed, 2008 model year main engines 1700 hp total, and 132 hp auxiliary).

Engine	Load Factor	2008 Model Year Zero-Hour Emission Factors in g/bhp-hr								
		ROG	CO	NOx	PM_{10}	$PM_{2.5}$	SOx	CO_2	CH_4	N_2O
Main	0.68	0.68	3.73	5.53	0.200	0.194	0.006	587	0.061	0.02
Auxiliary	0.43	0.81	3.73	5.10	0.220	0.213	0.006	587	0.073	0.02

Table 3-4. Dredged material transport activities.

	Destination	Round Trip Distance (nautical miles)	Speed (knot)	Time (hours)	Trips
USACE	SF-DODS[1]	49	8	6.1	247
POAK	SF-DODS[1]	49	8	6.1	42

[1] The location of SF-DODS is beyond the geographic scope of this inventory; the distance and emissions shown here reflect travel between the Harbor and the West buoy of the Precautionary Zone (see Fig. 2-1).

Table 3-5. Dredged material disposal emissions in 2017 (tons per year).[a]

Engine	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SO_x	CO_2	CH_4	N_2O	CO_2e
POAK Total	1.59	8.16	11.29	0.399	0.387	0.399	0.01	1,190	0.14	0.04	1,206
USACE Total	0.27	1.39	1.92	0.068	0.066	0.068	0.00	202	0.02	0.01	205
Total	**1.86**	**9.55**	**13.20**	**0.467**	**0.453**	**0.467**	**0.01**	**1,393**	**0.17**	**0.05**	**1,411**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.

3.1.4 Dredging Emissions Summary Results

Total emissions from Table 3-2 (dredging) and Table 3-5 (dredged material disposal) combined are listed in Table 3-6. Since all emissions are from diesel powered engines, PM_{10} emissions listed in Table 3-6 represent total DPM emissions.

Table 3-6. Summary of operation & maintenance dredging emissions in 2017 (tons per year).

Activity	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Dredging	2.93	6.83	26.00	1.11	1.08	1.11	0.02	2,365	0.47	0.02	2,381
Disposal	1.86	9.55	13.20	0.467	0.453	0.467	0.01	1,393	0.17	0.05	1,411
Total	**4.80**	**16.39**	**39.21**	**1.58**	**1.53**	**1.58**	**0.04**	**3,757**	**0.64**	**0.06**	**3,792**

3.2 Assist Tugs

3.2.1 Background

This section describes the emissions estimation methods and results for operation of tugs that assisted cargo vessel movements upon arrival and departure from the Port. Assist tug operations include two modes: the actual vessel assist operation and the transit trips the tugs make to and from their various berthing bases to conduct the assists.

The role of the assist tugs is to ensure safe navigation, which is particularly important in windy weather and when vessels turn to reverse direction near the Inner or Outer Harbor berths. As discussed in Section 2, cargo vessels operating in the San Francisco Bay have Bar Pilots on board to guide each vessel to and from its destination. On average, just over two tugs were used for each cargo vessel inbound or outbound between berths at the Port and the Federal Channel near the Bay Bridge.

Tugs perform a variety of services around the Bay including vessel escort, berthing and departure assists at Bay Area ports and refineries; and towing or pushing a wide variety of barges and other equipment. Not all tugs are equipped or certified to provide assist services to container vessels calling at the Port. Cargo vessels vary greatly in size, length, and maneuverability, and the tugs that assist them have different power levels, rudders, and other equipment. To ensure safe navigation, it is important that tugs be properly powered and equipped to handle the vessels they are assisting. As might be expected, larger vessels require more tugs (up to five) and the tugs might be larger and more powerful.

Vessel call data specific to the Port of Oakland was provided by the Marine Exchange as described in Section 2. This data set included the number of tugs by tug operator that performed each vessel assist, but did not identify the individual tugs that provided the assist. Tugs assigned to ships calling at the Port of Oakland are operated by five companies identified in the Marine Exchange vessel voyages: AMNAV, Foss Maritime, Starlight Marine (part of Harley Marine Services), Crowley, and BayDelta. AMNAV based their tugs at or near Berth 9 on the

Outer Harbor of the Port, and Starlight tugs are based on the Alameda side of the Inner Harbor Turning Basin for the Port. Together, these two companies accounted for about 78% of assist tug activity for Port of Oakland calls during 2017. BayDelta and Crowley tugs (which accounted for 7% and 8% of calls, respectively) are based in San Francisco near the Bay Bridge, and Foss tugs (8% of calls) are based in Richmond. We assumed that the overall transit activity for BayDelta, Crowley, and Foss were similar to trips to and from the facility at Berth 9. The transit distance from San Francisco to the Bay Bridge is shorter than from Berth 9, but the trip to the Outer Harbor is longer, and the distance to the Inner Harbor is the same. It was assumed that Foss tugs would transit to and from Richmond for every assist at the Port of Oakland but rather they would lay up at a location close to the Port between assists. Tugs from all five companies also operate elsewhere in the Bay, but the activity estimated in this study included only activity during transiting and assisting for the Port of Oakland ship calls.

3.2.2 Methodology

Assist tug emissions were estimated using an approach that closely follows the methodology developed for ARB's Commercial Harbor Craft Emission Inventory Database (ARB, 2011b). The ARB methodology provides emission factors that are specific to main propulsion and auxiliary engine model year and applies both an engine emissions deterioration rate and a fuel correction factor.

The basic equation used to calculate emissions from each group of assist tugs is:

$$\text{Assist Tug}_{\,Emiss} = \frac{AEF \times Time_{\,hrs} \times Engine_{\,bhp} \times LF_{\,wt}}{(453.6 * 2000)}$$

Where:

Assist Tug $_{Emiss}$ are the assist tug emissions in tons per year;

AEF is the main engine or auxiliary engine emission factor in grams per brake horsepower-hour, adjusted for model year, deterioration rate and fuel, and averaged by tug class;

Time $_{hrs}$ is the annual operating hours for the tugs in each group, based on the number of vessel calls, the average maneuvering time per call, and the average number of tugs assigned to each inbound and outbound assist;

Engine $_{Bhp}$ is the weighted average main propulsion and/or auxiliary engine brake horsepower rating of the engines in each tug group;

LF $_{wt}$ is the time weighted load factor for the maneuvering phase for the main engine and/or auxiliary engine, taken from the literature or the ARB methodology, stated as a fraction of full load; and

*(453.6 * 2000)* is the conversion of grams to tons.

3.2.3 Input Data and Emissions

A number of variables affect actual tug emissions during an assist event. Among the most important are the following:

- The number of tugs assisting a vessel,
- The horsepower ratings of assist tug propulsion engines (which vary from tug to tug),
- The load carried by the tug's main propulsion engines (which varies substantially during the assist),
- The time required to complete the assist operation (which varies depending on where the vessel is berthing or departing), and
- The model year of the engines used on the vessel.

The Port and Ramboll created a list of the fleet of tugs that were operating in 2017 and verified the vessel characteristics with the operators. The individual tugs and their relevant characteristics are listed in Table 3-7. Average auxiliary engine horsepower ratings were based on data from tugs for which auxiliary engine installed power was provided. For the assist tug providers, Ramboll distributed the assists for each company equally amongst the tugs listed.

Table 3-7. Assist tug fleet characteristics in 2017.

Company	Name	Engines			
		Model Year	Main Total (HP)	Aux. kW	Main Engine Tier
AMNAV Maritime Services	Patricia Ann	2008	5,080	210	Tier 2
AMNAV Maritime Services	Revolution	2006	5,080	210	Tier 1[a]
AMNAV Maritime Services	Sandra Hughes	2006	5,080	210	Tier 1[a]
AMNAV Maritime Services	Liberty	2008	3,300	210	Tier 2
AMNAV Maritime Services	Patriot	2006	4,300	210	Tier 1
BayDelta	Delta Billie	2009	6,712	215	Tier 2
BayDelta	Delta Cathryn	2009	6,712	215	Tier 2
BayDelta	Delta Audrey	2014	6,712	215	Tier 3
Crowley (BayDelta)	Valor	2007	6,772	215	Tier 1
Crowley (BayDelta)	Goliah	2013	5,150	215	Tier 3
Foss (AMNAV)	Keegan Foss	1998	3,900	198	Tier 2 Low NOx EMD
Foss (AMNAV)	Pacific Star	2008	6,610	198	Tier 1
Foss (AMNAV)	Caden Foss	2017	6,772	365	Tier 4
Foss (AMNAV)	America	2008	6,610	198	Tier 2 Low NOx EMD
Foss (AMNAV)	Lynn Marie	2001	6,250	210	Tier 1
Foss (AMNAV)	Point Fermin	2006	3,500	198	Bunkering, Tier 1
Foss (AMNAV)	Point Vicente	2006	3,500	198	Bunkering, Tier 1
Starlight Marine Services	Ahbra Franco	2013	6,850	290	Tier 3
Starlight Marine Services	Z-3	2012	4,000	204	Tier 2
Starlight Marine Services	Z-4	2012	4,000	204	Tier 2
Starlight Marine Services	Z-5	2012	4,000	204	Tier 2

[a]AMNAV was recently awarded funding under the Carl Moyer Program to retrofit the *Sandra Hughes* and *Revolution* with Tier III engines.

Ramboll used Port of Oakland-specific data to estimate the time tugs spent in the assist mode by assuming that the assist operation coincides with the vessel maneuvering mode. While assists generally start and end near the Bay Bridge, the time required for ships to maneuver between this location and each berth varies between the Inner and Outer Harbor as described for ocean-going vessel maneuvering time in Section 2. Ramboll estimated a specific maneuvering time for each vessel call based on berth location (Inner or Outer Harbor) and vessel length.

Ramboll estimated the time transiting to and from assists for each tug operator using the distances from each operator's home base to various assist destinations, and assuming the transit trips were made at an average speed of 8 knots. Occasionally, tugs may 'lay up' near their next assignment (such as at Berth 38-Nutter Terminal nearest the Bay Bridge or at the berth for the next outbound ship), but no adjustment was made for this circumstance. Thus, assuming a return to base for each assist may result in an overestimate of emissions associated with tug transiting. Transit trips included the following links:

- Base to incoming vessel pickup point (about 3.25 nautical miles from Berth 9, and 4 nautical miles from the Inner Harbor turning basin),
- Return trip to base from the Inner and Outer Harbor berths,
- Trip from base to Inner and Outer Harbor berths to begin outbound vessel assist, and
- Return to base from the outbound vessel assist.

In summary, Ramboll estimated the tug assist activity during the assist phase of their operation at the Port of Oakland as follows:

- Allocated annual assists by tug operator, based on the information contained in the Marine Exchange report described above.
- Developed a database that described the key characteristics of the fleet of the tugs that the five tug companies operate at the Port of Oakland.
- Assigned the number of tugs to incoming and outgoing vessel calls based on the Marine Exchange report, which showed an average of 2.20 inbound and 2.08 outbound per ship move in 2017.
- Estimated the time that assist tugs operate on Port of Oakland vessel maneuvering
  - While engaged in maneuvering ships inbound and outbound from the Port and
  - While transiting to and from maneuvering assists.

Ramboll used zero-hour emission factors, engine emissions deterioration factors and fuel correction factors for both main propulsion and auxiliary engines from ARB's database emission inventory tool (ARB, 2011b). However, the main engine load factor was estimated to be 0.31, and the auxiliary engines load factor was estimated to be 0.43. These load factors correspond to values used in the Port of Oakland 2005, 2012, and 2015 Seaport Air Emissions inventories

(ENVIRON, 2008a, 2013; Ramboll Environ, 2016) and the Port of Los Angeles Inventory of Air Emissions (Starcrest, 2012).

Table 3-8 summarizes the 2017 activity factors for both the assist and transit modes; emission estimates for assist tugs are shown in Table 3-9.

Table 3-8. Assist tug activity levels for 2017.

# of Inner Harbor Assists		# of Outer Harbor Assists		Assist Hours	Transit Hours	Total Hours
Inbound	Outbound	Inbound	Outbound			
2,624	2,397	908	929	7,106	4,084	11,191

Table 3-9. Tug assist emissions (tons per year).[a,b]

Engine	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Main	13.23	58.90	106.38	4.25	4.12	4.25	0.10	11,695	1	0	11,829
Auxiliary	1.19	5.28	6.69	0.25	0.24	0.25	0.01	917	0	0	928
Total	14.42	64.18	113.07	4.50	4.36	4.50	0.10	12,612	1	0	12,757

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., “0.00”) are not identically equal to zero.
[b]Includes both assist and transit modes

3.2.4 Bunkering Barges

3.2.4.1 Background

As mentioned in Section 1, in 2005, 2012, and 2015, bunkering activity was not provided to Ramboll and so was not included in the 2005, 2012, and 2015 air emissions inventories. For 2017, the Port and Ramboll collected the date and fuel cost for bunkering events in 2017 from Foss Maritime,[22] who provided this service to ships. Ship refueling was accomplished by pumping fuel from a barge to the ship while at berth. The bunkering barge was towed from and returned to the Richmond long wharf approximately 10 nautical miles from the Port. However, if the bunkering events at the Port occurred on the same day or on successive days, the bunkering barge may have stayed at the Port or tied up nearby at Treasure Island.

3.2.4.2 Methodology

Bunkering emissions were estimated using the same approach as that described above for dredging since each operation involves a barge and an accompanying tug. The tug load and time in mode for movement of the bunkering barge were used to estimate the emissions during the transit trip. Emissions from the tug used to tow the fuel barge between Richmond and the

[22] Foss Maritime 2018. Personal communication from Jason Knowlton, February 2018.

Port were calculated in the same manner as emissions from the tug used to tow the dredge spoils.

Emissions from the barge-mounted diesel-powered pumps were estimated from the ARB OFFROAD model emission rates for pumps.

3.2.4.3 Input Data and Emissions

A total of 314 bunkering events occurred in 2017. Of these, 95 second or third bunkering events occurred on the same day and thus were assumed to not require a trip to Richmond and back. Therefore, Ramboll assumed a total of 219 round trips to and from Richmond in 2017.

Propulsion and auxiliary engine model year and power data for the *Point Vicente* and *Point Fermin* tugs used to tow the bunkering barge are shown in Table 3-7. The company providing bunkering, Foss Maritime, estimated that the one-way trip from Richmond to the Port takes about 2.5 hours, thus accounting for 1,095 bunker barge towing hours in 2017.

Ramboll calculated the average cost of fuel per bunkering event and found that the average was about half the maximum event. Foss Maritime reported that the time to refuel ships ranged up to 8 hours. Therefore, we estimated that the average bunkering event would take four hours of pumping or about 1,256 hours of pumping for all 314 bunkering events. Pumping was performed by two 500 hp model year 2003 diesel barge pumps using non-road Tier 2 engines.

Total emissions for the bunkering operation tow boats and barge pumps are shown in Table 3-10. Bunkering volume levels were higher in 2005 although the 2005 bunkering emissions were not quantified.

Table 3-10. Tug towboat and barge pump emissions for bunkering events during 2017 (tons).[a]

Engine	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Tug Main	2.32	6.27	21.70	1.068	1.036	1.068	0.02	1,925	0.21	0.06	1,947
Tug Auxiliary	0.13	0.58	0.75	0.030	0.029	0.030	0.00	98	0.01	0.00	99
Pumps	0.23	0.72	3.24	0.082	0.075	0.082	0.00	397	0.02	0.00	398
Total	**2.68**	**7.57**	**25.69**	**1.180**	**1.141**	**1.180**	**0.02**	**2,420**	**0.24**	**0.06**	**2,444**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.

3.3 Summary of Commercial Harbor Craft Emissions

Table 3-11 summarizes harbor craft emissions for 2017. Note that emissions from bunkering were not reported in prior year inventories. All of the PM_{10} emissions listed here come from diesel engines and are therefore DPM.

Table 3-11. Total harbor craft & dredge emissions, 2017 (tons).

Harbor Craft	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SO_x	CO_2	CH_4	N_2O	CO_2e
O&M Dredging	4.80	16.39	39.21	1.58	1.53	1.58	0.04	3,757	0.64	0.06	3,792
Assist Tug	14.42	64.18	113.07	4.50	4.36	4.50	0.10	12,612	1	0	12,757
Subtotal	**19.22**	**80.56**	**152.28**	**6.08**	**5.90**	**6.08**	**0.14**	**16,369**	**1.93**	**0.44**	**16,548**
Bunkering Barges	2.68	7.57	25.69	1.18	1.14	1.18	0.02	2,420	0.24	0.06	2,444
Total Emissions	**21.91**	**88.13**	**177.96**	**7.26**	**7.04**	**7.26**	**0.16**	**18,789**	**2.18**	**0.50**	**18,992**

The harbor craft NOx and DPM emissions estimates for 2005, 2012, and 2015 are shown in Figure 3-1. Emissions declined between 2005 and 2015 as vessel fleets turned over to incorporate lower emitting engines. Emissions in 2017, excluding bunker barge activity, are estimated to be lower than in 2015 based on changes to the tug fleet mix despite an overall 10% increase in OGV activity levels.

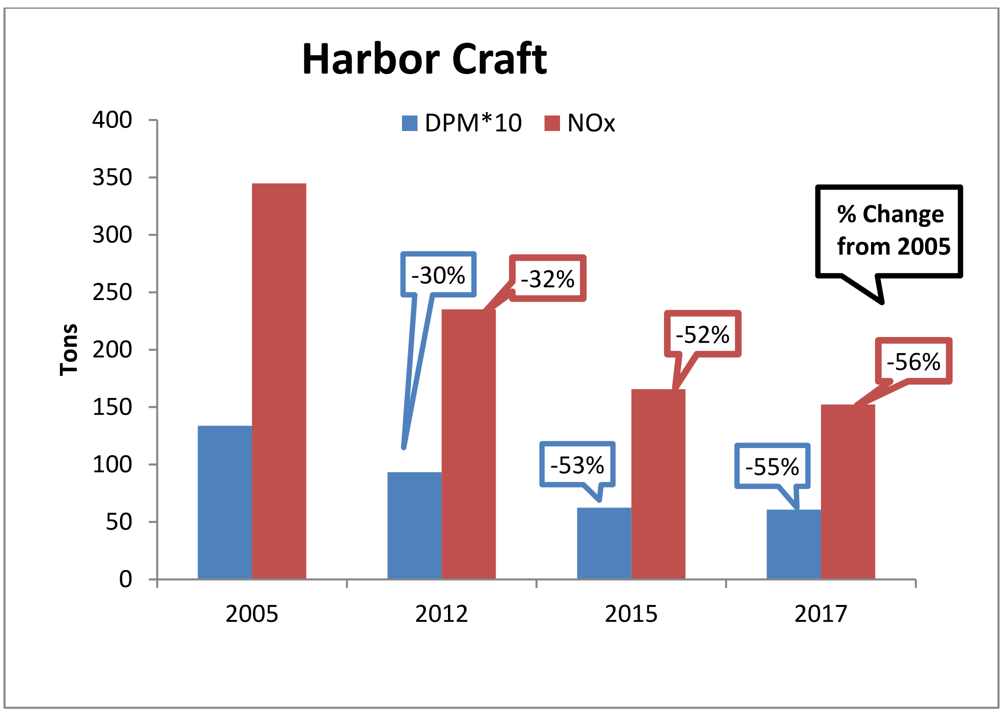


Figure 3-1. DPM and NOx emissions from harbor craft activity (2017 emissions shown here do not include bunkering – see text).

4.0 CARGO HANDLING EQUIPMENT

This section documents emission estimation methods and results for cargo handling equipment (CHE) operated at Port of Oakland. The 2017 Port of Oakland CHE emission inventory includes on-dock and off-dock terminals and the OIG rail yard. Previous Port of Oakland CHE emission inventories did not include CHE operated at off-dock terminals because activities at off-dock terminals are related to functions such as transloading that are not unique to port tenants, that is, such activities may occur at facilities that are on or off Port property. Nevertheless, in an effort to expand the Port of Oakland maritime inventory to include activities at all Port maritime tenant facilities, emissions from CHE at off-dock terminals are included in the 2017 emission inventory. As in past years, the Port maritime inventory does not include CHE at the Schnitzer Steel facility or the Union Pacific rail yard because those privately owned facilities are not located on Port property.

4.1 Background

CHE is primarily used to transfer freight between modes of transportation, such as between marine vessels and trucks or between trains and trucks. CHE are used in many types of operations, but at the Port of Oakland, CHE is used almost exclusively to move shipping containers. As such, the types of CHE at the Port are limited to yard tractors, rubber-tired gantry (RTG) cranes, top or side handlers (also called picks), and forklifts. Other types of equipment used as CHE for transfer of bulk materials are not currently used at the Port. Emissions from some general purpose equipment types including sweepers, bulldozers, backhoes, excavators, and other off-road equipment used for facility maintenance and construction, are included in the other off-road equipment category (see Section 7) and are not part of the CHE inventory.

4.2 Emission Calculation Methodology

Annual 2017 emissions for each piece of CHE equipment were estimated for each terminal based on equipment and engine characteristics (equipment type, model year, rated power, and after-treatment retrofit control device) and equipment operation (hours of operation and fuel consumption rates). Equipment population and operation estimates were derived from on-dock terminal, off-dock terminal and rail yard surveys conducted by the Port of Oakland in late 2017 and early 2018.

Per ARB (2011c) guidance, the following types of equipment were used to categorize CHE:

- Cranes (including rubber-tired gantry cranes);
- Forklifts;
- Container Handling Equipment (top or side handlers); and
- Yard Trucks (hereafter referred to as “Yard Tractors”).

CHE emissions were calculated using the following equation:

$$Equip_{emiss} = \frac{(EF_{zh} + dr \times CHrs) \times Engine_{bhp} \times FCF \times LF_{wt} \times CF \times Time_{hrs} \times Pop}{(453.6 \times 2000)}$$

Where:

Equip $_{emiss}$ is the annual emissions in tons per year,
EF $_{zh}$ is the zero-hour emission factor in grams per brake horsepower-hour,
dr is the deterioration rate or the increase in zero-hour emissions as the equipment is used (grams/bhp-hr/hr),
CHrs is the cumulative hours or total number of hours accumulated on the equipment,
Engine$_{bhp}$ is the engine brake horsepower rating,
FCF is the fuel correction factor (% reduction) used to adjust the base emission factor to account for use of California diesel fuel,
LF $_{wt}$ is the weighted load factor (average load expressed as a % of rated power),
CF is the control factor (% reduction) associated with use of emission control technologies where applicable,
Time $_{hrs}$ is the annual operating hours of the equipment,
Pop is the population number of the equipment, and
(453.6 x 2000) is a conversion from grams to tons.

4.3 Input Data and Use

Confidential surveys were sent to all Port of Oakland tenant on-dock and off-dock terminals and rail yards requesting the following detailed information for each piece of CHE:

1. Equipment Type
2. Number of Similar Equipment
3. Engine Model
4. Engine Model Year
5. Aftertreatment Retrofit Type
6. Chassis Make / Model
7. Chassis Model Year
8. Fuel Type
9. Annual hours of operation
10. Engine Rated horsepower

Surveys were returned from the four on-dock facilities operating in 2017, one railyard, and nine off-dock facilities. Where equipment-specific horsepower was not provided, Ramboll assumed (i) horsepower of similar make and model equipment provided in other responses to the Port's survey, or (ii) defaulted to horsepower assumed in applicable ARB models, or (iii) horsepower estimates obtained from web search. Similarly, in cases of missing annual activity, average annual operating hours for similar equipment types from the 2017 Port of Oakland surveys was used.

For diesel-powered equipment, zero-hour emission factors, deterioration rates, fuel correction factors, and emission control factors for HC, CO, NOx, and PM were obtained from ARB's Cargo Handling Equipment Inventory (CHEI) model (ARB, 2012). Diesel powered CO emission factors were taken from OFFROAD 2007 (ARB, 2007). The current version of the CHEI model does not include GHG or SO_2 emissions. Diesel-powered equipment SO_2 emission factors were estimated based on brake specific fuel consumption (BSFC) estimates from ARB 2017 Emission Off-road Diesel Emission Factors and a 15 ppm diesel fuel sulfur content based on use of ultra-low sulfur diesel (ULSD).[23] Diesel-powered equipment GHG (CO_2, CH_4, and N_2O) emission rates per unit of fuel consumption were taken from California's 2000-2015 GHG Inventory.[24]

Because the current version of the CHEI model does not support emission estimates for fuel types other than diesel, criteria air pollutant (HC, CO, NOx, SO_2, and PM) emission factors for gasoline and propane powered equipment were obtained from ARB's 2011 CHE Calculator (ARB 2011c), following methodologies described in the *2005 Mobile CHE at Ports and Intermodal Rail Yards* original rulemaking (ARB, 2005). Gasoline and propane powered equipment emissions factors for GHGs (CO_2, CH_4 and N_2O) were estimated using OFFROAD 2007 fuel consumption estimates and emission factors from California's 2000-2015 GHG Inventory.

CHE were grouped into equipment type categories as defined by ARB (2011c). The resulting 2017 populations by equipment type for the Port of Oakland are summarized in Table 4-1. Out of 386 total pieces of cargo handling equipment, 345 were diesel powered, 39 were gasoline powered, and 2 were LPG (liquid petroleum gas) powered. 89% of CHE operates at marine terminals or railyard facilities and 11% operates at off-dock facilities.

Table 4-1. Cargo handling equipment – population by type.

Equipment Type	Equipment Population	% Total
Container Handling Equipment (Top Picks and Side Picks)	123	32%
Forklift	14	4%
RTG Crane	24	6%
Yard Tractor	105	27%
Yard Tractor (On-road)	120	31%
Total	**386**	**100%**

[23] https://www.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017_v7.xlsx
[24] Documentation of California's 2000-2015 GHG Inventory, https://www.arb.ca.gov/cc/inventory/doc/doc_index.php

Table 4-2 summarizes the average horsepower and average annual operating hours by equipment type and power range. Annual hours of operation for each specific piece of equipment as determined from the survey responses were used to estimate emissions.

Table 4-2. Cargo handling equipment - Average horsepower and actual hours of operation by equipment type and horsepower range.

Equipment Type	HP Bin	Equipment Population	Average HP	Average Annual Operation (Hours)	Load Factor
Container Handling Equipment	175	3	170	460	0.59
	300	42	214	1,204	
	600	78	372	1,523	
Forklift	175	11	158	550	0.30
	300	3	207	600	
RTG Crane	600	7	512	1,259	0.20
	750	4	621	1,146	
	1001+	13	1,005	1,500	
Yard Tractor	175	43	168	1,295	0.39
	300	62	224	1,217	
Yard Tractor (On-road)	175	79	173	1,000	
	300	41	216	1,827	

4.4 Summary of Cargo Handling Equipment Emission Results

Table 4-3 and Table 4-4 present estimated CHE emissions by equipment type and by fuel type, respectively, based on the 2017 survey data. All PM_{10} from diesel engines listed in Table 4-4 is diesel particulate matter (DPM). $PM_{2.5}$ emissions were calculated as a fraction of PM_{10} based on fuel type-specific factors provided by ARB (2013).

As mentioned above, the 2017 Port of Oakland CHE emission inventory (summarized in Table 4-3 and Table 4-4 below) includes on-dock and off-dock terminals and the rail yard. Previous Port of Oakland CHE emission inventories include on-dock terminals and the rail yard, but do not include CHE operated at off-dock terminals. Off-dock terminals not included in previous emission inventories accounted for 0.27 tons per year (17%) of total CHE DPM emissions in 2017.

Table 4-3. 2017 Port of Oakland CHE emissions by equipment type (tons per year)[a].

Equipment Type	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Container Handling Equipment	10.43	41.39	95.36	0.71	0.65	0.71	0.16	17,382	0.70	0.14	17,442
Forklift	0.14	1.22	1.31	0.01	0.01	0.01	0.00	227	0.01	0.00	227
RTG Crane[b]	2.74	7.70	37.36	0.19	0.18	0.19	0.03	3,222	0.13	0.03	3,233
Yard Tractor	3.39	81.68	23.05	0.45	0.42	0.30	0.07	7,199	0.29	0.06	7,223
Yard Tractor On-road	1.94	30.17	15.92	0.37	0.34	0.36	0.07	7,369	0.30	0.06	7,394
Total	**18.64**	**162.16**	**172.99**	**1.73**	**1.59**	**1.58**	**0.33**	**35,398**	**1.44**	**0.29**	**35,520**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.
[b] SSA Terminals, which operates the Oakland International Container Terminal (OICT), was recently awarded funding under the Carl Moyer Program to repower 13 RTG cranes with hybrid-electric systems. Emissions estimates for the cost effectiveness of that project use different inputs, for example, the Carl Moyer Program used the average of the past three years of activity to determine emission reduction benefits.

Table 4-4. 2017 Port of Oakland CHE emissions by fuel type (tons per year)[a].

Fuel Type	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Diesel	17.20	92.38	167.00	1.58	1.45	1.58	0.31	33,045	1.34	0.27	33,158
Gasoline	1.07	58.37	5.11	0.13	0.12	--	0.02	2,175	0.09	0.02	2,182
Propane	0.37	11.41	0.88	0.02	0.02	--	0.00	178	0.01	0.00	179
Total	**18.64**	**162.16**	**172.99**	**1.73**	**1.59**	**1.58**	**0.33**	**35,398**	**1.44**	**0.29**	**35,520**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.

Figure 4-1 compares the CHE NOx and DPM emission estimates from the 2005, 2012, 2015, and 2017 inventories. NOx and DPM emissions have declined as the CHE fleet has turned over to lower emitting engines: DPM emissions have decreased by 93% and NOx emissions by 77% since 2005. Further emission reductions are expected in upcoming years, especially for DPM, as regulatory exemptions allowing the use of diesel particulate filters (DPF) expire and Tier 4 engines are installed. It is important to note that 2017 emissions shown in Figure 4-1 includes CHE emissions from both marine terminals and off-dock terminals; CHE emissions from off-dock terminals were not included in 2005, 2012, or 2015 emission inventories. As noted above, CHE emissions at off-dock terminals not included in previous emission inventories accounted for 0.27 tons per year (17%) of total CHE DPM emissions in 2017.

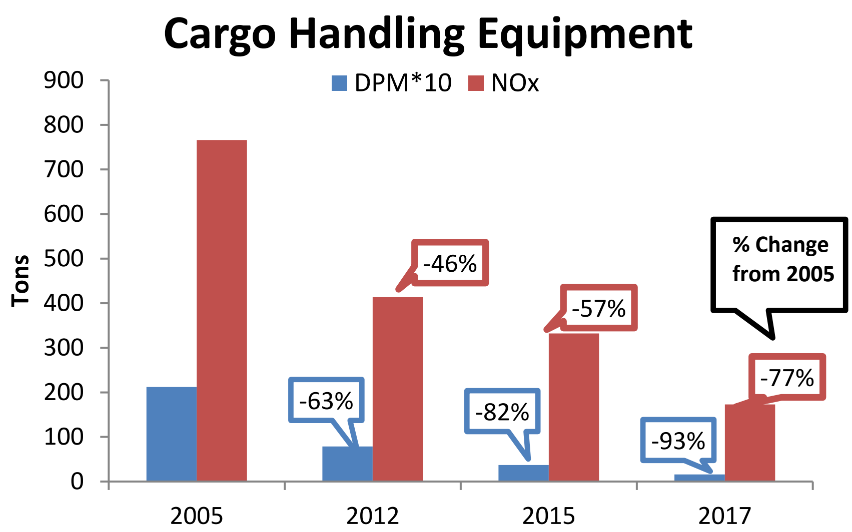


Figure 4-1. Cargo Handling Equipment DPM and NOx emissions estimates for 2005, 2012, 2015, and 2017.

5.0 ON-ROAD HEAVY-DUTY TRUCKS

Operations at the Port of Oakland create a demand for truck trips to transport containers between marine terminals, freeway interchanges, and nearby rail yards. Historically, emissions from on-road trucks servicing the Port (drayage trucks) have been an important component of diesel exhaust emissions at the Port. Prior to implementation of the ARB's Drayage Truck Regulation in 2009, the average drayage truck was older than that of the general on-road truck fleet, resulting in higher emission rates. In addition, drayage trucks generally follow driving patterns consisting of shorter trips, lower average speeds and more stop-and-go driving which generally results in higher emissions per mile traveled.

In 2009, the State of California instituted the Drayage Truck Regulation (ARB, 2009) in an effort to reduce emissions from the relatively old drayage truck fleet at that time. Under this regulation, by December 31, 2013, all drayage trucks engines were required to meet or exceed emission standards for 2007 model year engines, which included particulate matter controls. Different emission standards and compliance dates apply to non-drayage trucks until 2023, when the Drayage Truck Regulation sunsets.

The geographical boundaries of this Port of Oakland air emissions inventory include truck routes between the marine terminals and three nearby freeway interchanges and the two port area rail yards. Trucks must arrive at or depart from the Port area via the three freeway interchanges: Maritime/West Grand Street, Seventh Street, and Adeline/Market Street. Even if trucks arrive by surface streets, they must pass through one of these access points to enter the Port area. The Port emissions inventory also includes truck trips that move intermodal cargo containers between marine terminals and two rail yards in the Port area: the Port's OIG operated by BNSF and the Union Pacific rail yard.

The following sections describe the activity and emissions calculation methods for the 2017 drayage truck emission inventory, including the equations, assumptions, and the underlying truck activity data and emission factors. Truck activity in terms of trips to and from the Port's terminals were combined with emission factors from the ARB's on-road emissions factor model (EMFAC2017, v1.0.2[25]) to estimate emissions from the drayage trucks moving and idling within the Port area. A summary of the 2017 Port of Oakland truck emission inventory is provided at the end of this chapter.

5.1 Emission Calculation Methodology

Operating modes were separated into four categories: (1) idling inside marine terminals, (2) idling at gate queues, (3) driving within marine terminals, and (4) driving on surface streets between terminals and freeway interchanges or rail yards. For each of these modes, the average time and speed define the emissions for each trip.

[25] http://www.arb.ca.gov/msei/categories.htm

Emissions per trip were calculated by multiplying the appropriate emission factor (idling or by speed) by the activity level indicator (idling time or trip distance). As expressed in the following equation, emissions are the product of the number of trips, distance per trip, and emission rate per mile traveled. For the idling calculation, the emissions are the product of number of trips, average idling time per trip, and emission rate per hour of idling.

$$E_p = (n_{truck\ trip})(miles_{trip})(EF_{p,trip})$$

Where:

E_p = emissions of pollutant *p*,
n_p = number of trips,
$miles_{trip}$ = trip mileage or hours at idle,
$EF_{p,\ trip}$ = trip emission factor (grams/mile) or for idle (grams/hour) for pollutant *p* (Requires trip-based EFs defined on the basis of individual link speeds as described below).

A “link” is a term used by transportation planners to describe a segment of roadway. A “trip” for this analysis refers to one-way travel along multiple links pieced end-to-end. For example, one-way travel from the freeway interchange of I-880 at Adeline Street to Oakland International Container Terminal west gate is defined as one trip made up of seven links. Truck speeds differ by link, due to link-specific variables such as posted speed limits, traffic lights, and stop signs.

In summary, inputs to the emissions calculations are:

1. Number of truck trips, traveling between
   a. Marine terminal and freeway
   b. Marine terminal and rail yard
   c. Rail yard and freeway
2. Trip mileage
   a. Outside terminals and rail yards
   b. Within terminals and rail yards
3. Truck idling time
   a. Entrance queues at terminals and rail yards
   b. Within terminals and rail yards
4. Emission Factors derived from the EMFAC2017 model based on
   a. Age distribution
   b. Individual link speeds comprising a trip
   c. Idle emission rate

5.2 Truck Trip Counts

Two data sources were used to estimate the number of truck trips: 1) a survey of gate counts and 2) counts of the number of container lifts. A gate count refers to the terminal recordkeeping of the number of trucks entering a marine terminal. Container lifts (i.e., the number of containers moved onto or off of a ship) provide a second data source by which to estimate the number of truck trips. Container lift data are reliable because payments to operators are based on the number of lifts. However, trucks may move a container in and another container out on a single terminal entry (a double transaction) or move no containers at all when repositioning empty chassis or for other reasons, so the gate count will not match the number of container lifts exactly.

The 2017 truck trip counts for the marine terminals were derived from gate counts provided by the Port or the terminal operators. For the OIG rail terminal, the reported number of lifts was doubled to estimate the sum of inbound and outbound truck trips. Table 5-1 summarizes the resulting estimated total number of truck trips for the Port area in 2017 and compares this with the number of lifts (defined as movement of one container, whether a 20-foot or 40-foot container). If each truck carries one container either to or from the terminal, and no containers on the opposite leg, then the number of trips would be equal to twice the number of lifts. The fact that the number of trips is less than twice the number of lifts indicates that trucks are often moving more than one container during their visit to the terminal.

Table 5-1. On-road trucking – estimated truck trips in 2017.

Terminal Type	Reported 2017 truck trips	Lifts
Marine	2,081,932	1,361,006
Rail[1]	154,872	77,436

[1] Rail results are only reported here for the rail yard located within the Port boundary (BNSF-operated OIG). Trips to the Union Pacific rail yard were assumed to be twice the number to the OIG rail yard.

5.3 Truck Trip Definitions

This section defines trip routes and link speeds for trucks traveling on streets between the marine terminals and either the rail yards or any of the three freeway interchanges. In-terminal driving is discussed separately. A simple but accurate method to capture the VMT and estimate trip speeds was developed based on typical routes to and from each marine terminal. A traffic study would be required to identify more precise routes.

As previously mentioned, one-way trips can occur between any marine terminal and any freeway interchange or rail yard as listed in Table 5-2. These locations are shown on the Port of Oakland map in Figure 5-1. Roadway links numbered 0 through 33, which make up potential truck routes, are also labeled. Trips to truck parking areas in the Port area (former Ports America Outer Harbor terminal and Howard Terminal in 2017) are not included, since trips to and from the parking areas replace trips to and from freeway interchanges at the beginning and end of the day, or are short-term stopovers during the day. The emissions impacts are expected to be negligible.

Table 5-2. On-road trucking – list of marine terminals, freeway interchanges, and rail yards.

Berths	Terminal
B 25-33	Trapac
B 35-37	Everport
B 55-59	OICT
B 60-63	Matson
Rail yard	
OIG (BNSF)	
Union Pacific	

Freeway Interchange
Adeline/Market Street
7th Street
Grand/Maritime Street

Figure 5-1. On-road trucking – roadway links within the Port of Oakland (2017 Terminal Configuration).

While the precise routes for truck trips between terminals and the highway are not known, geographic proximity influences which highway interchange truck drivers will prefer—Adeline/Market Street, 7th Street, or Grand/Maritime Street. The distribution of truck trips between freeway and Port terminals is shown in Table 5-3. This trip distribution is based on historic surveys conducted at the port (CCS, 2003) and the subsequent analysis of the data for the Port's 2005 emission inventory (ENVIRON, 2008a). Although additional data on port-wide trip distributions has recently been collected by the Port, the data obtained to date focus on routes by which trucks leave the Port of Oakland area without reference to the terminal at which each trip started or ended. Therefore, it was not feasible to incorporate the recently collected trip data into this inventory analysis. Trip routes estimates may be updated in future inventories if new terminal-specific data become available.

Table 5-3. On-road trucking distribution of truck trips between freeway and Port Terminals.

Berths	Terminal	Fraction of Traffic		
		Adeline/Market	7th Street	West Grand/ Maritime
B 20-24	former Ports America Outer Harbor (idled during 2017)	0%	30%	70%
B 25-33	TraPac	0%	65%	35%
B 35-37	Everport	0%	65%	35%
B 55-59	OICT	2.5%	65%	32.5%
B 60-63	Matson	40%	40%	20%
B 67-68	Howard (idled during 2017)	100%	0%	0%

Based on the preferred routes indicated in Table 5-3, individual links were combined to create realistic trip routes to assign to the total trip counts. Table 5-4 lists all possible constructed trips, their constituent links, total distance, and average speed. The trip distances are summed over individual links that comprise the trip. Reported average speeds are the VMT-weighted averages of the links by trip. The same link-level speeds were determined from a previous study performed for the 2005, 2012, and 2015 calendar year inventories.

Table 5-4. On-road trucking – trip IDs, constituent link IDs, total distance, and average speeds.

Trip ID	Terminal	Berth	Trip Beginning/ End	Road Link Segments, One-way	One-way Trip Length (feet)	Average Speed (mph)
T1	former Ports America Outer Harbor	B 20-23	West Grand	0, 28	3,193	30
T2	former Ports America Outer Harbor	B 20-23	7th	0, 1, 9, 31, 15	6,780	32
T3	former Ports America Outer Harbor	B 20-23	Adeline	0, 1, 9, 31, 16, 21, 13, 19, 24, 33, 25	15,635	31
T4	former Ports America Outer Harbor	B 20-23	BNSF	0, 1, 9, 31, 16, 17	8,816	29
T5	former Ports America Outer Harbor	B 20-23	Union Pacific	0, 1, 9, 31, 16, 21, 13, 19	12,189	32
T6	Trapac	B 25-26	West Grand	2, 1, 28	6,401	34
T7	Trapac	B 25-26	7th	2, 9, 31, 15	4,580	26
T8	Trapac	B 25-26	Adeline	2, 9, 31, 16, 21, 13, 19, 24, 33, 25	13,435	29
T9	Trapac	B 25-26	BNSF	2, 9, 31, 16, 17	6,616	24
T10	Trapac	B 25-26	Union Pacific	2, 9, 31, 16, 21, 13, 19	9,989	29
T11	Trapac	B 30	West Grand	5, 4, 3, 29, 9, 1, 28	9,888	33
T12	Trapac	B 30	7th	5, 4, 3, 30, 15	6,280	30
T13	Trapac	B 30	Adeline	5, 4, 11, 20, 13, 19, 24, 33, 25	13,462	34
T14	Trapac	B 30	BNSF	5, 4, 3, 30, 16, 17	8,316	27
T15	Trapac	B 30	Union Pacific	5, 4, 11, 20, 13, 19	10,016	36
T16	Trapac	B 32-33	West Grand	6, 7, 4, 3, 29, 9, 1, 28	11,301	32
T17	Trapac	B 32-33	7th	6, 7, 4, 3, 30, 15	7,693	29
T18	Trapac	B 32-33	Adeline	6, 7, 4, 11, 20, 13, 19, 24, 33, 25	14,875	34
T19	Trapac	B 32-33	BNSF	6, 7, 4, 3, 30, 16, 17	9,729	28
T20	Trapac	B 32-33	Union Pacific	6, 7, 4, 11, 20, 13, 19	11,429	35
T21	Everport	B 35-37	West Grand	8, 7, 4, 3, 29, 9, 1, 28	12,474	34
T22	Everport	B 35-37	7th	8, 7, 4, 3, 30, 15	8,866	33
T23	Everport	B 35-37	Adeline	8, 7, 4, 11, 20, 13, 19, 24, 33, 25	16,048	35
T24	Everport	B 35-37	BNSF	8, 7, 4, 3, 30, 16, 17	10,902	30
T25	Everport	B 35-37	Union Pacific	8, 7, 4, 11, 20, 13, 19	12,602	37
T26	OICT	B 55-56	West Grand	10,11, 3, 29, 9, 1, 28	11,201	33
T27	OICT	B 55-56	7th	10,11, 3, 30, 15	7,593	30
T28	OICT	B 55-56	Adeline	10, 20, 13, 19, 24, 33, 25	11,555	32
T29	OICT	B 55-56	BNSF	10, 20, 21, 17	7,068	32
T30	OICT	B 55-56	Union Pacific	10, 20, 13, 19	8,109	34
T31	OICT	B 57-59	West Grand	18, 21, 16, 31, 9, 1, 28	11,849	32
T32	OICT	B 57-59	7th	18, 21, 16, 15	7,534	28
T33	OICT	B 57-59	Adeline	18, 13, 19, 24, 33, 25	8,307	27
T34	OICT	B 57-59	BNSF	18, 21, 17	3,820	21
T35	OICT	B 57-59	Union Pacific	18, 13, 19	4,861	26
T36	Matson	B 60-63	West Grand	22, 19, 13, 21, 16, 31, 9, 1, 28	15,632	31
T37	Matson	B 60-63	7th	22, 19, 13, 21, 16, 15	11,317	28
T38	Matson	B 60-63	Adeline	22, 24, 33, 25	5,214	25

Trip ID	Terminal	Berth	Trip Beginning/ End	Road Link Segments, One-way	One-way Trip Length (feet)	Average Speed (mph)
T39	Matson	B 60-63	BNSF	22, 19, 13, 21, 17	7,603	25
T40	Matson	B 60-63	Union Pacific	22	1,768	15
T41	Howard	B 67-68	West Grand	27, 26, 32, 24, 19, 13, 21, 16, 31, 9, 1, 28	19,074	32
T42	Howard	B 67-68	7th	27, 26, 32, 24, 19, 13, 21, 16, 15	14,759	30
T43	Howard	B 67-68	Adeline	27, 26, 32, 33, 25	3,720	23
T44	Howard	B 67-68	BNSF	27, 26, 32, 24, 19, 13, 21, 17	11,045	28
T45	Howard	B 67-68	Union Pacific	27, 26, 32, 24	5,210	28

5.4 Truck Idling and VMT inside Terminals

Vehicle miles traveled (VMT) within marine and rail terminals is limited to driving between the terminal gates and container storage areas. Previously, the Port conducted surveys of terminal operators to determine in-terminal VMT and average speed. These previous survey data were used to estimate 2017 activity (per-truck speed, distance, and idling time). Table 5-5 below shows the activity summary for the average truck idling at gates, idling in terminal, and driving in-terminal along with average speed in-terminal.

Table 5-5. On-road trucking – average in-terminal activity parameters.

Mode	Average estimate[a]
Idling at gate (hrs)	0.14
Idling in terminal (hrs)	0.34
Distance traveled (mi)	2.54
Speed (mph)	13.5

[a]Based on 2012 and 2005 survey data and 2017 by terminal trip activity

5.5 Emission Factors and Age Distribution

Ramboll used the most recent version of ARB's on-road emission factor model, EMFAC2017[26], to calculate emission factors for trucks idling and moving in the Port area. Emission factors from on-road trucks depend on the age distribution of the trucks and site conditions such as temperature, humidity, fuel sulfur, and especially average speeds. ULSD fuel is used exclusively in all diesel trucks visiting the Port. The age distribution is particularly important because of ARB's Drayage Truck Regulation, which affects specific model years, causing steep declines in NOx and PM emission rates for EMFAC2011 vehicle category Class 8 POAK Drayage Trucks as shown in Figure 5-2. The EMFAC2017 model accounts for the benefits of the Drayage Truck Regulation applicable to calendar year 2017, including:

[26] It should be noted that EMFAC2017 has not yet been approved by the EPA for use in State Implementation Plan and transportation conformity analyses. However, EMFAC2017 was used here as it is the most recent published ARB model.

1. Model years 2008-2010 meet 2007 engine emission standards for NOx and PM.
2. Model years 2010 and newer meet 2010 engine emission standards for NOx.

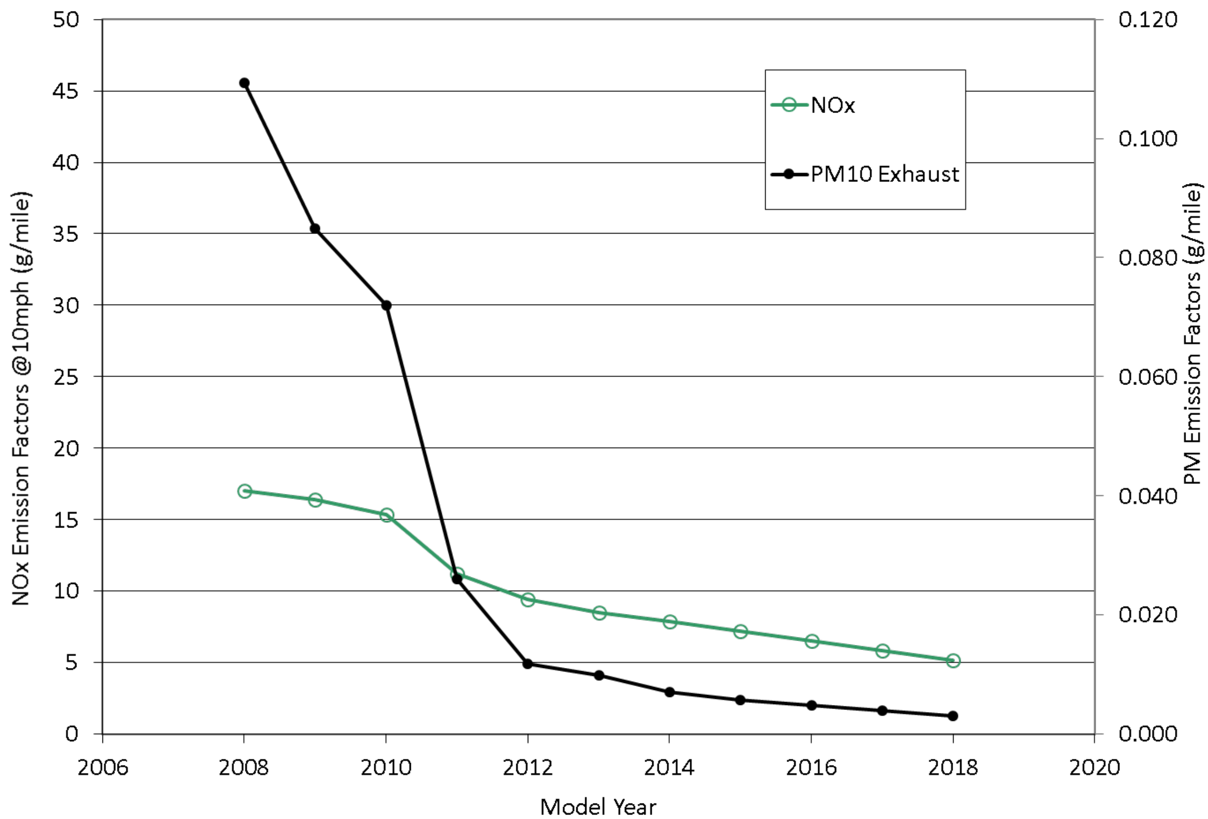


Figure 5-2. 2017 calendar year POAK drayage truck EMFAC2017 emission factors by model year for PM and NOx at 10 mph.

The truck age distribution used in this analysis was developed from end of year 2017 registration data[27] collected by the Port under the Secure Truck Enrollment Program (STEP). Approximately 8,900 trucks are registered for STEP, although not all registered trucks currently work at the Port or work at the Port every day. Approximately 1% of the truck fleet was comprised of pre-2008 model year trucks which would not originally have 2007 engines and thus would have been prohibited from performing drayage under the ARB rule. Based on STEP compliance checks to assure compliance with the ARB rule, we assumed that these older trucks would have been repowered with a 2007 engine and considered to be equivalent to the 2008 model year trucks. Figure 5-3 shows the resulting age distribution along with emission factors for several pollutants by model year. Emission factors shown in Figure 5-3 represent emissions per mile for a representative average speed of 10 miles per hour (mph).

[27] http://www.portofoakland.com/port/seaport/comprehensive-truck-management-program/registry/

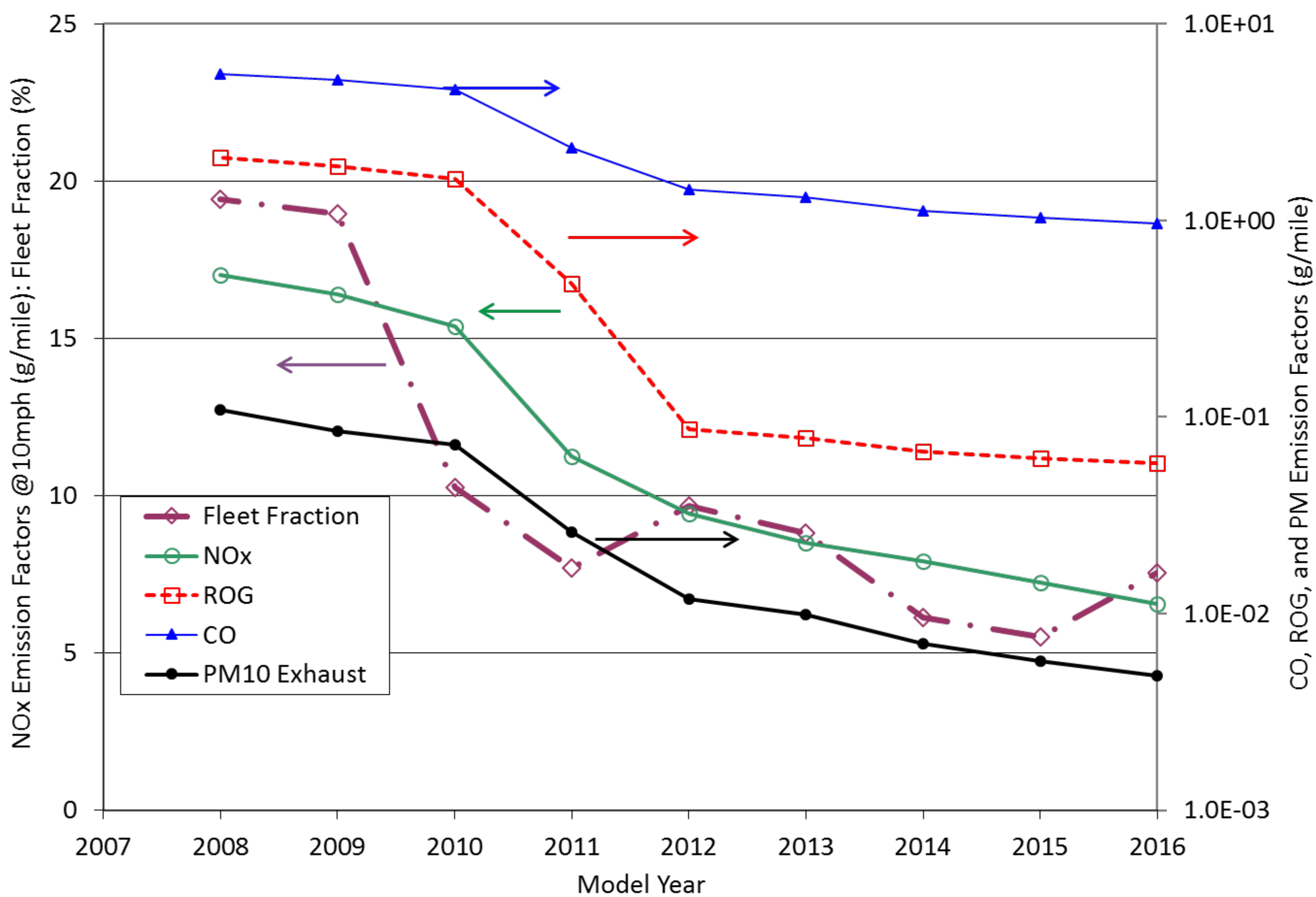


Figure 5-3. Port of Oakland drayage truck age distribution as fraction of fleet by model year (diamond symbols connected by dash-dot line) and NOx, ROG, CO and PM_{10} exhaust emission factors at 10 mph by model year.

All trucks must have 2007 and later model year engines to enter Port terminals and rail yards. The age distribution (fleet fraction) shown in Figure 5-3 indicates that model years 2008, 2009, and 2010 (using engine model years 2007, 2008, and 2009 respectively) comprised the largest percentage (49% together) of the Port's truck fleet in 2017. These truck engines produce higher emissions than 2011 and later trucks.

Table 5-6 lists all emission factors for the Port's truck fleet in 2017, including idling (grams/hour) and driving (grams/mile) by speed. Speed effects on emission rates are based on pollutant specific EMFAC2017 speed correction factors. As shown in Table 5-6, emission factors are generally highest at low speeds and lowest at high speeds. For example, PM_{10} exhaust emission rates are 32% higher at 5 mph and 23% lower at 40 mph relative to 20 mph emission rates and NOx emission rates are 46% higher at 5 mph and 57% lower at 40 mph relative to 20 mph emission rates.

Table 5-6. Port of Oakland specific average drayage truck emission factors in 2017 for speeds 0 to 40 mph.[28]

Speed (mph)	ROG	CO	NOx	PM_{10} Total	PM_{10} Exhaust	$PM_{2.5}$ Total	Unit
0	2.38	22.68	46.03	0.02	0.016	0.02	g/hr
5	1.27	4.28	14.71	0.15	0.056	0.09	g/mile
10	1.00	3.22	12.24	0.15	0.050	0.08	g/mile
15	0.68	2.14	9.52	0.14	0.043	0.08	g/mile
20	0.49	1.52	7.89	0.14	0.038	0.07	g/mile
25	0.36	1.13	6.86	0.13	0.035	0.07	g/mile
30	0.27	0.84	6.09	0.13	0.033	0.07	g/mile
35	0.20	0.62	5.48	0.13	0.032	0.07	g/mile
40	0.15	0.46	5.04	0.13	0.031	0.07	g/mile

Effects of emission control systems failures on truck emissions are incorporated into EMFAC2017 emission rates. Based on (1) Port of Oakland fleet STEP truck age distribution, (2) EMFAC default odometer mileage by vehicle age for Port of Oakland trucks, and (3) EMFAC default heavy duty truck DPF failure frequencies by model year grouping, the Port of Oakland drayage truck fleet average EMFAC2017 DPF failure rate is 12%. Over three-quarters of failures are from 2008 and 2009 model year vehicles. Preble et al. (2016) measured emissions from 891 Port of Oakland drayage trucks in 2015 and identified 8% as high emitters with failing DPFs, which is a lower failure rate than the EMFAC2017 estimate for the 2017 drayage truck fleet despite the higher percentage of 2008 – 2009 model year trucks in the 2015 fleet. This suggests that the EMFAC default failure rate is conservatively high and use of EMFAC default failure rate results in a more conservative estimate of drayage truck DPM emissions than if Preble et al. (2016) failure rates were assumed (all else being equal).

5.6 Summary of Drayage Truck Emissions Results

Drayage trucks that provided service to Port of Oakland marine terminals and rail yards emitted approximately 80 tons of NOx and less than 0.3 ton of diesel PM (DPM) within the Port area during 2017 as shown in Table 5-7. All trucks used diesel engines in 2017, so the PM_{10} exhaust emissions are DPM emissions but total PM_{10} and total $PM_{2.5}$ also include non-diesel PM (i.e., brake and tire wear). Trucks traveling on surface roads represented the largest source of emissions of total PM. For ROG, NOx, and DPM however, the largest contributor was in-terminal driving while for CO the largest contributor was in-terminal idling. Idling and slow-speed driving produce higher emission rates for all pollutants, but for some pollutants the difference is more extreme. For example, CO has much higher emission rates during idling than during driving (refer back to Table 5-6), relative to other pollutants and idling accounts for 57% of CO emissions. Idling emissions account for 4% of PM_{10} exhaust, 35% of NOx and 22% of SOx emissions.

[28] Based on EMFAC vehicle category: Port of Oakland Drayage Trucks

Table 5-7. 2017 total emissions by trucks within the terminal and outside the terminal to the nearest freeway entrance (tons per year).

Emission Category	Criteria Pollutant Emissions								Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10} Total	PM_{10} Exhaust	$PM_{2.5}$ Total	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Surface roads	1.07	3.35	23.15	0.488	0.125	0.251	0.125	0.07	6,949	0.05	1.09	7,276
Gate idling in queue	0.43	4.10	8.31	0.003	0.003	0.003	0.003	0.01	1,238	0.02	0.11	1,272
In terminal idling	0.99	9.50	19.27	0.007	0.007	0.006	0.007	0.03	2,870	0.05	0.26	2,947
In terminal driving	2.19	6.96	29.17	0.404	0.127	0.222	0.127	0.07	7,936	0.10	1.25	8,310
Truck totals	**4.68**	**23.90**	**79.91**	**0.901**	**0.261**	**0.482**	**0.261**	**0.18**	**18,992**	**0.22**	**2.71**	**19,805**

Drayage truck NOx and DPM emission estimates for 2017 are compared with emissions from the 2005, 2012, and 2015 inventories in Figure 5-4.[29] Changes in emissions from year to year are a result of 1) changes in the number of truck trips, 2) modernization of the truck fleet due to the introduction of restrictions on older trucks and fleet turnover, and 3) revisions to emission rates associated with updates to ARB's EMFAC model. Modernization of the drayage truck fleet was the overwhelming factor responsible for DPM emission reductions of 91% between 2005 and 2012, and 83% between 2012 and 2015. Differences in drayage truck emission rates between EMFAC2014 (which was used to prepare the 2015 inventory) and EMFAC2017 (used to prepare the 2017 inventory) drove the 5% DPM emission increase between 2015 and 2017. Overall, DPM emissions decreased by 98% between 2005 and 2017. Similarly, NOx emissions decreased 72% between 2005 and 2012, 5% between 2012 and 2015, and 12% between 2015 and 2017 for an overall 2005 – 2017 NOx emission reduction of 76%.

[29] Emissions from travel between the terminals and freeway access ramps were inadvertently overstated by a factor of two in the 2012 and 2015 inventories; this has been corrected in the comparisons presented here.

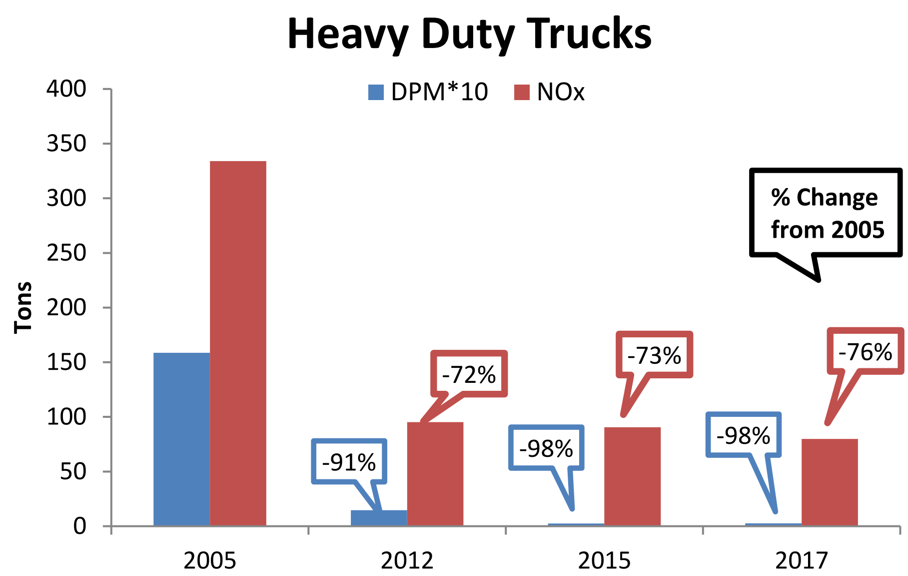


Figure 5-4. Drayage truck NOx emission estimates for 2005, 2012, 2015, and 2017.

6.0 RAIL LOCOMOTIVE

6.1 Introduction

This section describes the data and methods used in estimating emissions from locomotives at the Oakland International Gateway (OIG) rail yard and the Outer Harbor Intermodal Terminal (OHIT). OIG is a Port of Oakland terminal under lease to and operated by the Burlington Northern Santa Fe (BNSF) railway. BNSF is a Class I interstate railroad as defined by the Surface Transportation Board and is regulated by the federal government. Oakland Global Rail Enterprise (OGRE) operates OHIT, a small regional (Class III) railroad serving portions of the former Oakland Army Base.

The Union Pacific (UP) rail yard (also known as UP Railport – Oakland) sits adjacent to the Port terminals and serves as an intermodal yard for freight movements through the Port as well as a yard for domestic non-Port freight handling. UP Railport is not considered in this evaluation because the UP yard is privately owned and not leased from the Port. Union Pacific previously provided ARB an independent analysis of the emissions at their Oakland facility (Sierra Research, 2007).

Locomotives are used for line-haul operations (movement of long haul trains into and out of California) and switching operations (moving individual or small numbers of rail cars to make up trains). Line-haul locomotives move into and out of rail yards with idle periods after arrival and prior to departure. Switching engines work in the yard with idle periods interspersed throughout the day. Line-haul and switching locomotives can undergo maintenance, engine load testing, and refueling at some rail yards. However, maintenance and load testing is not performed at the OIG. Refueling of locomotives may occur at the OIG but only infrequently.

Locomotives operate using a series of load modes called “notches.” The notch settings and the locomotive idle periods constitute the operating profile for locomotives. The ARB (2006b) guidance for rail yard emission modeling suggests using per engine model per mode emission rates with average time in mode profiles for each visit multiplied by the number of engines visiting the rail yard.

6.2 Locomotive Emission Factors

Emission factors and fuel consumption by notch used in this study are the same as those used in previous Port of Oakland Seaport Air Emissions Inventories with adjustments to account for idle reduction devices on line-haul locomotives and in-use fuel characteristics.

Since 2012, locomotive fuel has been required to contain no more than 15 ppm fuel sulfur nationwide, and meet the same sulfur levels as on-road diesel when refueling within California. California limits the aromatic content and sets minimum cetane levels, which have been shown to lower NOx and PM compared with the nationwide fuel requirements. Line-haul locomotives may be fueled out of state, and therefore the fuel may not necessarily comply with California standards.

Emission rate data by operating mode and by engine model are available from earlier Port emission inventory reports (ENVIRON 2008a and 2013). The original source of the emission rate data reported in ENVIRON (2008a) used fuel with 0.3% (or 3,000 ppm) sulfur, and Ramboll adjusted emissions rates to the 2017 in-use fuel assuming 15 ppm sulfur content. The methodology described by ARB (2015) was used to adjust emissions and as shown in the following equation (the four numerical terms on the far right account for unit and molecular weight conversions and the difference in sulfur content):

PM Adjustment (lb/hour) = Fuel consumption (gal/hr) * 7.1 * 0.02247 * (224/32) * (0.000015 – 0.003)

In addition, ARB (2015) expected that California diesel fuel would lower NOx emissions by 3% (0.97 adjustment factor) and PM by 7% (0.93 adjustment factor). These adjustments were applied to the switching locomotive emission factors for BNSF and OGRE, but not the BNSF line-haul emission factors because line-haul locomotives may be fueled outside of California.

Locomotive engine emission regulations[30] have been phased in starting with Tier 0 in 2000 using Tier levels to describe ever increasing stringency. Tier 4 is the current and most stringent emission standard beginning with the 2015 model year. In addition, the regulations have included additional stringency requirements for locomotives originally certified to Tier 0, Tier 1 and Tier 2 when rebuilt as well as requiring rebuild of some uncontrolled locomotives to Tier 0.

Emissions data are available for Tier 2, Tier 1, Tier 0 and uncontrolled locomotives engines only. No emissions data were available for rebuilt Tier 0, 1, and 2 engines (referred to as 0+, 1+, and 2+, respectively) or new Tier 3 and 4 engines, so the emission factor ratio adjustments shown in Table 6-1 were applied to the pre-rebuild engine emission rates using the EPA estimated emission factors (EPA, 2009). No change in CO or fuel consumption was expected from rebuilds, and Tier 2 rebuild (labeled 2+) emission rates were assumed the same as for Tier 3 engines because the emission standards are identical.

Table 6-1. Emission ratio due to rebuild or new emission standards.

Tier Ratio	Total HydroCarbon*	CO	NOx	PM
0+ / 0	0.625	1.0	0.837	0.625
1+ / 1	0.617	1.0	1.000	0.625
2+ / 2	0.500	1.0	0.900	0.444
3 / 2	0.500	1.0	0.900	0.444
4 / 2	0.154	1.0	0.182	0.083

* - Total hydrocarbon (THC) is primarily composed of ROG but includes methane and excludes some other minor compounds.

To estimate CH_4 and N_2O emissions, a ratio was applied to THC emissions and fuel consumption, respectively. The CH_4/THC ratio was determined using the ARB SPECIATE[31] TOG profile number 818 for diesel engines, which provides the weight fraction of methane and other

[30] https://www.epa.gov/emission-standards-reference-guide
[31] ARB, Speciation Profiles Used in ARB Modeling, https://www.arb.ca.gov/ei/speciate/speciate.htm

chemical species in the exhaust emissions. The fraction of TOG that is THC was determined by subtracting the weight fraction of the oxygenated species (alcohol, aldehydes, and ketones) that do not respond to the flame ionization detection method that is used to measure THC. The N_2O estimate was derived from the emission factor of 0.018 g/kW-hr available in the ARB's Marine Emissions Model emission inventory tool for ocean-going vessels[32] and dividing by an assumed average fuel consumption of 210 g/kW-hr. This leads to an N_2O emission factor of 0.039 g/lb-fuel.

6.3 OIG Rail Yard Operations

6.3.1 Overview

BNSF uses the OIG as a near-dock transfer point for Port of Oakland maritime cargo containers. Only Port containers are handled at this yard. As shown in the schematic of the Port terminals in Section 5, the OIG is situated along a generally northwest-southeast axis. Entrance and exit tracks curve north and east of the main yard. Locomotives and trains enter the general port area from the north via the UP main line, and leave in the same direction via tracks going north through Richmond and then onto BNSF lines leading out of the Bay Area.

6.3.2 Locomotive Facility Operations

The OIG locomotive operations consist primarily of two activities: 1) line-haul locomotive movements for train arrival and departure and 2) switching locomotive movements to break up arriving and build departing trains.

Because different locomotive types and engine models have different emission characteristics, it was necessary to characterize the types and models of the locomotives that are operated at OIG based on data provided by BNSF. Locomotive types and models for each type of railyard activity are described below.

6.3.2.1 Switching Engine Activity

Switching engine fleet characteristics in the OIG area were determined from a sample of engines operating at OIG in 2017 made available by BNSF (2018).[33] BNSF usually assigns one switching locomotive to OIG at any given time. Switching locomotives assigned to OIG rotate in and out of service, but the typical type found at the yard in early 2018 was either a GP25 model or GP60 models as shown in Table 6-2. Average emission rates of two typical locomotive engine surrogates for which data are available and which bracket the power of the locomotive used at the yard were used to estimate emissions of the in-use switching locomotive.

[32] ARB, 2016. Marine Emissions Model v2.3L, (http://www.arb.ca.gov/msei/categories.htm)
[33] BNSF 2018, Personal communication with Amanda Maruffo, January and February 2018.

Table 6-2. Locomotive – Switching engine characterization for the OIG facility in 2017.

Locomotive Model	Certification Tier	HP	Number of Engines	Engine Surrogate
GP25	Precontrolled	2500	1	Average of GP-3x (2000 hp) and GP-4x (3000 hp)
GP60	Precontrolled	3600-3800	2	GP60 (3600 hp)

The relative time in mode for switching engine activity from the 2005 Port of Oakland emission inventory (ENVIRON, 2008a) was used for this work and is shown in Table 6-3. Switch locomotive operations at OIG have been similar to how they were used in 2005.

Table 6-3. Locomotive – Switching engine relative time in mode at the OIG facility in 2005.

Throttle Notch	Time in Mode
Dynamic Braking	1.4%
Idle	59.8%
1	6.6%
2	15.0%
3	9.5%
4	4.4%
5	1.9%
6	0.3%
7	0.0%
8	1.0%

Source: Port of Oakland 2005 Seaport Air Emissions Inventory, (ENVIRON 2008)

Total switching engine activity in 2015 was estimated using the early 2016 switch locomotive schedule. This activity consisted of one engine operating a 7.5 hour shift per day, every day, which was equivalent to 2,738 hours for 2015.[34] The lift count at OIG in 2017 was down about 21% from 2015, so for 2017, the switching locomotive activity was proportionally reduced to 2,157 hours.

6.3.2.2 Line-Haul Locomotive Activity

Activities of line-haul engines in the OIG yard include: arriving with a train, separating from the train, potentially moving to the "ready area" where the engines are assigned to a train, moving to an assigned train, and leaving the yard. BNSF provided the locomotive counts by models that arrived at the yard in 2017 as shown in Table 6-4.

[34] BNSF 2016. Personal communication with Marcelino Ratunil, April 29, 2016.

Table 6-4. Locomotive – Fleet characterization for locomotive arrival and departure at the OIG facility in the OIG facility in 2017.

Model	Tier	Fleet Fraction	Count
GP-4x	N/0	0.78%	2
Dash 8	0	0.39%	1
Dash 9	0	1.57%	4
Dash 9	0+	0.00%	0
Dash 9	1	2.75%	7
Dash 9	1+	27.84%	71
ES44	2	10.59%	27
SD70	2	1.57%	4
ES44	2+	18.82%	48
ES44	3	29.41%	75
SD70	3	2.35%	6
ES44	4	3.92%	10
Total			**255**

In the 2005 and 2012 Port of Oakland Seaport Emission Inventories, samples of line-haul engine activity while in the yard were used to develop the average time in mode for line-haul locomotive arriving and departing from the yard. Because all or nearly all line-haul locomotives now use automatic idle shut-off devices beginning as early as the 2001 model year[35] and restrict idling to 15 minutes per event per agreement with ARB,[36] the idle time was adjusted to 1.0 hour assuming four in-yard movements per arrival and departure in this inventory and the 2015 inventory. The average time in mode data are summarized in Table 6-5.

Table 6-5. Locomotive – Time in mode per trip for arriving and departing locomotives at the OIG facility in 2017.

Throttle Notch	Average Operation Time (hours)
DB[a]	0.2963
Idle	1.00[b]
1	0.1726
2	0.0758
3	0.0340
4	0.0049
5	0.0059
6	0.0004
7	0.0036
8	0.0017

[a] Dynamic Braking
[b] Adjusted from 12.15 hours in the 2005 activity to account for idle shut-off devices for ½ hour each on arrival and departure

[35] https://www.businesswire.com/news/home/20030421005337/en/GE-Transportation-Systems-Launches-New-Fuel-Saving
[36] https://www.arb.ca.gov/msprog/offroad/loco/loco.htm

The fleet characterization for locomotives, provided in Table 6-4, was derived from all engines entering the site in 2017, and the operating profile described in Table 6-5 was used to estimate the emissions by model and summed to obtain total emissions.

6.3.3 Summary OIG Emissions

The locomotive emissions for the OIG facility are summarized in Table 6-6. Note that all locomotive PM_{10} emissions are classified as diesel particulate matter (DPM).

Table 6-6. Locomotive – Estimated annual locomotive emissions (tons) the OIG facility - 2017.[a]

Source Type	Criteria Pollutant Emissions						Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG [b]	CO	NOx	PM_{10} [c]	$PM_{2.5}$ [d]	SOx	CO_2	CH_4	N_2O	CO_2e
Switching Engines	0.50	0.70	10.88	0.175	0.161	0.00	432	0.02	0.01	436
Train Arrival / Departure	0.03	0.05	0.40	0.007	0.007	0.00	40	0.00	0.00	40
Total	**0.53**	**0.76**	**11.28**	**0.182**	**0.168**	**0.00**	**472**	**0.02**	**0.01**	**476**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero
[b] ROG to THC ratio for diesel engines used 1.21
[c] All PM_{10} emissions are DPM.
[d] $PM_{2.5}$ size fraction of PM_{10} was estimated to be 0.92, consistent with the ARB (2015) Vision Locomotive Module

6.4 OGRE Activity

6.4.1 Service

Oakland Global Rail Enterprise, LLC (OGRE) is a Class III, Surface Transportation Board-certified short line rail company created in 2014 that is currently operating at the former Oakland Army Base (OAB). In 2017, the OGRE railroad exclusively served non-marine facilities located on the OAB. Activity at these facilities was not included in the original 2005 Seaport Air Emissions Inventory.

6.4.2 Activity and Locomotive Characteristics

Switching engine fleet characteristics and annual activity were provided by OGRE. Emission rates were available for a locomotive engine surrogate of similar power to the locomotives used by OGRE as shown in Table 6-7.

Table 6-7. Locomotive – Switching engine characterization for the OIG facility in 2015.

Locomotive Model	Certification Tier	HP	Number of Engines	Engine Surrogate
EMD GP9/16 EMD MP15	Precontrolled	1500 / 1600	2	EMD 12-645E (1500 hp)

The time in mode chosen for switching engine activity was the EPA default for switching engines as shown in Table 6-3.

OGRE estimated the total switching engine activity in 2017 to be 780 hours mixed between the two locomotives. Total hours were distributed by notch setting according to Table 6-3, emissions were estimated for each notch and then summed.

6.4.3 OGRE Summary Emissions

Locomotive emissions at the OGRE for 2017 are summarized in Table 6-8.

Table 6-8. Estimated annual locomotive emissions (tons) at the OGRE facility - 2017.[a]

Source Type	Criteria Pollutant Emissions						Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG [b]	CO	NOx	PM_{10}[c]	$PM_{2.5}$[d]	SOx	CO_2	CH_4	N_2O	CO_2e
Switching and Total[e]	0.24	0.49	5.55	0.077	0.071	0.00	225	0.01	0.01	227

[a] All values are rounded to indicate number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.
[b] ROG to THC ratio for diesel engines used 1.21[37]
[c] All PM_{10} emissions are DPM.
[d] $PM_{2.5}$ size fraction of PM_{10} was estimated to be 0.92, consistent with the ARB (2015) Vision Locomotive Module
[e] OGRE was recently awarded funding under the Carl Moyer and Diesel Emissions Reduction Act Programs to retrofit one switcher locomotive with a new Tier 4 locomotive.

6.5 Summary of Locomotive Emission Results

Total 2017 locomotive emissions at the Port of Oakland are summarized in Table 6-9.

Table 6-9. Estimated total annual locomotive emissions (tons) - 2017.[a]

Source Type	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG [b]	CO	NOx	PM_{10}	$PM_{2.5}$[c]	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
OIG Switching Engines	0.50	0.70	10.88	0.175	0.161	0.175	0.00	432	0.02	0.01	436
OIG Train Arrival / Departure	0.03	0.05	0.40	0.007	0.007	0.007	0.00	40	0.00	0.00	40
Subtotal: OIG	**0.53**	**0.76**	**11.28**	**0.182**	**0.168**	**0.182**	**0.00**	**472**	**0.02**	**0.01**	**476**
OGRE	0.24	0.49	5.55	0.077	0.071	0.077	0.00	225	0.01	0.01	227
Total	**0.77**	**1.24**	**16.83**	**0.26**	**0.24**	**0.26**	**0.01**	**697**	**0.04**	**0.02**	**703**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., "0.00") are not identically equal to zero.
[b] ROG to THC ratio for diesel engines used 1.21
[c] $PM_{2.5}$ size fraction of PM_{10} was estimated to be 0.92, consistent with the ARB (2015) Vision Locomotive Module

[37] https://www.arb.ca.gov/msei/ordiesel.htm, 2017 Emissions Inventory Aggregated at County/Air Basin/State

Locomotive emissions in 2017 are compared with emissions from prior inventory years in Figure 6-1. Total emissions in 2017 were 22% (NOx) and 15% (DPM) higher than in 2015 due to the added activity in the OGRE yard. Overall, NOx emissions have decreased by 78% and DPM emissions by 87% from 2005 levels.

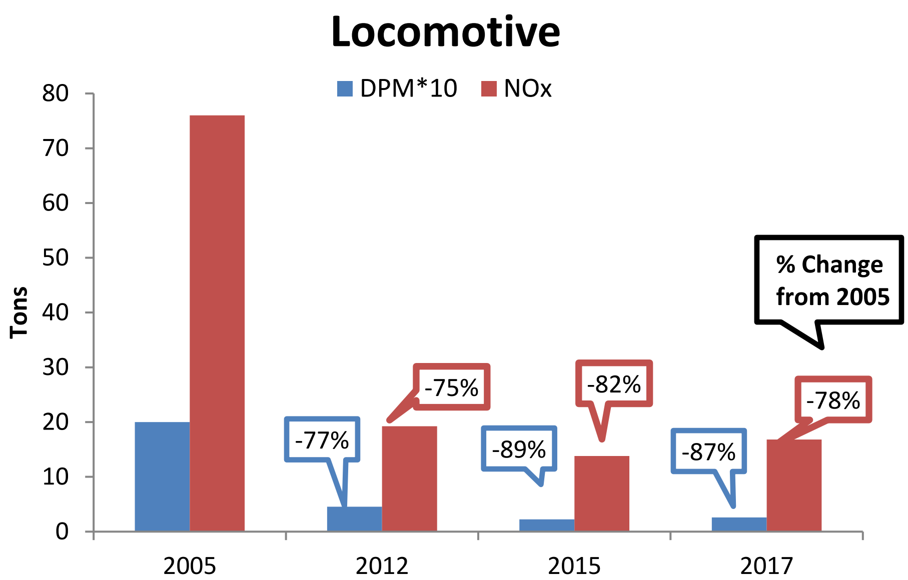


Figure 6-1. Locomotive DPM and NOx emissions.

7.0 OTHER OFF-ROAD EQUIPMENT

This section documents emission estimation methods and results for construction and maintenance equipment operated at Port of Oakland terminals and the rail yards. The 2017 Port of Oakland other off-road equipment emission inventory includes on-dock and off-dock terminals and the rail yard. Previous Port of Oakland other off-road equipment emission inventories did not include other off-road equipment operated at off-dock terminals because activities at off-dock terminals are related to functions such as transloading that are not unique to port tenants; such activities may occur at facilities that are on or off Port property. However, in an effort to expand the Port of Oakland maritime inventory to include activities at all Port maritime tenant facilities, emissions from other off-road equipment at off-dock terminals are included in the 2017 emission inventory. As in past years, the Port maritime inventory does not include off-road equipment at the Schnitzer Steel facility or the Union Pacific rail yard because those privately owned facilities are not located on Port property.

7.1 Background

Off-road equipment considered in this section include general industrial and construction equipment that are most often used for maintenance and construction activity occurring at the Port. They are not to be confused with CHE, which is primarily used to transfer shipping containers or intermodal freight cargo. The CHE activities and emissions are discussed in this emission inventory under Section 4. In this section, three off-road equipment sources are considered: (1) facility maintenance and construction at each terminal, (2) Port of Oakland general maintenance, and (3) Cool Port Oakland construction.

7.2 Emission Calculation Methodology

To estimate the annual 2017 off-road equipment emissions, a list of equipment including engine characteristics (model year, rated power, and equipment type) and equipment operation (hours of usage and fuel consumption rates) were collected from terminal operators and the Port. Equipment population and operation estimates by terminal were derived from surveys of terminal operators conducted by the Port of Oakland. Fleet data for the Port's general maintenance equipment and equipment used for Cool Port Oakland construction were provided by the Port.

The types of construction and maintenance equipment considered in this inventory include:

- Aerial Lifts
- Air Compressors
- Cranes
- Excavators
- Forklifts
- Generator Sets
- Paving Equipment
- Pumps
- Rollers
- Rubber Tired Dozers
- Rubber Tired Loaders
- Scrapers

- Graders
- Lifts
- Other Construction Equipment
- Other General Industrial Equipment
- Pavers
- Skid Steer Loaders
- Surfacing Equipment
- Sweepers/Scrubbers
- Tractors/Loaders/Backhoes
- Welders

Off-road equipment emissions were calculated using the following equation:

$$Equip_{emiss} = \frac{EF_{adj} \times Engine_{bhp} \times LF_{wt} \times Time_{hrs} \times Pop}{(453.6 \times 2000)}$$

Where:

$Equip_{emiss}$ is the annual emissions in tons per year,
EF_{adj} is the emission factor adjusted for deterioration, in grams per brake horsepower-hour,
$Engine_{bhp}$ is the brake horsepower of the engine,
LF_{wt} is the weighted load factor (average load expressed as a % of rated power),
$Time_{hrs}$ is the annual operating hours of the equipment,
Pop is the population (number of the equipment), and
(453.6 x 2000) is a conversion from grams to tons.

7.3 Input Data and Use

For terminal maintenance equipment, the same surveys as those presented for CHE (Section 4) were used. Off-road equipment included in survey responses that were characterized as “non-CHE” are included in this section. The Port provided the rest of the maintenance and construction equipment data. When equipment specific horsepower were not provided, Ramboll assumed (i) horsepower of similar make and model provided in the Port survey or (ii) defaulted to values used in ARB models or (iii) values obtained from a web search. Similarly, for annual activity, average annual operation of similar equipment from the port inventory was used.

A combination of the OFFROAD 2007 and OFFROAD 2011 models was used to estimate emissions. OFFROAD 2011 only estimates HC, NOx, and PM emissions from diesel-fueled equipment; therefore, emissions from diesel-fueled equipment for other criteria pollutants and emissions of all pollutants from non-diesel-fueled equipment were taken from OFFROAD 2007. GHG emission rates were estimated based on CARB’s GHG inventory. Emission factors back-calculated from these inventory models are adjusted for engine deterioration. For diesel-powered equipment, emission factors for HC, NOx, and PM were derived from OFFROAD 2011.

OFFROAD 2011 does not support emission estimates for other fuel types (emission factors for gasoline) and for other pollutants (CO, SO_2 and the greenhouse gases CO_2, CH_4, and N_2O). Diesel-powered equipment SO_2 emission factors were estimated based on brake specific fuel consumption estimates from ARB 2017 Emission Off-road Diesel Emission Factors.[38] Diesel-powered equipment GHG (CO_2, CH_4, and N_2O) emission rates per unit of fuel consumption were taken from California's 2000-2015 GHG Inventory. Diesel-powered CO emission factors were taken from OFFROAD 2007. Criteria air pollutant emission factors for gasoline and propane powered equipment were obtained from ARB's OFFROAD 2007 model. Gasoline and propane powered equipment emissions factors for GHGs, CO_2, CH_4, and N_2O were estimated using OFFROAD 2007 fuel consumption estimates and California's 2000-2015 GHG Inventory emission factors.[24]

Populations of off-road equipment evaluated in this section are summarized in Table 7-1 below. Of the 250 pieces of construction and maintenance equipment at the Port of Oakland in 2017, 66 were diesel powered (26% of total), 117 were gasoline powered (47% of total), 51 were propane powered (20% of total), and 16 were electric powered (6% of total). 25% of other-off-road equipment were used for general Port maintenance, 69% operated at marine terminals and railyard facilities, 28% operated at off-dock terminals, and 6% were used for construction at new Cool Port Oakland facility. Indirect emissions associated with electricity production for the electric powered equipment were not estimated. Average horsepower and average annual hours by equipment type are shown in Table 7-1. However, actual horsepower and actual annual hours of operation for each piece of equipment from survey responses were used to estimate emissions.

Table 7-1. Construction and maintenance equipment – population, average horsepower, and average annual hours of operation by type.

Equipment Type	Population	Average Horsepower	Average Annual Hours of Operation
Aerial Lifts	2	74	350
Air Compressors	59	11	627
Bobtail	1	56	0
Bore/Drill Rigs	3	206	435
Cranes	1	226	56
Crushing/Proc. Equipment	1	135	592
Excavators	3	134	716
Forklifts	51	80	1235
Generator Sets	2	80	338
Golf Carts	1	9	780
Graders	2	162	173
Lifts	22	100	250
Off-Highway Trucks	3	385	350
Other Construction Equipment	2	172	1,020

[38] https://www.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017_v7.xlsx

Equipment Type	Population	Average Horsepower	Average Annual Hours of Operation
Other General Industrial Equipment	2	148	61
Pallet Jack	2	186	2920
Pavers	2	81	19
Paving Equipment	1	123	20
Pressure Washers	2	19	220
Rollers	3	53	75
Rubber Tired Dozers	1	255	320
Rubber Tired Loaders	1	260	20
Scrapers	1	362	584
Skid Steer Loaders	5	72	259
Sweepers/Scrubbers	1	66	192
Tractors/Loaders/Backhoes	17	149	519
Welders	59	10	298

7.4 Summary of Construction and Maintenance Equipment Emission Results

Table 7-2 and Table 7-3 present emission estimates for the construction and maintenance equipment by equipment type and by fuel type, respectively. DPM emissions are equivalent to the diesel PM_{10} emissions listed in Table 7-3. As mentioned above, the 2017 Port of Oakland construction and maintenance equipment emission inventory (summarized in Table 7-2 and Table 7-3 below) includes on-dock and off-dock terminals and the rail yards.

As mentioned above, previous Port of Oakland construction and maintenance equipment emission inventories include on-dock terminals and the rail yards, but do not include construction and maintenance equipment operated at off-dock terminals. Off-dock terminals not included in previous emission inventories accounted for 0.07 tons per year (24%) of total construction and maintenance equipment DPM emissions in 2017.

Table 7-2. 2017 Port of Oakland construction and maintenance equipment emissions by equipment type (tons per year).[a]

Equipment Type	Criteria Air Pollutants						Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	CO_2	CH_4	N_2O	CO_2e
Aerial Lifts	0.001	0.055	0.024	0.000	0.000	0.000	10	0.000	0.000	10
Air Compressors	0.097	4.432	0.126	0.002	0.002	0.000	35	0.000	0.001	36
Bobtail	0.000	0.000	0.000	0.000	0.000	0.000	0	0.000	0.000	0
Bore/Drill Rigs	0.022	0.154	0.375	0.011	0.010	0.001	78	0.002	0.004	80
Cranes	0.002	0.005	0.027	0.001	0.001	0.000	2	0.000	0.000	2
Crushing/Proc. Equipment	0.032	0.222	0.237	0.013	0.012	0.000	36	0.001	0.002	37
Excavators	0.041	0.493	0.531	0.026	0.024	0.001	77	0.030	0.144	121
Forklifts	0.102	19.321	3.065	0.069	0.064	0.001	474	0.055	0.276	557
Generator Sets	0.038	0.162	0.241	0.017	0.016	0.000	26	0.000	0.001	26
Golf Carts	0.019	0.995	0.014	0.001	0.001	0.000	3	0.000	0.000	3
Graders	0.018	0.090	0.209	0.012	0.011	0.000	14	0.008	0.037	25
Lift	0.045	8.215	2.007	0.018	0.017	0.000	204	0.002	0.010	207
Off-Highway Trucks	0.076	0.342	1.083	0.048	0.044	0.001	57	0.063	0.315	153
Other Construction Equipment	0.070	0.501	0.881	0.047	0.043	0.001	85	0.002	0.005	86
Other General Industrial Equipment	0.004	0.013	0.066	0.002	0.002	0.000	5	0.037	0.187	61
Pallet Jack	0.000	0.000	0.000	0.000	0.000	0.000	0	0.000	0.000	0
Pavers	0.001	0.007	0.009	0.000	0.000	0.000	1	0.000	0.001	1
Paving Equipment	0.000	0.003	0.002	0.000	0.000	0.000	1	0.004	0.021	7
Pressure Washers	0.009	0.583	0.014	0.001	0.001	0.000	9	0.000	0.000	9
Rollers	0.009	0.042	0.029	0.003	0.003	0.000	3	0.016	0.080	27
Rubber Tired Dozers	0.021	0.084	0.261	0.012	0.011	0.000	19	0.000	0.001	19
Rubber Tired Loaders	0.001	0.002	0.011	0.000	0.000	0.000	1	0.009	0.044	15
Scrapers	0.042	0.191	0.600	0.024	0.022	0.001	59	0.002	0.003	60
Skid Steer Loaders	0.003	0.125	0.061	0.001	0.001	0.000	22	0.014	0.069	43
Sweepers/Scrubbers	0.000	0.020	0.009	0.000	0.000	0.000	4	0.030	0.151	50
Tractors/Loaders/Backhoes	0.065	1.426	0.556	0.030	0.028	0.003	347	0.142	0.709	562
Welders	0.065	2.750	0.100	0.002	0.002	0.000	30	0.000	0.001	30
Totals	**0.783**	**40.235**	**10.538**	**0.341**	**0.314**	**0.009**	**1602**	**0.419**	**2.064**	**2,228**

[a] All values are rounded to indicated number of significant figures; any values shown as zero (e.g., “0.00”) are not identically equal to zero.

Table 7-3. 2017 Port of Oakland construction and maintenance equipment emissions by fuel type (tons per year).

Fuel Type	Criteria Air Pollutants							Greenhouse Gas CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SO_2	CO_2	CH_4	N_2O	CO_2e
Diesel	0.487	4.360	5.638	0.280	0.258	0.280	0.009	912	0.412	2.032	1528
Gasoline	0.190	8.760	0.253	0.005	0.005	0.005	0.001	77	0.001	0.003	78
Propane	0.107	27.115	4.647	0.055	0.052	0.055	0.000	613	0.006	0.029	622
Totals	**0.783**	**40.235**	**10.538**	**0.341**	**0.314**	**0.341**	**0.009**	**1602**	**0.419**	**2.064**	**2228**

8.0 SUMMARY AND COMPARISONS WITH PRIOR YEAR INVENTORIES

This section presents an overall summary of the 2017 Seaport Emissions Inventory and discusses comparisons of 2017 emissions with emissions previously estimated for 2005, 2012, and 2015.

8.1 Summary of 2017 Seaport Emissions

Seaport emissions for 2017 based on the updated methods described in previous sections (i.e., use of AIS-based speed data and revised low load adjustment factors) are summarized in Table 8.1a (for criteria pollutants) and 8.1b (for GHGs) and in Figure 8.1. This methodology can be considered to be a refined methodology, compared to the methods used in the 2005 inventory, in that it uses input data and methods that were not available in 2005. For the sake of comparison between inventory years, 2005, 2012, 2015, and 2017 emissions are compared below in Section 8.2 using consistent methods for OGVs for all years, as discussed in Section 2.

OGVs accounted for the largest fraction of DPM (73%) and NOx (82%) emissions in 2017 using the refined methodology. Berthing accounted for 34% (9 tons) of the OGV DPM emissions as shown in Figure 8.2 and for 24% of total Seaport DPM emissions in 2017. Additional reductions in berthing emissions – whether by increased shore power utilization or other means – thus represent the largest single opportunity for future reductions in total Seaport DPM emissions. Even if shore power utilization as a fraction of ship calls were to remain constant, the current trend towards fewer calls per year that is being driven by increases in vessel TEU capacity can be expected to reduce berthing emissions in future years as the total hours at berth with engines running during shore power connect/disconnect operations is reduced.

Harbor craft accounted for the next largest fraction of 2017 DPM emissions (20% with bunkering included). Harbor craft emissions are expected to decrease in the future as older engines are replaced by newer models with lower emissions.

Table 8.1a. Summary of 2017 Seaport emissions: criteria pollutants (AIS-based speeds and revised low load adjustment factors). (tons per year)

	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx
OGV	88.7	149	2,068	33.3	31.0	26.1	121.4
Harbor Craft: Dredge & OGV assist	19.2	81	152	6.1	5.9	6.1	0.1
Harbor Craft: Bunkering	2.7	8	26	1.2	1.1	1.2	0.0
CHE	18.6	162	173	1.7	1.6	1.6	0.3
Trucks	4.7	24	80	0.9	0.5	0.3	0.2
Locomotives	0.8	1	17	0.3	0.2	0.3	0.0
Other	0.8	40	11	0.3	0.3	0.3	0.0
Total	**135.5**	**465**	**2,526**	**42.4**	**40.8**	**35.8**	**123.4**

Sum of individual values may not equal indicated totals due to rounding

Table 8.1b. Summary of 2017 Seaport emissions: GHGs (AIS-based speeds and revised low load adjustment factors). (tons per year)

	CO_2	CH_4	N_2O	CO_2e[a]
OGV[b]	114,308	12.2	3.1	125,431[c]
Harbor Craft: Dredge & OGV assist	16,369	1.9	0.4	16,548
Harbor Craft: Bunkering	2,420	0.2	0.1	2,444
CHE	35,398	1.4	0.3	35,520
Trucks	18,992	0.2	2.7	19,805
Locomotives	697	0.0	0.0	703
Other	1,602	0.4	2.1	2,228
Total	**189,787**	**16.5**	**8.6**	**202,679**

Sum of individual values may not equal indicated totals due to rounding

[a]CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (25), and N_2O (298).

[b]Auxiliary engine emissions while berthing based on ARB default 18% load assumption in all years although actual power draw during use of shore power is about one-half the value implied by the ARB default assumption (based on 2017 shore power records).

[c]Shore power CO_2e emissions of 9,905 tons from electricity generation and transmission in CO_2e are added here based on recorded shore power electricity consumption.

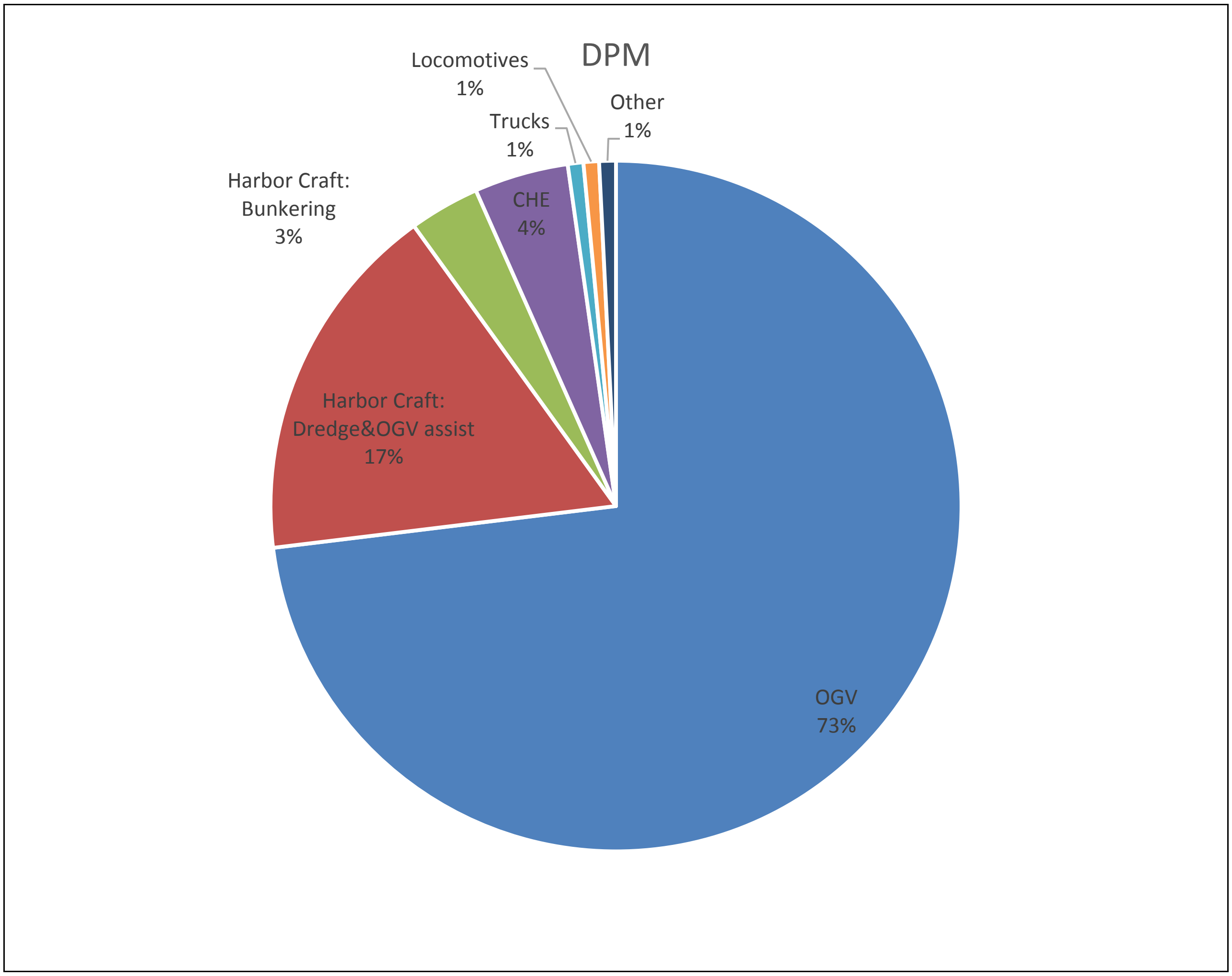


Figure 8-1a. 2017 DPM emissions (AIS-based speeds and revised low-load adjustment factors).

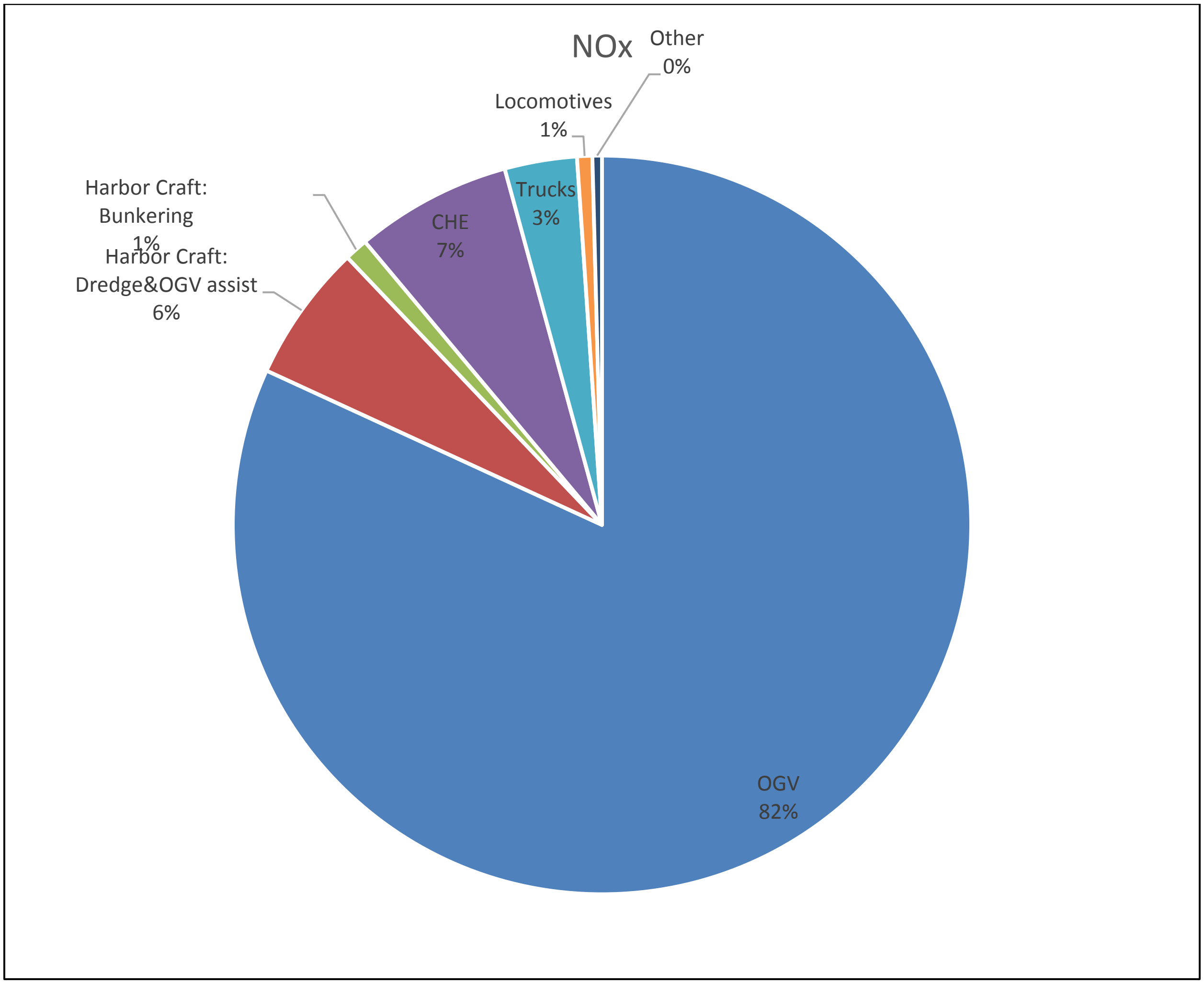


Figure 8-1b. 2017 NOx emissions (AIS-based speeds and revised low-load adjustment factors).

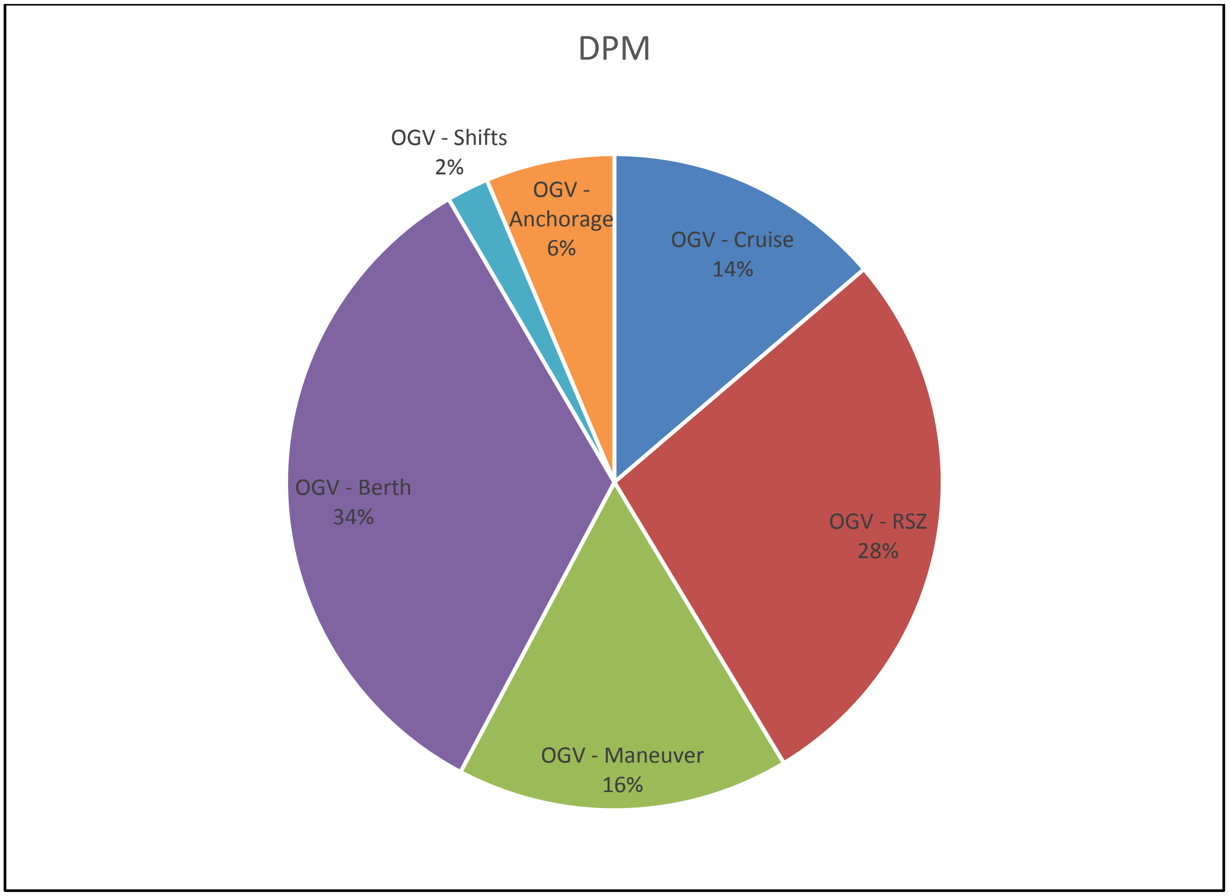


Figure 8-2. DPM emissions associated with OGV operating modes in 2017 (AIS-based speeds and revised low-load adjustment factors).

8.2 Comparison with Prior Year Inventories

Port emissions change from year to year due to replacement of older equipment, implementation of new regulations, changes in work practices, changes in port tenants (including opening of new businesses and closing of old ones), and fluctuations in cargo volume. Moreover, comparisons of emission inventories completed for different years can be confounded by changes in inventory methodology, including changes in assumptions, emission factors, and other inputs. Overall, an attempt has been made to use consistent methods in developing the 2005, 2012, 2015, and 2017 Seaport emission inventories. However, new data sources and procedures have become available over the years which have provided opportunities to improve the accuracy of the inventory and continue the use of "best practice" inventory methods. Application of these improvements comes with the disadvantage of complicating comparisons with prior year inventories. Where the methodological changes are significant, the Port has decided to present refined emission estimates based on both the new, improved methods as well as the older methods so as to provide a more consistent comparison with prior year results.

Key features of the 2017 inventory methodology which confound comparisons with prior year inventories are:

> Ocean Going Vessels: Calculation of propulsion engine loads using AIS data as described in Section 2.2.3.2 and revised low load adjustment factors as described in Section 2.3.2.1 results in emission estimates that cannot be directly compared with prior year estimates which were based on assumed average speeds as described in Section 2.2.3.1 and historical low load adjustment factors. We therefore calculated OGV emissions using both the old and new methods as described in Section 2.4. Comparisons with prior year inventories are based on the old methods for consistency.
>
> Commercial Harbor Craft: Methods used to calculate 2017 harbor craft emission are consistent with those used in prior year inventories. However, bunkering emissions were not included in prior year inventories so comparison of 2017 emissions with previous inventories are made with bunkering emissions excluded.
>
> Cargo Handling Equipment: Methods used for estimating 2017 CHE emissions are consistent with prior year inventories. However, in an effort to expand the Port of Oakland maritime inventory to include activities at all Port maritime tenant facilities, emissions for 2017 include CHE emissions from both marine terminals and off-dock terminals whereas CHE emissions from off-dock terminals were not included in the prior year inventories. Emissions at the off-dock terminals accounted for 0.27 tons per year (17%) of total CHE DPM emissions in 2017.
>
> On-Road Heavy-Duty Trucks: Methods used to estimate 2017 truck emissions are consistent with those used in prior year inventories. As in prior years, however, the latest ARB on-road emissions model was used to maintain consistency with other on-road inventories. Differences in drayage truck emission rates between EMFAC2014

(which was used to prepare the 2015 inventory) and EMFAC2017 (used to prepare the 2017 inventory) resulted in most of the estimated 5% DPM emission increase between 2015 and 2017.

Rail Locomotives: Methods used to estimate 2017 rail locomotive emissions are consistent with those used in prior year inventories. Locomotive activity in 2017 included activity at the new OHIT as well as the OIG (BNSF) railyard. Emissions for 2017 from both facilities are included in the comparisons with prior year inventories since all of the inventories represent total rail locomotive activities on port-owned property.

Other Off-Road Equipment: The 2017 Port of Oakland other off-road equipment emission inventory includes construction and maintenance equipment at on-dock and off-dock terminals and the rail yard. Previous Port of Oakland other off-road equipment emission inventories did not include other off-road equipment operated at off-dock terminals because activities at off-dock terminals are related to functions such as transloading that are not unique to port tenants; such activities may occur at facilities that are on or off Port property. However, in an effort to expand the Port of Oakland maritime inventory to include activities at all Port maritime tenant facilities, emissions from other off-road equipment at off-dock terminals are included in the 2017 emission inventory. Note that a significant amount of construction occurred at the Port in 2005, including several terminal and wharf reconstruction and expansion projects and the -50-foot dredging of the Oakland Navigational channel. Emissions from 2005 construction activity were not included in the Port's 2005 inventory report (ENVIRON, 2008a) but were included in a separate report (ENVIRON, 2008b). The 2005 construction emissions are not included in the year-to-year comparisons described below.

Criteria pollutant emissions for each year by source category are summarized in Table 8-2a; GHG emissions are summarized in Table 8-2b. CO_2e emissions associated with shore power generation and transmission (G&T) have been added for 2017 in Table 8-2b; shore power was not used in 2005 and G&T CO_2e emissions have not been estimated for 2012 or 2015. Note that an inadvertent double counting of the on-road portion of each truck trip included in the originally published 2012 and 2015 inventories has been corrected in these tables. Total DPM, NOx, and CO_2e emission changes from 2005 are summarized in Table 8-3. Total DPM emissions have been reduced by 81% below 2005 levels while NOx reductions have reached 31%. As shown in Table 8-4, most (79%) of the DPM reductions between 2005 and 2017 are attributable to reductions in OGV DPM emissions. Nearly half of the NOx reductions are a result of reductions in CHE emissions.

Factors influencing emission changes over time for each of the source categories along with bar charts of emission trends for each category were described above in the concluding summary subsections for source category (i.e., Sections 2.4, 3.3, 4.4, 5.6, 6.5, and 7.4). Highlights of the comparisons with prior year inventories are summarized below:

For OGVs, both NOx and DPM emissions were lower for 2017 as compared with three previous inventories.[39] NOx emission reductions resulted both from the use of shore power and fleet turnover to newer ship engines designed to meet lower NOx emission standards. DPM reductions since 2005 are primarily attributable to increased use of low sulfur fuel and the use of shore power.

Harbor craft emissions - excluding bunker barge activity - declined between 2005 and 2017 as vessel fleets turned over to incorporate lower emitting engines. 2017 emissions were lower than in 2015 despite an overall greater than 10% increase in vessel calls at the Port. Port records indicate bunkering volume levels were higher in 2005 as compared to 2017, so including bunkering in the comparison would probably have led to a larger calculated emissions reduction.

Cargo handling equipment emissions have declined as the CHE fleet has turned over to lower emitting engines. DPM emissions have decreased by 93% and NOx emissions by 77% since 2005. Further emission reductions are expected in upcoming years, especially for DPM, as regulatory exemptions allowing the use of DPF expire and Tier 4 engines are installed.

On-road heavy-duty truck NOx and DPM emissions in 2017 were sharply reduced from 2005. Changes in emissions from year to year are a result of 1) changes in the number of truck trips, 2) modernization of the truck fleet due to the introduction of restrictions on older trucks and fleet turnover, and 3) revisions to emission rates associated with updates to ARB's EMFAC model. Modernization of the drayage truck fleet was the overwhelming factor responsible for DPM emission reductions of 91% between 2005 and 2012, and 83% between 2012 and 2015. Overall, DPM emissions decreased by 98% between 2005 and 2017. Similarly, NOx emissions decreased 72% between 2005 and 2012, 5% between 2012 and 2015, and 12% between 2015 and 2017 for an overall 2005 – 2017 NOx emission reduction of 76%.

Year to year changes in locomotive emissions reflect the gradual introduction of newer and retrofit locomotives with lower emissions and the introduction of idle reduction measures as well as changes in the amount of cargo moved by rail instead of trucks. Locomotive emissions in 2017 were 22% (NOx) and 15% (DPM) higher than in 2015 due at least in part to the added activity in the OGRE yard. Overall, locomotive NOx emissions at the Port have decreased by 78% and DPM emissions by 87% from 2005 levels.

As emission reductions occurred over time, the relative contributions of each source category to total emissions changed as illustrated for DPM in Figures 8-3 and 8-5 and for NOx in Figures 8-4 and 8-6. As truck emissions decreased from 6% to less than 1% of the inventory between

[39] Direct comparison with only the 2015 inventory is not representative, as there was an unusual amount of berthing, shifts, and anchorage activity in 2015 due to a slow down at the beginning of the year.

2005 and 2017, the relative contribution of OGV emissions increased from 80% in 2005 to 83% in 2017 and harbor craft increased from 5% in 2005 to 12% in 2017.

Table 8-2a. Comparisons of 2017 with prior year Port inventories: criteria pollutants.

2017 Inventory	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx
Ocean-going vessels[a]	177	219	2,345	49.5	45.9	42.2	129
Harbor craft	19	81	152	6.1	5.9	6.1	0
CHE	19	162	173	1.7	1.6	1.6	0
Truck	5	24	80	0.9	0.5	0.3	0
Locomotive	1	1	17	0.3	0.2	0.3	0
Other Offroad Equipment	1	40	11	0.3	0.3	0.3	0
Total	**221**	**527**	**2,777**	**58.8**	**54.4**	**50.7**	**130**
% Reduction from 2005	11%	40%	31%	78%	78%	81%	91%
2015 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going vessels	182	259	2,715	58.7	54.3	51.8	141
Harbor craft	23	97	166	6.6	6.4	6.2	0
CHE	43	253	332	3.9	3.6	3.7	1
Truck[b]	5	16	91	0.8	0.4	0.2	0
Locomotive	0	2	14	0.2	0.2	0.2	0
Other Offroad Equipment	1	12	11	0.6	0.5	0.6	0
Total	**254**	**639**	**3,328**	**70.8**	**65.5**	**62.8**	**142**
2012 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going vessels	176	232	2,591	66.9	62.1	57.4	289
Harbor craft	25	95	235	9.3	9.0	9.3	0
CHE	35	207	413	8.0	7.4	7.9	1
Truck[b]	11	43	95	2.1	1.6	1.5	0
Locomotive	1	2	19	0.5	0.4	0.5	0
Other Offroad Equipment	1	4	4	0.3	0.3	0.3	0
Total	**249**	**584**	**3,358**	**87.2**	**80.8**	**76.9**	**290**
2005 Inventory	**ROG**	**CO**	**NOx**	**PM**	**$PM_{2.5}$[c]**	**DPM**	**SOx**
Ocean-going vessels	117	235	2,484	219.5	201.9	208.5	1,413
Harbor craft	22	83	344.75	13.4	12.3	13.4	3
CHE	53	408	766	21.7	19.9	21.2	7
Truck	49	149	334	15.9	14.6	15.9	2
Locomotive	7	11	76	2.0	1.8	2.0	2
Total	**248**	**886**	**4,005**	**272.4**	**250.6**	**260.9**	**1427**

[a]Emissions based on same methods used in prior year inventories.
[b]Corrected to account for double counting of on-road portion of each trip.
[c]Not included in 2005 inventory; based on assumption that 8% of PM is coarse PM.

Table 8-2b. Comparisons of 2007 with prior year Port inventories: GHGs

2017 Inventory	CO_2	CH_4	N_2O	CO_2e[a]
Ocean-going vessels[b]	122,542	13.1	3.0	133,680[c]
Harbor craft	16,369	1.9	0.4	16,548
CHE	35,398	1.4	0.3	35,520
Truck	18,992	0.2	2.7	19,805
Locomotive	697	0.0	0.0	703
Other Offroad Equipment	1,602	0.4	2.1	0
Total	**195,600**	**17.2**	**8.6**	**208,484**
2015 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[c]**
Ocean-going vessels[b]	168,745	18.0	4.1	170,405
Harbor craft	16,837	2.1	0.5	17,039
CHE	32,606	4.3	0.0	32,713
Truck[d]	18,596	0.3	0.5	18,761
Locomotive	639	0.0	0.0	645
Other Offroad Equipment	1,155	0.0	0.1	1,191
Total	**238,578**	**24.7**	**5.2**	**240,754**
2012 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[e]**
Ocean-going vessels[b]	133,005	14.1	3.3	134,332
Harbor craft	20,134	3.6	0.5	20,377
CHE	38,556	5.3	0.0	38,667
Truck[d]	20,517	0.6	0.6	20,697
Locomotive	926	0.1	0.0	935
Other Offroad Equipment	368	0.1	0.0	370
Total	**213,505**	**23.8**	**4.4**	**215,380**
2005 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[e]**
Ocean-going vessels[b]	141,191	24.5	7.9	144,141
Harbor craft	19,795	2.0	0.7	20,053
CHE	37,238	7.7	0.3	37,486
Truck	21,460	1.7	0.6	21,676
Locomotive	1,216	0.0	0.0	1,220
Total	**220,900**	**36.0**	**9.4**	**224,576**

[a] CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (25), and N_2O (298).
[b] Auxiliary engine emissions while berthing based on ARB default 18% load assumption in all years although actual power draw during use of shore power is about one-half the value implied by the ARB default assumption (based on 2017 shore power records).
[c] Shore power CO_2e emissions of 9,905 tons from electricity generation and transmission in CO_2e are added here based on recorded shore power electricity consumption.
[d] Corrected to account for double counting of on-road portion of each trip.
[e] CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (21), and N_2O (310).

Table 8-3. 2017 percentage reductions from 2005.

	DPM	NOx	CO_2e[a]
OGV	80%	6%	7%
Harbor Craft	55%	56%	17%
Cargo Handling Equipment	93%	77%	5%
Trucks	98%	76%	9%
Locomotives	87%	78%	42%
Total	**81%**	**31%**	**7%**

[a]2017 CO_2e emissions include shore power electricity generation and transmission.

Table 8-4. 2017 percentage contributions to total tons of emissions reduced since 2005.[40]

	DPM	NOx	CO_2e[a]
OGV	79%	11%	65%
Harbor Craft	3%	16%	22%
Cargo Handling Equipment	9%	48%	12%
Trucks	7%	21%	12%
Locomotives	1%	5%	3%

[a]2017 CO_2e emissions include shore power electricity generation and transmission.

[40] Values do not sum to 100% due to inclusion of Other Offroad Equipment emissions in 2017 total.

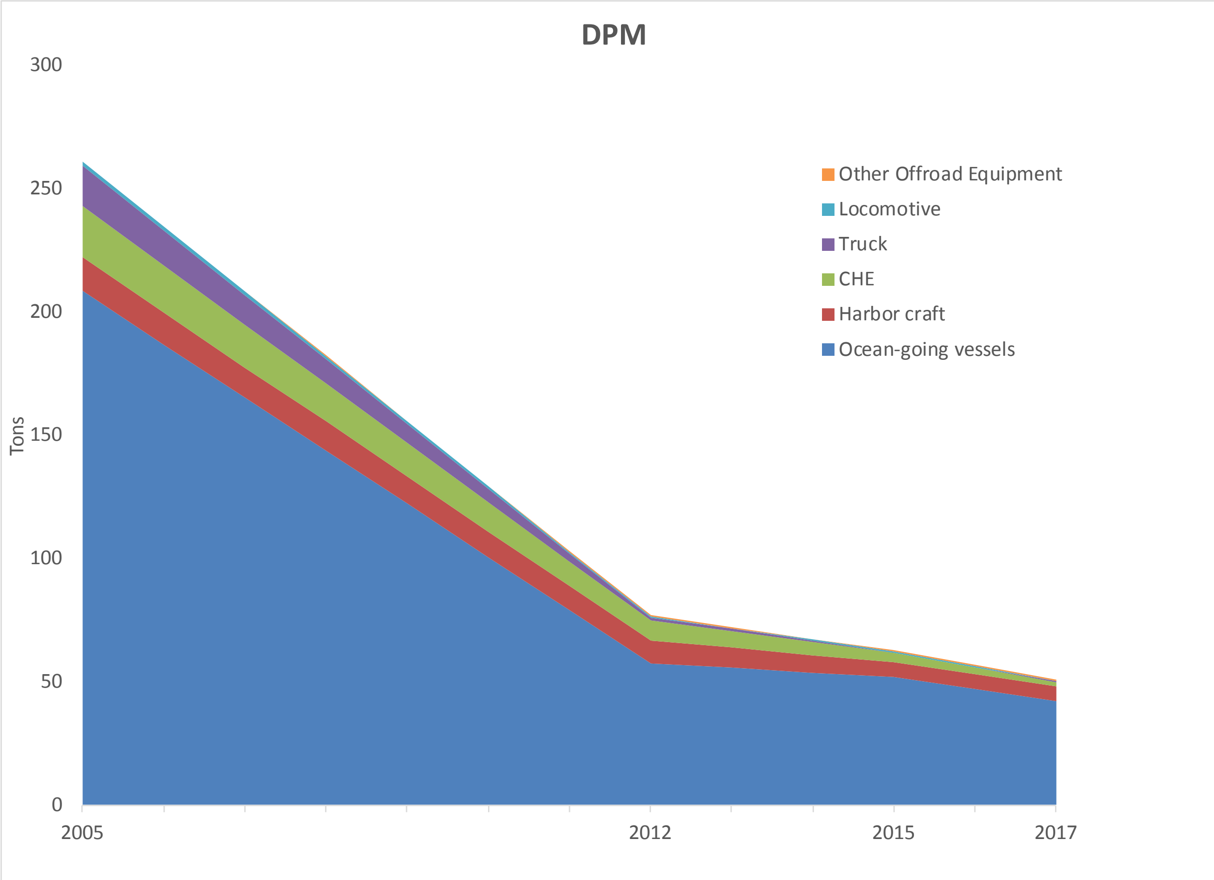


Figure 8-3. Seaport diesel particulate matter (DPM) emissions (tons).

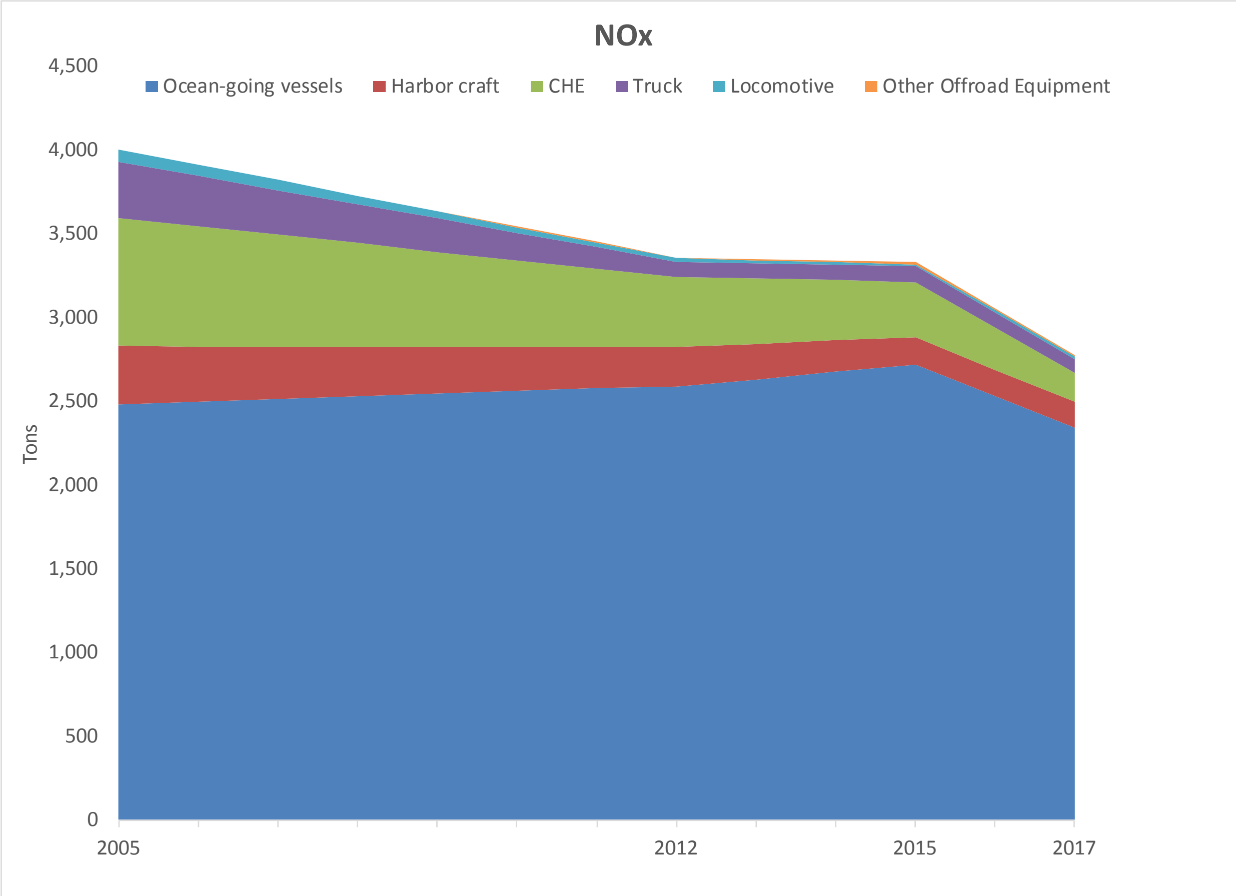


Figure 8-4. Seaport NOx emissions (tons).

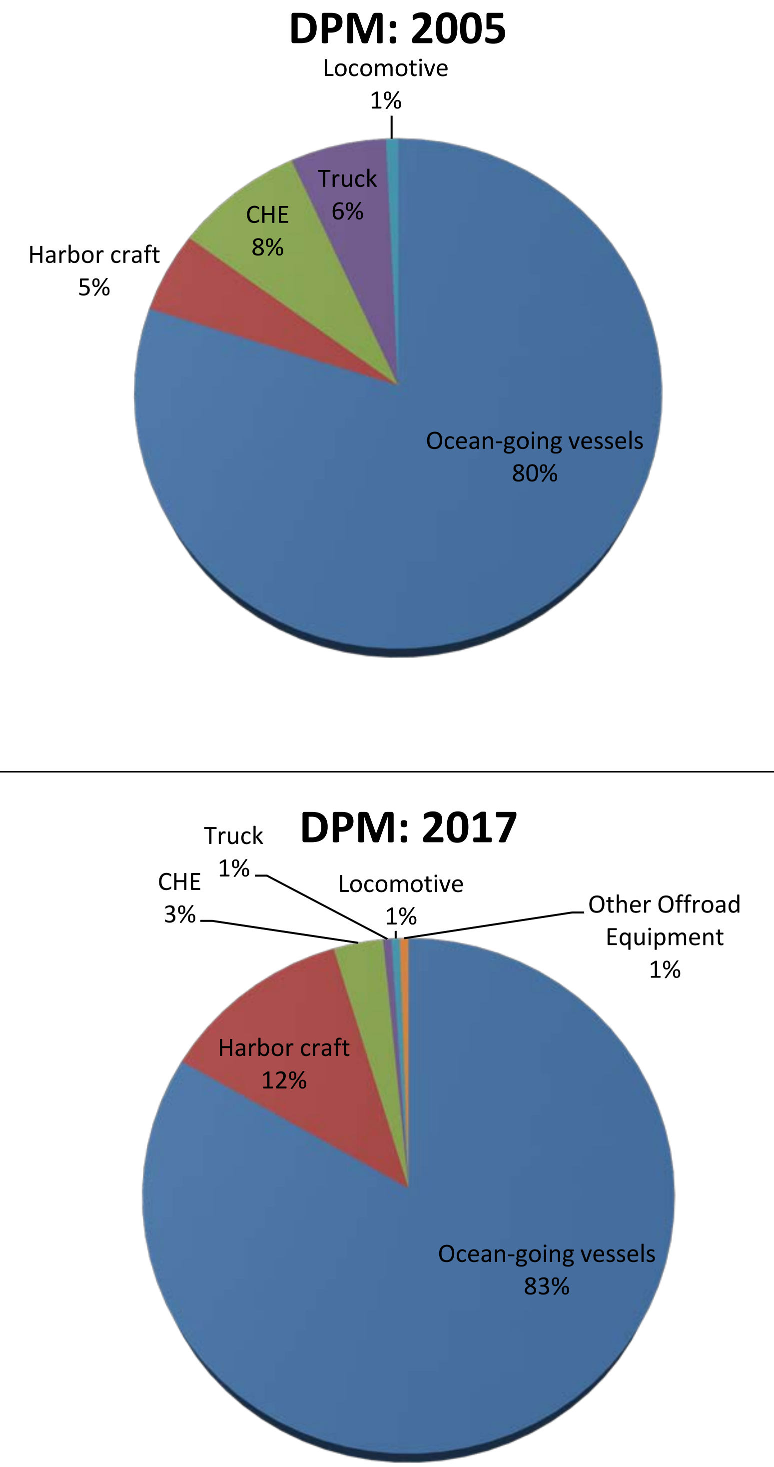
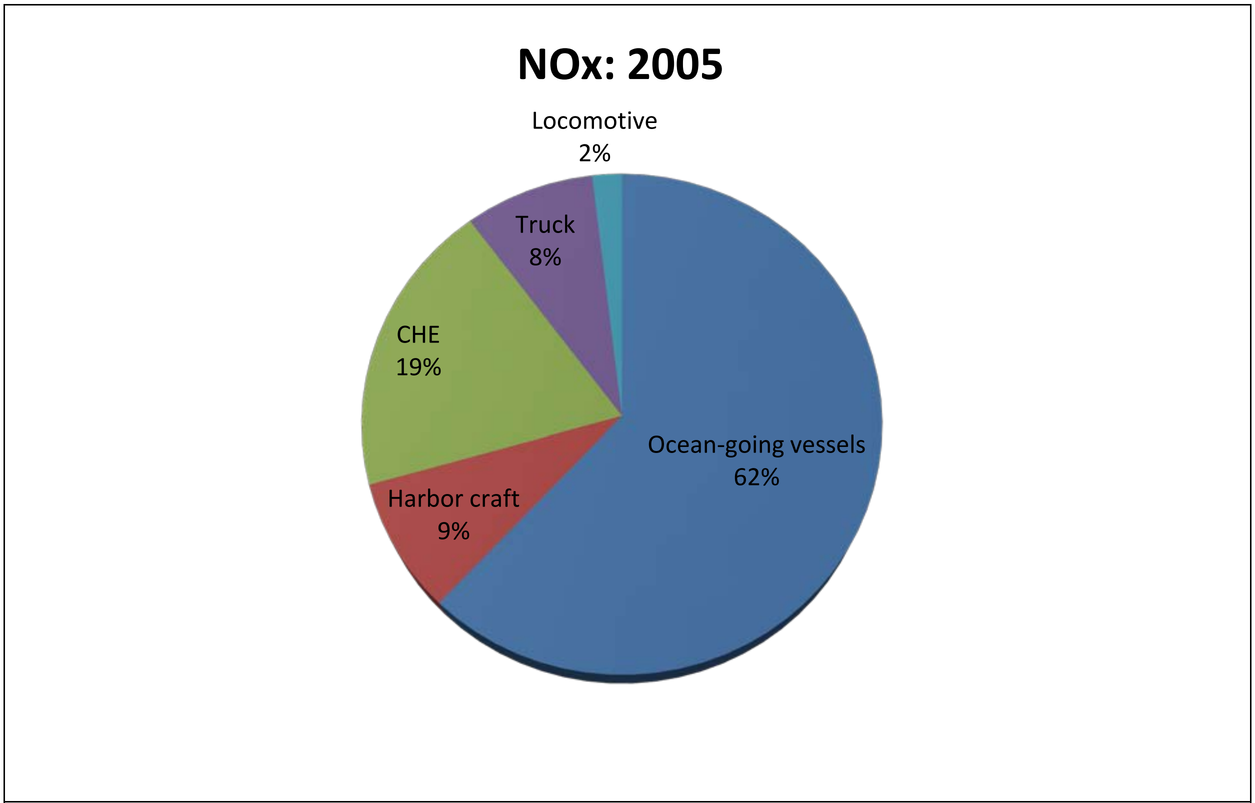


Figure 8-5. Contributions by source category to Seaport DPM emissions: 2005 (top) and 2017 (bottom).



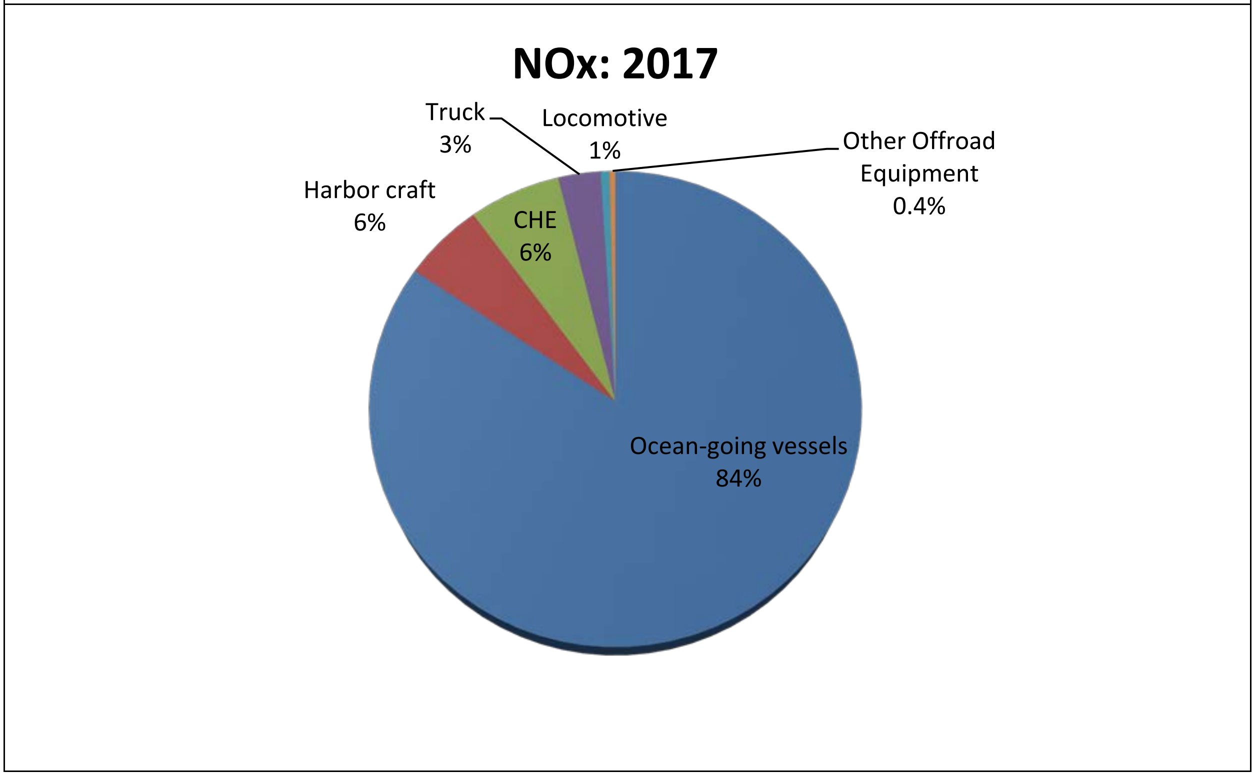


Figure 8-6. Contributions by source category to Seaport NOx emissions: 2005 (top) and 2017 (bottom).

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APPENDIX A

Speed Profiles for All Modes - Developed from AIS Data

APPENDIX A SPEED PROFILES FOR ALL MODES - DEVELOPED FROM AIS DATA

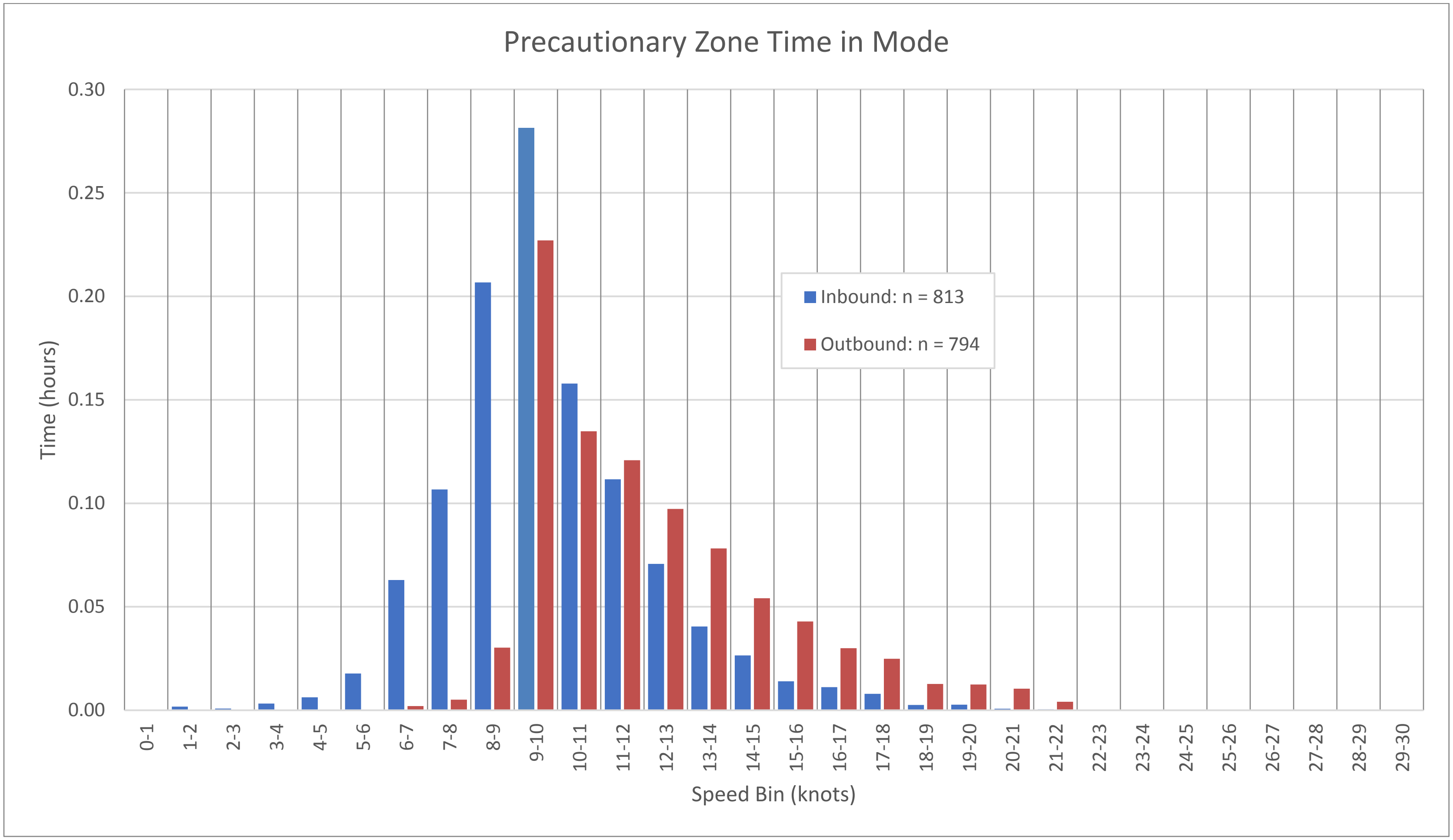

Figure A-1. Precautionary zone speed profile

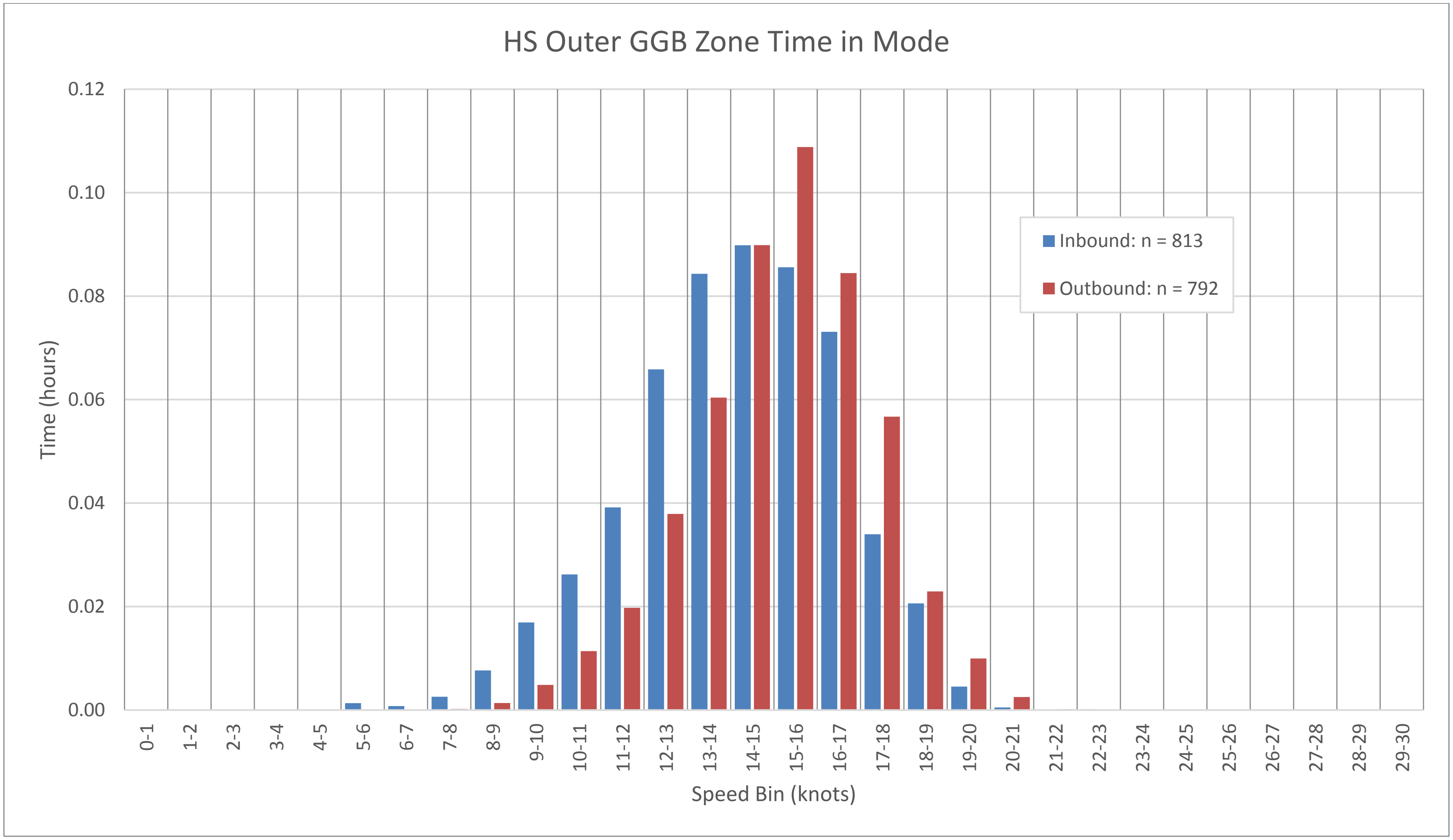

Figure A-2. HS Outer to GGB zone speed profile

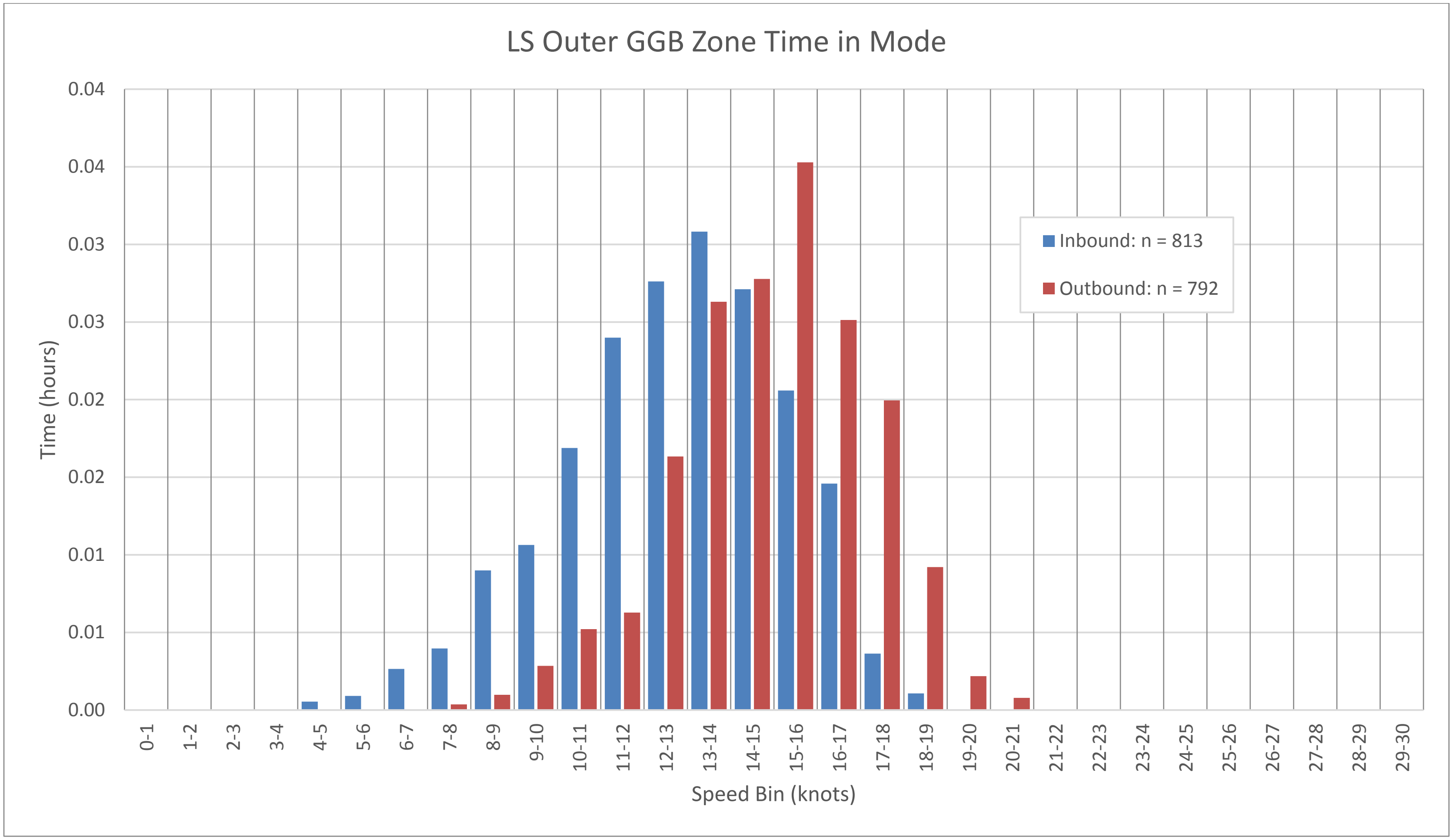

Figure A-3. LS Outer to GGB zone speed profile

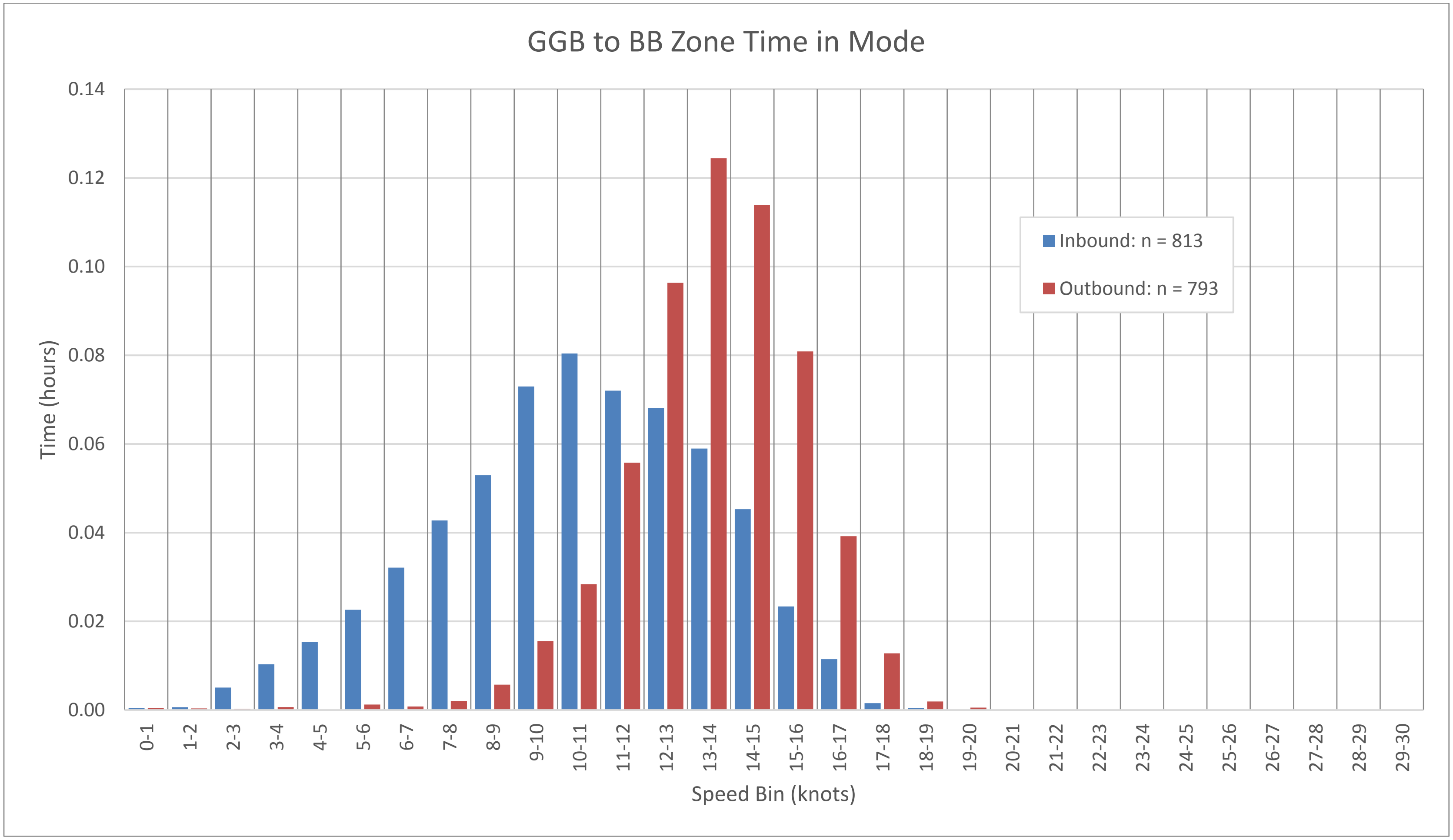

Figure A-4. GGB to BB zone speed profile

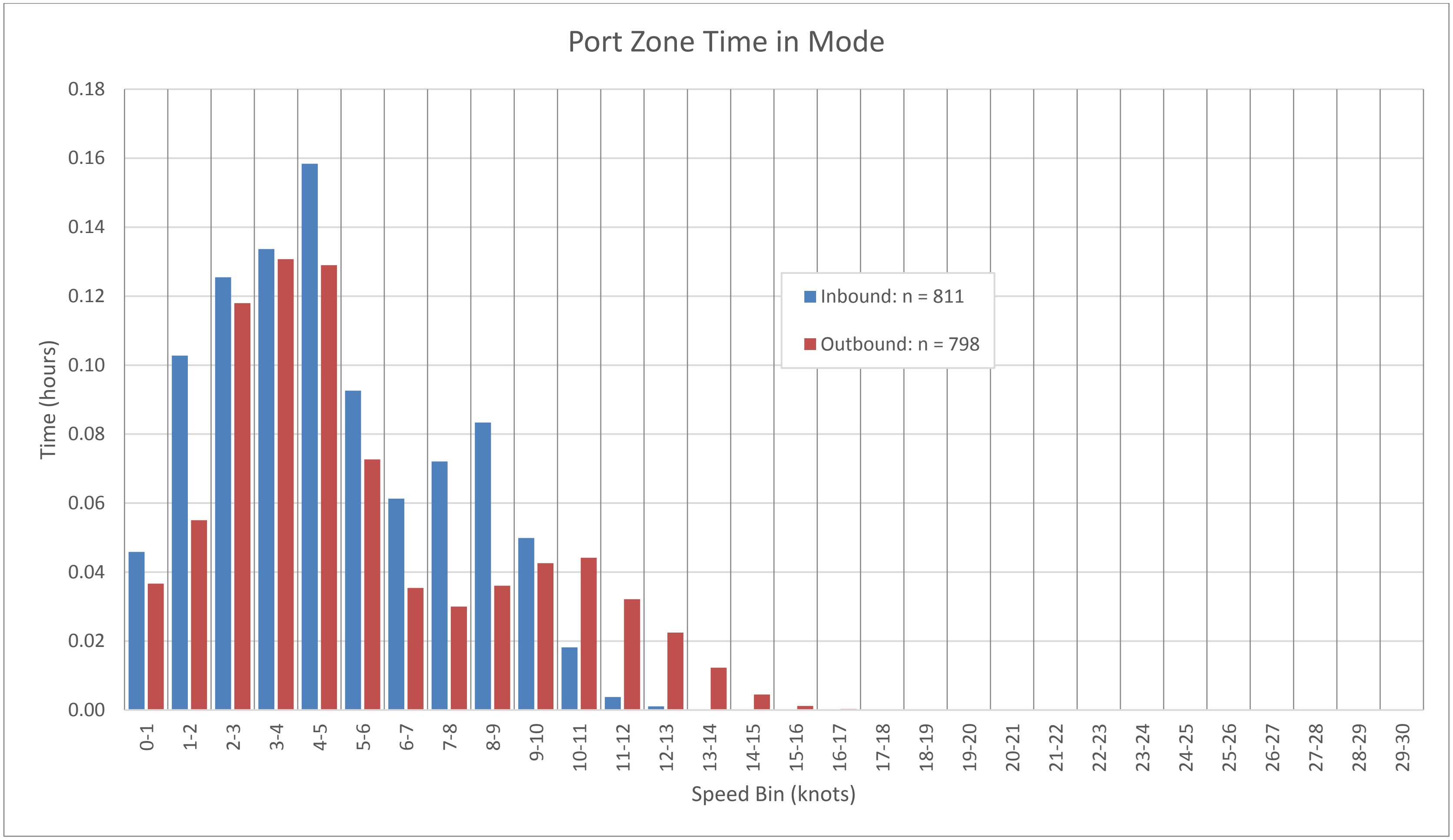

Figure A-5. Port zone speed profile

APPENDIX B

OGV Engine Load Adjustment Factors

APPENDIX B OGV ENGINE LOAD ADJUSTMENT FACTORS

Table 1. Alternative Load Adjustment Factors (Starcrest 2015): MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	N_2O	CH_4
1%	0.36	0.36	0.36	1.9	1.1	0.12	1.36	1.1	1.9	1.36
2%	0.37	0.37	0.37	1.86	1.1	0.12	1.32	1.1	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	1.2	1.09	1.74	1.2
6%	0.4	0.4	0.4	1.7	1.08	0.12	1.17	1.08	1.7	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	1.6	1.07	0.12	1.08	1.07	1.6	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	1.5	1.07	0.39	0.99	1.07	1.5	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	0.9	1.06	1.39	0.9
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%	0.5	0.5	0.5	1.32	1.05	1.12	0.84	1.05	1.32	0.84
20%	0.51	0.51	0.51	1.3	1.05	1.2	0.82	1.05	1.3	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	1.4	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	1.2	1.03	1.51	0.75	1.03	1.2	0.75
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%	0.6	0.6	0.6	1.13	1.02	1.68	0.7	1.02	1.13	0.7
31%	0.6	0.6	0.6	1.12	1.02	1.7	0.7	1.02	1.12	0.7
32%	0.61	0.61	0.61	1.1	1.02	1.72	0.69	1.02	1.1	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

Load	PM	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	N_2O	CH_4
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%	0.7	0.7	0.7	1.03	1.01	1.72	0.67	1.01	1.03	0.67
42%	0.7	0.7	0.7	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	1.67	0.68	1	1.01	0.68
45%	0.73	0.73	0.73	1.01	1	1.65	0.69	1	1.01	0.69
46%	0.74	0.74	0.74	1	1	1.62	0.69	1	1	0.69
47%	0.75	0.75	0.75	1	1	1.6	0.7	1	1	0.7
48%	0.76	0.76	0.76	1	1	1.57	0.7	1	1	0.7
49%	0.77	0.77	0.77	0.99	1	1.54	0.71	1	0.99	0.71
50%	0.78	0.78	0.78	0.99	1	1.51	0.71	1	0.99	0.71
51%	0.79	0.79	0.79	0.99	1	1.48	0.72	1	0.99	0.72
52%	0.8	0.8	0.8	0.99	1	1.45	0.73	1	0.99	0.73
53%	0.81	0.81	0.81	0.99	1	1.41	0.74	1	0.99	0.74
54%	0.82	0.82	0.82	0.99	1	1.38	0.75	1	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	1.2	0.8	0.99	0.98	0.8
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%	0.9	0.9	0.9	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	1	1	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	0.99	0.99	1
76%	1.05	1.05	1.05	0.99	0.99	0.66	1.02	0.99	0.99	1.02

Load	PM	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	N_2O	CH_4
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%	1.1	1.1	1.1	0.99	0.99	0.6	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	1.1	0.99	0.99	1.1
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%	1.2	1.2	1.2	0.96	0.99	0.58	1.2	0.99	0.96	1.2
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	0.61	1.23	1	0.95	1.23
92%	1.23	1.23	1.23	0.95	1	0.63	1.24	1	0.95	1.24
93%	1.25	1.25	1.25	0.94	1	0.65	1.25	1	0.94	1.25
94%	1.26	1.26	1.26	0.93	1	0.67	1.27	1	0.93	1.27
95%	1.27	1.27	1.27	0.93	1	0.7	1.28	1	0.93	1.28
96%	1.28	1.28	1.28	0.92	1	0.73	1.29	1	0.92	1.29
97%	1.29	1.29	1.29	0.91	1	0.77	1.3	1	0.91	1.3
98%	1.31	1.31	1.31	0.9	1	0.81	1.31	1	0.9	1.31
99%	1.32	1.32	1.32	0.89	1	0.85	1.32	1	0.89	1.32
100%	1.33	1.33	1.33	0.88	1	0.9	1.34	1	0.88	1.34

Table 2. Alternative Load Adjustment Factors (Starcrest 2015): MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	N_2O	CH_4
1%	0.84	0.84	0.84	1.91	1.11	1.38	2.53	1.11	1.91	2.53
2%	0.83	0.83	0.83	1.86	1.11	1.36	2.45	1.11	1.86	2.45
3%	0.83	0.83	0.83	1.82	1.1	1.34	2.37	1.1	1.82	2.37
4%	0.82	0.82	0.82	1.77	1.1	1.33	2.3	1.1	1.77	2.3
5%	0.82	0.82	0.82	1.72	1.1	1.31	2.23	1.1	1.72	2.23
6%	0.81	0.81	0.81	1.68	1.09	1.29	2.16	1.09	1.68	2.16
7%	0.81	0.81	0.81	1.64	1.09	1.28	2.1	1.09	1.64	2.1
8%	0.8	0.8	0.8	1.6	1.09	1.26	2.03	1.09	1.6	2.03
9%	0.8	0.8	0.8	1.56	1.08	1.25	1.97	1.08	1.56	1.97
10%	0.79	0.79	0.79	1.52	1.08	1.24	1.91	1.08	1.52	1.91
11%	0.79	0.79	0.79	1.49	1.08	1.22	1.86	1.08	1.49	1.86
12%	0.78	0.78	0.78	1.45	1.07	1.21	1.8	1.07	1.45	1.8
13%	0.78	0.78	0.78	1.42	1.07	1.2	1.75	1.07	1.42	1.75
14%	0.78	0.78	0.78	1.39	1.07	1.19	1.7	1.07	1.39	1.7
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	1.3	1.06	1.16	1.56	1.06	1.3	1.56
18%	0.77	0.77	0.77	1.28	1.06	1.15	1.52	1.06	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	1.2	1.05	1.13	1.41	1.05	1.2	1.41
22%	0.76	0.76	0.76	1.18	1.05	1.12	1.37	1.05	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	1.1	1.31	1.04	1.14	1.31
25%	0.75	0.75	0.75	1.12	1.04	1.1	1.28	1.04	1.12	1.28
26%	0.75	0.75	0.75	1.11	1.04	1.09	1.25	1.04	1.11	1.25
27%	0.75	0.75	0.75	1.09	1.04	1.08	1.22	1.04	1.09	1.22
28%	0.75	0.75	0.75	1.07	1.03	1.08	1.2	1.03	1.07	1.2
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	1.03	1.07	1.15	1.03	1.05	1.15
31%	0.75	0.75	0.75	1.03	1.03	1.06	1.13	1.03	1.03	1.13
32%	0.75	0.75	0.75	1.02	1.03	1.06	1.11	1.03	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	1.02	1.05	1.08	1.02	1	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	1.02	1.04	1.05	1.02	0.98	1.05
37%	0.76	0.76	0.76	0.98	1.02	1.03	1.04	1.02	0.98	1.04
38%	0.76	0.76	0.76	0.97	1.02	1.03	1.02	1.02	0.97	1.02

Load	PM	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	N_2O	CH_4
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	1.01	0.96	1
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	1.01	1	0.97	1.01	0.94	0.97
45%	0.78	0.78	0.78	0.94	1.01	1	0.97	1.01	0.94	0.97
46%	0.78	0.78	0.78	0.94	1.01	0.99	0.96	1.01	0.94	0.96
47%	0.79	0.79	0.79	0.94	1	0.99	0.96	1	0.94	0.96
48%	0.79	0.79	0.79	0.93	1	0.98	0.96	1	0.93	0.96
49%	0.79	0.79	0.79	0.93	1	0.98	0.96	1	0.93	0.96
50%	0.8	0.8	0.8	0.93	1	0.98	0.96	1	0.93	0.96
51%	0.8	0.8	0.8	0.94	1	0.97	0.95	1	0.94	0.95
52%	0.81	0.81	0.81	0.94	1	0.97	0.95	1	0.94	0.95
53%	0.81	0.81	0.81	0.94	1	0.96	0.95	1	0.94	0.95
54%	0.82	0.82	0.82	0.94	1	0.96	0.95	1	0.94	0.95
55%	0.82	0.82	0.82	0.94	1	0.96	0.96	1	0.94	0.96
56%	0.83	0.83	0.83	0.94	1	0.95	0.96	1	0.94	0.96
57%	0.84	0.84	0.84	0.95	1	0.95	0.96	1	0.95	0.96
58%	0.84	0.84	0.84	0.95	1	0.95	0.96	1	0.95	0.96
59%	0.85	0.85	0.85	0.95	1	0.94	0.96	1	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%	0.9	0.9	0.9	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	0.99	0.99	1
70%	0.94	0.94	0.94	0.99	0.99	0.91	1	0.99	0.99	1
71%	0.94	0.94	0.94	0.99	0.99	0.91	1	0.99	0.99	1
72%	0.95	0.95	0.95	1	0.99	0.91	1.01	0.99	1	1.01
73%	0.96	0.96	0.96	1	0.99	0.91	1.01	0.99	1	1.01
74%	0.97	0.97	0.97	1	0.99	0.91	1.01	0.99	1	1.01
75%	0.98	0.98	0.98	1.01	0.99	0.9	1.01	0.99	1.01	1.01
76%	0.99	0.99	0.99	1.01	0.99	0.9	1.01	0.99	1.01	1.01
77%	1	1	1	1.01	0.99	0.9	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

Load	PM	$PM_{2.5}$	DPM	NOx	SOx	CO	HC	CO_2	N_2O	CH_4
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	0.99	1.02	1
85%	1.1	1.1	1.1	1.02	0.99	0.92	1	0.99	1.02	1
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	0.99	0.96	0.96	0.99	1.01	0.96
92%	1.19	1.19	1.19	1	0.99	0.97	0.94	0.99	1	0.94
93%	1.2	1.2	1.2	1	0.99	0.98	0.93	0.99	1	0.93
94%	1.22	1.22	1.22	0.99	0.99	0.99	0.92	0.99	0.99	0.92
95%	1.23	1.23	1.23	0.99	0.99	1.01	0.91	0.99	0.99	0.91
96%	1.24	1.24	1.24	0.98	0.99	1.02	0.89	0.99	0.98	0.89
97%	1.26	1.26	1.26	0.97	1	1.03	0.87	1	0.97	0.87
98%	1.28	1.28	1.28	0.97	1	1.05	0.86	1	0.97	0.86
99%	1.29	1.29	1.29	0.96	1	1.07	0.84	1	0.96	0.84
100%	1.31	1.31	1.31	0.95	1	1.08	0.82	1	0.95	0.82