Port of Oakland
2020 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.

Anchorage: Ships may lie at anchor away from ports while waiting for a berth to open or for their next assignment, and anchorage locations are designated in the South Bay.

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.

Bunkering: Delivery of fuel from a tug and fuel barge.

Call: Ship docking at a specific berth

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

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 as 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 may also incorporate auxiliary engine power.

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.

Lay berth: A lay berth is defined for this report as a vessel at berth that did not transfer cargo or passengers.

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 Bar 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]

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

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.

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 (CHC). 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 Bar 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

Shift: Ship moving from one berth to another during the same voyage.

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.

VOC: Volatile Organic Compounds.

Voyage: The Marine Exchange of the San Francisco Bay Region defines a voyage as when a vessel enters and exits through the Golden Gate and may involve multiple calls to various San Francisco Bay area ports and berths.

EXECUTIVE SUMMARY

The Port of Oakland 2020 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),
- On-Road Trucks,
- Locomotives, and
- Other Off-road Equipment.

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 any related air quality impacts.

This is the fifth Seaport Air Emissions Inventory prepared by the Port. The Port's 2005, 2012, 2015, and 2017 inventories are available on the Port's website.[2] This calendar year 2020 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 34% below 2005 levels from on-and near-shore sources by 2020. This goal is stated in the Port Maritime Air Quality Policy Statement adopted by the Board of Port Commissioners in March 2008. As shown at the end of this Executive summary, results of the 2020 emission inventory show that the Port has met the emission reduction goals stated in the Air Quality Policy Statement. Additional emission reductions can be expected over the coming years as new, lower emitting equipment, along with alternative fueled and electrically powered equipment, comes into wider use.

Geographic Scope

This is an inventory of the air emissions generated by routine operation and construction activities occurring at the Port of Oakland Seaport during 2020. 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 berth 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

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

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 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 that are regulated by the U.S. Environmental Protection Agency and the California Air Resources Board (CARB):

- 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

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 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

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 (DPM). DPM has been designated a toxic air contaminant by CARB.

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 2020

Port of Oakland Seaport emissions for 2020 are summarized in Table ES-1a for criteria pollutants and Table ES-1b for GHG emissions. As a result of disruptions to cruise ship operations caused by the world-wide COVID-19 pandemic[4], the Port allowed several cruise ships to lay over at the Port for extended periods of time during the year. Emissions from these unprecedented cruise ship visits, which are not representative of normal Port operations, are tabulated in a separate line item in Table ES-1.

Table ES-1a. Summary of 2020 Seaport emissions: criteria pollutants (tons).

	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx
OGV [a]	63.5	119.3	1,461.9	18.8	17.3	12.6	56.1
Harbor Craft: Dredge & OGV assist	20.9	101.5	156.0	5.3	5.1	5.3	0.2
Harbor Craft: Bunkering	2.5	7.4	22.5	1.1	1.1	1.1	<0.1
CHE	39.7	116.2	195.9	2.8	2.5	2.5	0.4
Trucks	4.7	30.0	89.3	1.7	0.7	0.2	0.2
Locomotives	0.6	1.2	6.5	0.1	0.1	0.1	<0.1
Other	1.4	40.1	3.0	0.1	0.1	<0.1	<0.1
Subtotal	**133.1**	**415.7**	**1,935.0**	**29.9**	**27.0**	**22.0**	**57.0**
Cruise Ship Lay Berth	9.5	19.8	223.5	3.7	3.4	3.2	9.1
Total[b]	**142.6**	**435.5**	**2,158.5**	**33.6**	**30.3**	**25.2**	**66.1**

[a]Emissions for OGVs based on "best estimate" approach as described in Section 2.2.3.2
[b]Sum of individual values may not equal indicated totals due to rounding

[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.
[4] The Centers for Disease Control and Prevention (CDC) issued a No Sail Order for cruise ships on March 14 2020 (https://www.cdc.gov/quarantine/pdf/signed-manifest-order_031520.pdf).

Table ES-1b. Summary of 2020 Seaport emissions: GHGs (tons[5]).

	CO_2e[b]
OGV[a]	92,379
Electricity Generation & Transmission	2,401
Harbor Craft: Dredge & OGV assist	19,772
Harbor Craft: Bunkering	2,077
CHE	44,506
Trucks	25,782
Locomotives	491
Other	637
Subtotal	**188,046**
Cruise Ship Lay Berth	14,740
Total[c]	**202,786**

[a]Emissions for OGVs based on "best estimate" approach as described in Section 2.2.3.2
[b]CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (25), and N_2O (298).
[c]Sum of individual values may not equal indicated totals due to rounding

Not including the cruise ship visits, results in Table ES-1a show that OGVs accounted for the largest fraction of DPM (57%) and NOx (76%) emissions at the Port in 2020. Figure ES-1 shows a breakdown of OGV emissions, with berthing accounted for 29% (3.7 tons) of the OGV DPM, and thus represents 15% of Seaport total DPM emissions in 2020. Harbor craft accounted for the next largest fraction of 2020 Seaport DPM emissions (29%). Harbor craft emissions are expected to decrease in the future as older engines continue to be replaced by newer models with lower emissions.

Emission reductions at the Port since 2005 are described at the end of this section.

[5] Emissions for all pollutants, including GHGs, are presented in units of U.S. short tons (1 ton = 2,000 lbs).

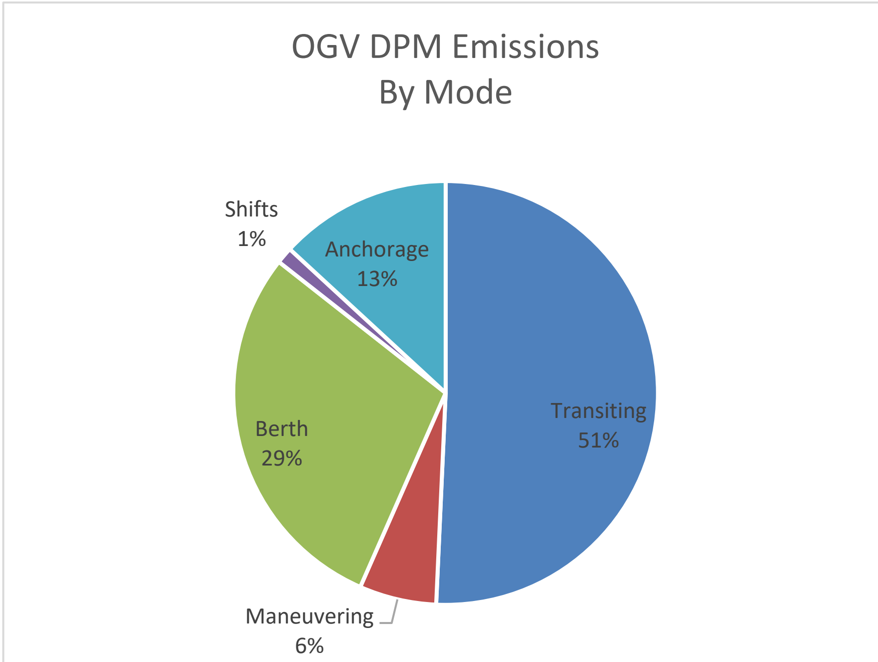


Figure ES-1. DPM emissions associated with OGV operating modes in 2020.

Port Activity Levels in 2020

Activity at the Port during 2020 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 2020 was 2,461,262, a 7.6% increase over 2005. Cargo vessels made a total of 1,231 voyages to the Port in 2020, which is 36% lower than in 2005. The Port is getting more cargo volume on fewer calls due at least in part to an increase in average ship size. A total of 2,892,052 one-way drayage truck trips (1.18 trips/TEU) are estimated to have occurred in 2020 based on the Port's eModal automated gate count data. This is approximately equal to the 2,620,483 trips (1.15 trips/TEU) estimated for 2005. In contrast to 2005, when many older trucks operated at the Port, the 2020 drayage truck fleet consisted exclusively of trucks with 2007 or newer (or equivalent) engines, with 49% of the fleet comprised of trucks with 2013 or new engines that meet lower emission standards.

Aside from the pandemic-related cruise ship visits, all of the 1,231 ship visits to the Port of Oakland in 2020 were by deep-draft vessels designed as container ships. The Port's four marine terminals operate cargo handling equipment to transfer containers to and from vessels and to and from trucks. Some of the cargo transiting by truck went to or came from one of the three near-dock rail facilities. In addition, several other off-dock businesses operate at the Port as transloading facilities where cargo is repackaged and transferred between international and domestic containers, for transit via trucks or trains.

Methods

The emissions in this inventory were estimated 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 allows emissions to be allocated to 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 CARB. Assumptions and methods used to develop the inventory are consistent with CARB methodologies.

Comparison of 2020 with Prior Year Inventories

This inventory was developed using methods consistent with the approach used by the CARB 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 2020 have been kept as similar as possible to those used to develop the 2005, 2012, 2015, and 2017 inventories.[6] In this way, the main factor responsible for year-to-year differences in reported

[6] Although methods used to develop the 2020 inventory have been kept mostly the same as in previous inventories, the most recent available CARB off-road engine emission factors and EMFAC on-road vehicle emission factor model version (in this case EMFAC2021) were used.

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 2020 Seaport Emissions Inventory update are compared with the 2005, 2012, 2015, and 2017 inventories in Tables ES-2a and ES-2b.[7,8] Figures ES-2 and ES-3 show the reductions over time in each source category for DPM and NOx emissions, respectively. Emission reductions from the 2005 baseline by source category are summarized in Table ES-3 and the relative contributions of each source category to total emission reductions since 2005 are shown in Table ES-4. Overall, DPM emissions have decreased 86% since 2005, thus achieving the Port's 85% reduction goal as stated in the Maritime Air Quality Policy Statement. NOx emissions from on- and near-shore sources, which represent all sources included in the inventory except for ocean-going vessel anchoring and transiting activity away from the Port beyond the Bay Bridge, declined 54%, exceeding the Maritime Air Quality Policy Statement goal of 34%. Total NOx emissions decreased by 40%.

The 2020 Seaport emissions shown in Tables ES-2a and ES-2b and Figures 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, 2015, and 2017 inventories. In particular, OGV emissions for 2020 shown in Tables ES-2a and ES-2b are based on the same assumptions about vessel speeds and engine load adjustment factors used in the prior year inventories. This differs from the updated assumptions used to calculate the "best estimate" emissions for 2020 shown in Table ES-1a and ES1b and Figure ES-1 above (the "best estimate" assumptions are described in Section 2.2.3.2). Also, the 2020 commercial harbor craft emissions in Tables ES-2a and ES2b do not include emissions from bunkering operations as bunkering was not included in the inventories prior to 2017. Bunkering operations accounted for 18% (1.2 tons) of total commercial harbor craft DPM emissions in 2020, 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}. Appropriate size fractions were then applied to estimate the associated PM2.5 emissions.

[7] 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.
[8] GHG emissions were not originally included in the 2005 inventory but were added in the course of developing the 2017 inventory.

For OGVs, both NOx and DPM emissions were lower for 2020 as compared with the four previous inventories. NOx emission reductions resulted from the use of shore power, fleet turnover to newer ship engines designed to meet lower NOx emission standards, and a decrease in the number of vessels calling at the Port. DPM reductions since 2005 are primarily attributable to increased use of low sulfur fuel, shore power, and fewer vessel calls.

Harbor craft emissions declined between 2005 and 2020 as vessel fleets turned over to incorporate lower emitting engines. Port records indicate bunkering volume levels were higher in 2005 as compared to 2020, 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 88% and NOx emissions by 74% since 2005.

On-road heavy-duty truck NOx and DPM emissions in 2020 were sharply reduced from 2005. Changes in emissions from year to year are a result of 1) modernization of the truck fleet due to the introduction of restrictions on older trucks and fleet turnover, 2) changes in the number of estimated truck trips, and 3) revisions to emission rates associated with updates to CARB'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 CARB's EMFAC2014 model (which was used to prepare the 2015 inventory) and the updated EMFAC2021 model (used to prepare the 2020 inventory), along with continued fleet turnover to newer trucks, are responsible for an additional 16% DPM reduction between 2015 and 2020. Overall, DPM emissions from trucks decreased by 99% between 2005 and 2020. Similarly, NOx emissions decreased 73% between 2005 and 2020.

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 out of the Port by rail instead of trucks (the number of truck trips carrying containers between the rail yards and the marine terminals was 44% lower in 2020 compared to 2005). Locomotive DPM emissions at the Port have decreased by 94% and NOx emissions by 92% from 2005 levels.

As shown in Table ES-2b, emissions of GHGs (as CO_2e) from OGVs declined 20% between 2005 and 2020 after accounting for emissions from shore power electricity generation and transmission while total CO2e emissions from all sources declined 8%, despite the 7.6% growth in TEU throughput. Some of this decrease is attributable to the use of shore power by OGVs while at berth in 2020 that is less carbon intensive than combustion of diesel in OGV auxiliary engines; shore power was not available in 2005. GHG emissions from generation and transmission (G&T) of electricity used for shore power in 2020 (2,401 tons CO_2e) were estimated based on electricity consumption records. 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.

DPM, NOx and GHG emission reductions from 2005 levels as of 2020 are summarized in Table ES-3; Table ES-4 shows the relevant contributions from each source category to total emission reductions. Both DPM and NOx emission reductions have exceeded the Port's goals described above. Truck emissions exhibited the largest percentage DPM reductions due primarily to the introduction of newer, lower emitting engines. However, as shown in Table ES-4, the reduction in total DPM emissions has been driven primarily by the 87% reduction in OGV DPM emissions which accounted for 80% of the drop in total DPM. CO2 emissions from CHE and trucks were higher in 2020 (as indicated by the negative values in Table ES-3) due primarily to higher estimated activity levels in 2020.

Table ES-2a. Comparisons of 2020 with 2005 Port inventory: criteria pollutants in tons per year.

2005 Inventory	**ROG**	**CO**	**NOx**	**PM**	**$PM_{2.5}$[a]**	**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**
2020 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going vessels	145.4	217.1	1954.2	32.7	30.1	27.7	69.0
Harbor craft	20.9	101.5	156.0	5.3	5.1	5.3	0.2
CHE	39.7	116.2	195.9	2.8	2.5	2.5	0.4
Truck	4.7	30.0	89.3	1.7	0.7	0.2	0.2
Locomotive	0.6	1.2	6.5	0.1	0.1	0.1	0.0
Other Offroad equipment	1.4	40.1	3.0	0.1	0.1	0.0	0.0
Total	**212.6**	**506.1**	**2404.9**	**42.7**	**38.7**	**35.9**	**69.8**
% Reduction from 2005	14%	43%	40%	84%	85%	86%	95%

[a]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 2020 with prior year Port inventories: GHGs (tons).

2005 Inventory	CO_2	CH_4	N_2O	CO_2e[a]
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**
2020 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[e]**
Ocean-going vessels[b]	111,418	1.39	5.31	115,437[c]
Harbor craft	19,583	1.88	0.48	19,772
CHE	44,353	1.80	0.36	44,506
Truck	24,621	0.22	3.87	25,782
Locomotive	483	0.03	0.02	491
Other Offroad equipment	635	0.03	0.01	637
Total	**201,094**	**5.35**	**10.05**	**206,625**
% Reduction from 2005[d]	9%	85%	-7%	8%

[a]CO_2e equals global-warming potential (GWP)-weighted sum of CO_2 (1), CH_4 (21), and N_2O (310).
[e]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 CARB 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 CARB default assumption (based on 2017 shore power records).
[c]Shore power CO_2e emissions of 2,401 tons from electricity generation and transmission in CO_2e are added here based on recorded shore power electricity consumption.
[d]Negative values indicate increase

Table ES-3. 2020 percentage emission reductions from 2005.[a]

Source	DPM	NOx	CO_2e[b]
Ocean-going Vessels	87%	21%	20%
Harbor Craft	60%	55%	1%
Cargo Handling Equipment	88%	74%	-19%
Trucks	99%	73%	-19%
Locomotives	94%	92%	60%
Total	**86% (Goal: 85%)**	**40%**	**8%**
Total: On- & Near-Shore[d]	**87%**	**54% (Goal: 34%)**	**N/A[c]**

[a]Negative values indicate emission increases; extraordinary cruise ship lay berthing in 2020 not included.
[b]2020 CO_2e emissions include shore power electricity generation and transmission.
[c]GHG emissions were not estimated separately for on- and near-shore portions of the 2005 OGV inventory.
[d]Excludes emissions from anchoring and ocean-going vessel transiting beyond the Bay Bridge

Table ES-4. 2020 percentage contributions to total tons of emissions reduced since 2005.[a]

Source	DPM	NOx	CO_2e[b]
Ocean-going Vessels	80%	33%	160%
Harbor Craft	4%	12%	2%
Cargo Handling Equipment	8%	35%	-43%
Trucks	7%	15%	-25%
Locomotives	1%	4%	4%

[a]Negative values result from emission increases.
[b]2020 CO_2e emissions include shore power electricity generation and transmission.

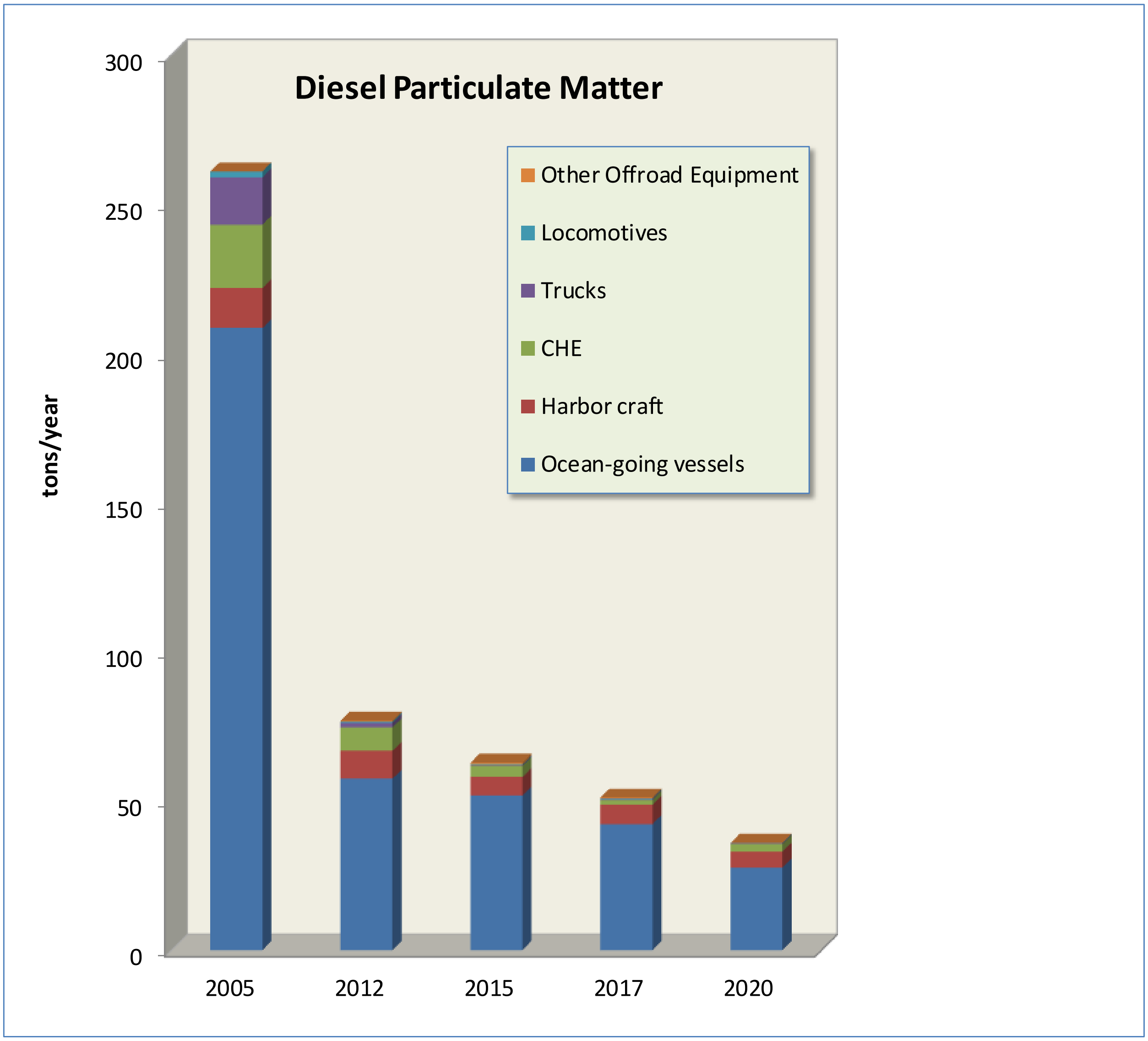


Figure ES-2. Seaport diesel particulate matter (DPM) emissions (tons).

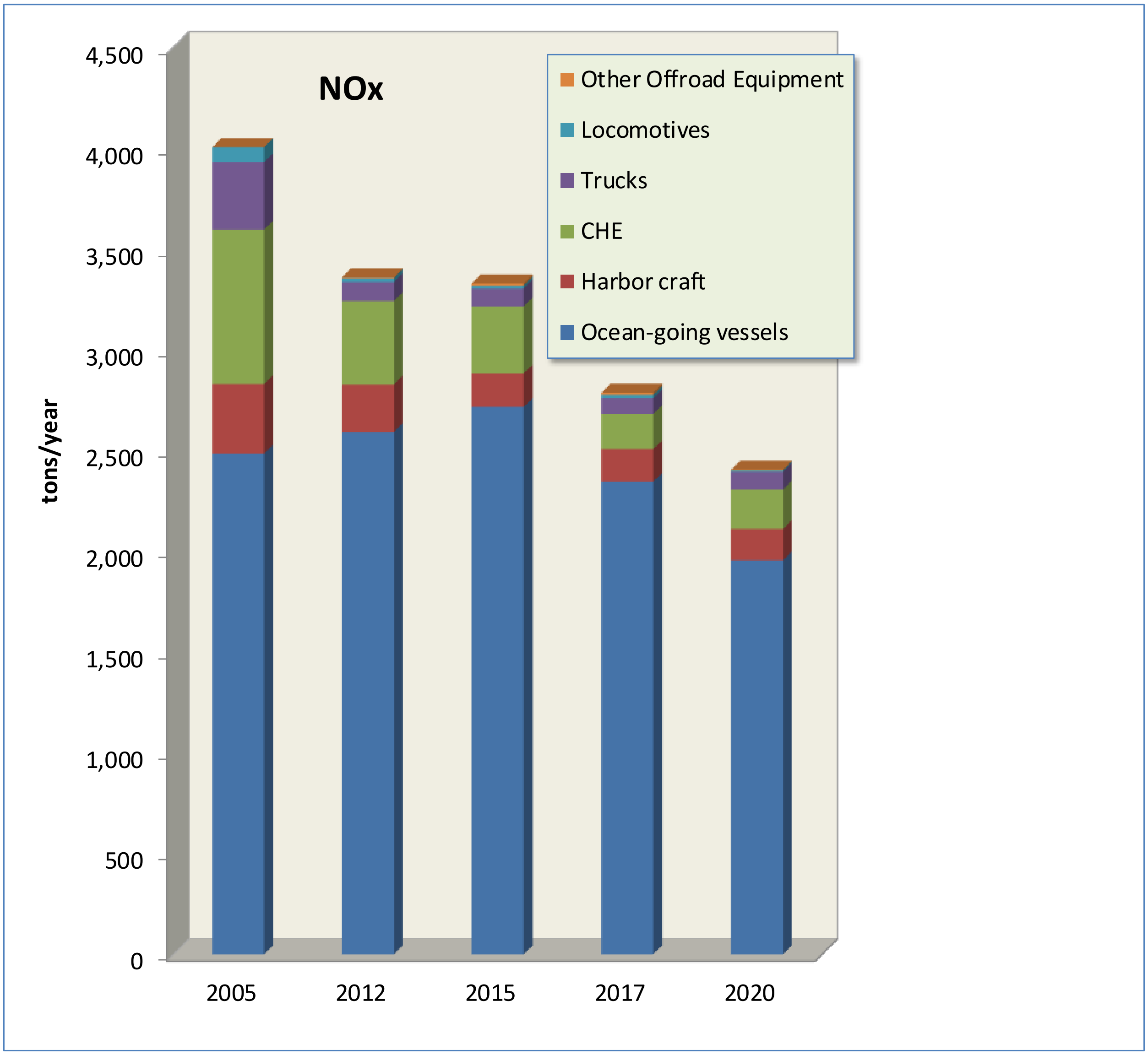


Figure ES-3. Seaport NOx emissions (tons).

1.0 INTRODUCTION

1.1 Purpose and Background

The Port of Oakland (Port) has prepared this 2020 Seaport Air Emissions Inventory (emissions inventory) for the purpose of identifying and quantifying any air quality impacts from the maritime operations of the Port and its tenants. This emissions inventory updates the 2005, 2012, 2015, and 2017 Seaport Air Emissions Inventories (ENVIRON, 2008a, 2013; Ramboll Environ, 2016; Ramboll 2018) for the major categories of maritime equipment:

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

The Port voluntarily chose to prepare the original 2005 inventory and has continued with voluntary periodic updates to help in air quality planning and to meet its commitment to develop and implement an air emissions reduction program. Updates are important because annual emissions from operations vary over time due to changes in cargo volume, engine turnover, implementation of regulations, and other factors. The 2020 update is particularly important because it is a milestone year to evaluate whether the Port was able to achieve the emission reduction goals established in the Maritime Air Quality Improvement Plan (MAQIP).[9]

This emissions inventory highlights the Port's commitment to improve understanding of the nature, location, and magnitude of emissions from its maritime-related operations.

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 very technical, a characteristic that makes the limitations of emissions inventories less transparent to the general public. Emissions

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

inventories should be used in context with proper interpretation and in conjunction with other information and tools to evaluate and assess air quality problems.

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 fact that there can be a poor correlation between the total magnitude of Port-wide emissions and the resulting air quality impact at a given location or "receptor site". The importance of a given ton of emissions depends on the location of the emissions source relative to the receptor site: generally, emissions from more distant sources will have a lower impact than those from nearby sources. Emissions inventories should be used with care and in conjunction with other information and tools to evaluate and assess air quality problems.

1.3 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 2020. Port tenants for which emissions were estimated include marine terminal operators, off-dock (e.g., transload) terminal operators, and rail yards. Non-tenant maritime operations that are part of this inventory include sources for which the Port has no direct leasing arrangements; these emissions sources include shipping lines, trucks, dredges[10] 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, 2017) inventories. On the water side, the spatial domain of the inventory includes Port-related marine vessel transit from berth 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. Within this defined geographic domain, three areas were specifically excluded: the City of Oakland's portion of the former Oakland Army Base adjacent to the approaches to the Bay Bridge, the Schnitzer Steel

[10] However, the Port has contractual arrangements for dredging of berths.

terminal at the Inner Harbor Turning Basin, and the Union Pacific rail yard north of the Matson Terminal adjacent to I-880. As in previous inventory years, these areas were not controlled or operated by the Port of Oakland in 2020 and are therefore not included in this update. Figures 1-1 and 2-1 illustrate the spatial scope of the inventory.

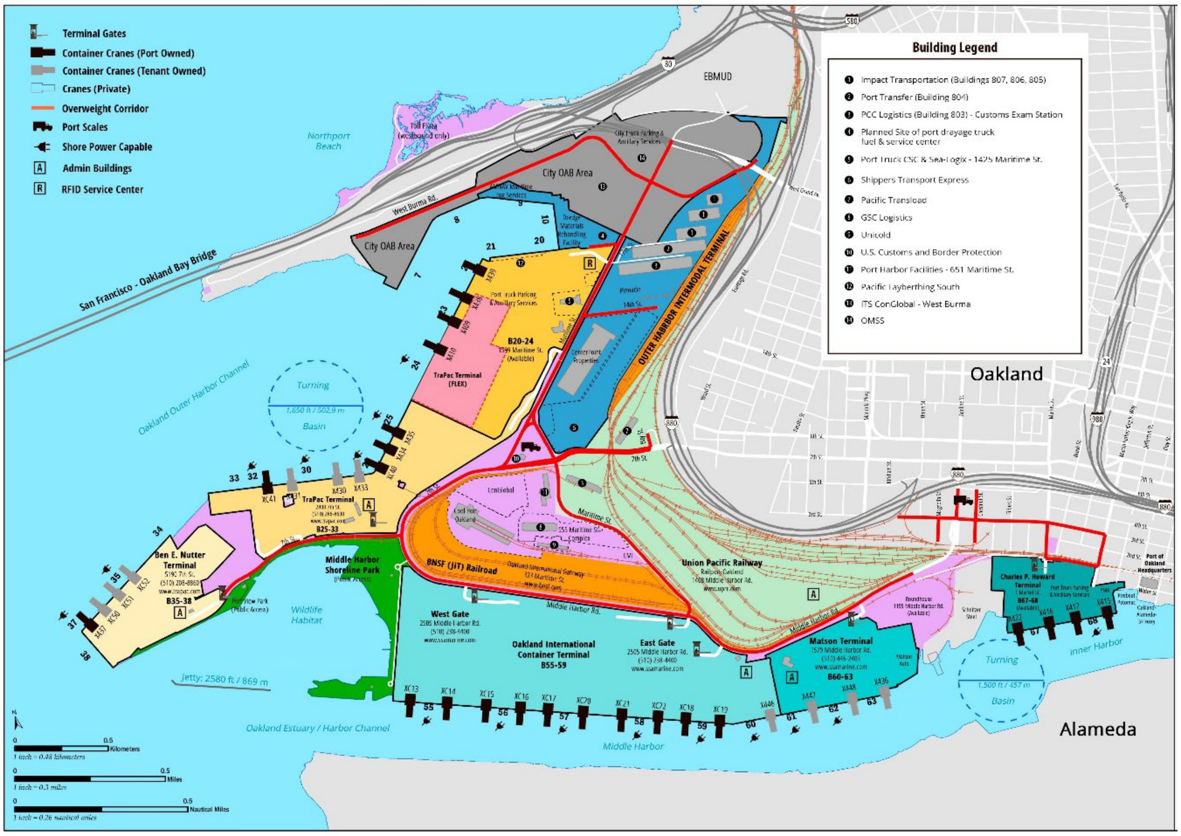


Figure 1-1. Port of Oakland maritime facilities – 2020 (bold magenta line indicates landside boundaries of the emissions inventory).

Ramboll prepared this inventory by analyzing all maritime activity in 2020 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. CARB, Port, and terminal and rail operator records were the source of these data. Previous studies and literature reviews and CARB 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 CARB inputs and methodologies except as specifically noted otherwise.

1.3.1 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 3,760 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.[11]

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.

[11] 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.

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.

The particulate matter estimated in this report is primarily diesel particulate matter (DPM) emitted from diesel engines. CARB 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 CARB. 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. 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 Organization of this Report

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.
- Section 1 contains this introduction to the report.
- Section 2 describes deep-draft ocean-going 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 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, 2015, and 2017 seaport emission inventories.
- Section 9 provides the references used in developing the emissions inventory.
- A glossary (included in the frontmatter after the Table of Contents and Acknowledgements) defines the technical terms used in the report.
- Appendix A: OGV Speed Distributions.
- Appendix B: Low-load Adjustment Factors.

2.0 OCEAN-GOING VESSELS

This section documents the vessel activity data and assumptions, emission inventory methods, and resulting emission estimates for deep-draft ocean-going vessels (OGVs) calling the Port of Oakland in 2020. Emission factors and methods used to estimate emissions are consistent with the latest CARB emission estimation methodology for ocean-going vessels (CARB, 2011a, 2016, 2019a,b).

As discussed above, one of the key applications of the 2020 Seaport emissions inventory is an evaluation of trends in emissions at the Seaport starting with the original 2005 annual inventory. However, methods and assumptions used to prepare emission estimates have been refined over time and these changes, while resulting in more accurate emission estimates, can confound comparisons of inventories from more recent years with older inventories. While it is not practical to fully account for the impacts of all of these methodological changes on estimated emission trends, an effort was made to account for the more significant ones by presenting two alternative OGV emission estimates for 2020:

1. A “Best Estimate” inventory which includes refinements in estimated vessel speeds and engine loads, and

2. A “Historical Method” inventory based on the same vessel speeds and engine load assumptions as used in previous Port of Oakland Seaport emissions inventories.

In both cases, the current CARB OGV engine and boiler emission factors (CARB, 2019a,b) were used to prepare the 2020 emission estimates. CARB most recently updated certain OGV emission factors in 2019 in connection with revisions to the At-Berth (shore power) regulation. Implications of the updated emission factors for comparisons with prior year inventories are discussed in Section 2.4.2.

2.1 Vessel Activity and Inventory Description

Aside from some COVID-19 related emergency activities, OGVs berthing at the Port of Oakland in 2020 were exclusively container ships, including some with capability to handle roll on/roll off cargo. No container vessel calling at the Port of Oakland in 2020 made calls to other San Francisco Bay (SF Bay) ports during their visits. Due to the pandemic, the Port hosted a few extraordinary passenger vessel visits in 2020. These visits and associated emissions are described in Section 2.4.1. Emissions from these visits are tracked separately from cargo vessel emissions because they represent abnormal activity, outside the Port’s usual line of business.

OGVs 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 types, and power that affect estimates of engine emissions for each vessel voyage.

Vessel activity and characterization data, operational estimates, and other inputs as well as the emission estimation methodology, including emission factors and other considerations, are presented in the following sections. Lastly, total emissions by mode and pollutant are reported in Section 2.4.

2.2 Input Data and Use

The basic data used to calculate emissions from OGVs include a list of all vessel voyages in 2020, installed power and vessel design speeds for each vessel that called the Port in 2020, and vessel speeds during each segment of the vessel trips included in the inventory. These data include:

1) Vessel Activities
   a) San Francisco Marine Exchange (SFMX) voyage data
      i) Date/Time Stamp at key waypoints
      ii) Time at Berth (First line on, Last line off)
      iii) Time at Anchor
      iv) Shifts between berths
   b) Port-provided shore power berth location and connect/disconnect date and time stamps
2) Vessel Characteristics (from 2020 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[12] 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. For the "Historic Method" emission estimates, ship speeds at various locations were assumed the same as in prior Port maritime inventories for sake of consistency with the prior inventories. For the "Best Estimate" emissions estimate, speeds were calculated based on speed profiles derived from AIS (Automatic Identification System) data as described in Section 2.2.3.2.

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, 2020). Data on vessel calls to Port of Oakland berths were provided by the Marine Exchange of the San Francisco Bay Region (SFMX, 2021) 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.

[12] 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.

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.

As in prior Port inventories, Ramboll excluded from this inventory the 27 voyages by ships calling at the privately owned Schnitzer Steel facility in 2020. Although this facility lies between two Port of Oakland terminals, it is not located on Port property. Emissions from vessel voyages associated with calls at Schnitzer Steel are not included in the Port's Seaport inventory because the Schnitzer facility is not owned or controlled by the Port of Oakland. Schnitzer Steel receives only bulk carriers calling for scrap steel.

The heavy load vessel *Zhen Hua 35* brought three new ship-to-shore cranes to the Port in late December. The *Zhen Hua* spent time at anchor in the SF Bay but did not spend any time hoteling at any of the Oakland berths in 2020.

As discussed later in Section 2.4.1, worldwide cruise ship operations were suspended in 2020 due to the COVID-19 pandemic. This resulted in emergency visits to the Port by four cruise ships for purposes of lay berthing (i.e., berthing for extended periods with minimal activity). Three of the four cruise ships briefly left berth for housekeeping purposes and returned one or more times during their visit. Due to the unusual nature of these visits, cruise ship emissions were calculated separately from cargo ship emissions. Emissions from the cruise ship visits are presented in Section 2.4.1.

Not including the ships calling Schnitzer Steel and the extraordinary cruise ship calls, there were 1,231 vessel voyages to the Port of Oakland in 2020. The voyages are summarized in terms of ship sizes and ages and number of voyages in Table 2-1. Ship sizes were defined by three different metrics:

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

Each of these size measurements may affect one emission source or another, but larger ships typically have higher propulsion and auxiliary engine rated power. As was the case in 2017, some of the ships calling in 2020 are significantly larger than in prior years including vessels exceeding 1,100 feet LOA and with carrying capacity over 18,000 TEUs.

Table 2-1. Ocean-Going Vessels – 2020 Port of Oakland vessel calls by three different ship size measures.

Dead Weight Tonnage	Voyages	Capacity (TEU)	Voyages	Length Overall (ft)	Voyages
<20,000	11	<1,000	0	<750	122
<40,000	179	- <2,000	27	750 – 1,100	816
<60,000	116	- <3,000	137	>1,100	293
<80,000	220	- <4,000	74		
<100,000	166	- <5,000	216		
<120,000	335	- <6,000	21		
<140,000	119	- <7,000	111		
<160,000	65	- <8,000	37		
<180,000	15	- <10,000	372		
<200,000	3	- <12,000	119		
<220,000	2	- <14,000	56		
		- <16,000	56		
		16,000+[a]	5		
All	1,231	All	1,231	All	1,231

[a]The largest vessels calling at the Port in 2020 were 19,224 TEUs.

Vessels visit the Port of Oakland at both regular and irregular frequencies. Many vessels follow regular routes and schedules while others make infrequent calls to the SF Bay. Table 2-2 lists the distribution of Port of Oakland voyage counts (some voyages resulted in more than one call) by individual ships in 2020.

Table 2-2. Ocean-Going Vessel - Port of Oakland vessel voyages counts in 2020.

Number of Voyages in 2020	Ship Count	Cumulative Voyages		Number of Voyages in 2020	Ship Count	Cumulative Voyages
1	100	100		14	0	1,108
2	65	230		15	0	1,108
3	50	380		16	0	1,108
4	20	460		17	0	1,108
5	27	595		18	0	1,108
6	20	715		19	0	1,108
7	14	813		20	0	1,108
8	22	989		21	0	1,108
9	6	1,043		22	0	1,108
10	4	1,083		23	1	1,131
11	0	1,083		24	1	1,155
12	1	1,095		25	2	1,205
13	1	1,108		26	1	1,231

The age distribution of the vessels calling at the Port in 2020 is shown in Table 2-3. Most were relatively new with 90% of voyages by vessels built since 2000, but there were several frequently calling vessels older than 38 years. The voyage-weighted median age of vessels calling at the Port in 2020 was 12 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
- Tier III started with model year 2016

In 2020, 55% of calls were by vessels required to comply with Tier I standards and 32% of calls were by vessels required to comply with Tier II 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)[13] with model year 2016. In 2020, 3% of calls to the Port were by Tier III vessels. A study by the Ports of Los Angeles and Long Beach[14] found that over 1,200 keels were laid in 2015 (including 106 for container ships), thus allowing for fitting of Tier II engines under the IMO regulations, while only 99 total keels were laid in 2016 when Tier III engines were required. The 2015 spike in keels laid has delayed the further introduction of Tier III container ships visiting North American.

Steamships (ships powered by propulsion boilers) are among the oldest vessels calling at the Port. Steamships that were not originally designed to run on marine distillate fuel or natural gas were exempt from the North American ECA fuel sulfur requirements until January 1 2020 as per International Maritime Organization resolution MEPC.202(62).[15] Steamship propulsion boilers are also exempt from the CARB fuel sulfur requirements as these only apply to diesel engines. Auxiliary boilers, however, are not exempt from the CARB fuel requirements. NOx emission limits from the IMO emission standards do not affect steamship propulsion boilers, which have low NOx emission rates even without any additional controls.

[13] Emission Control Areas (ECAs) cover certain coastal waters defined by the International Maritime Organization (IMO) within which certain additional restrictions on emissions apply.
[14] https://www.portoflosangeles.org/pdf/CAAP_Vessel_Tier_Forecasts_2015-2050-Final.pdf
[15] http://asp.mot.gov.il/en/shipping/imo-resolutions/mepc/813-mepc202-62

Table 2-3. Ocean-Going Vessels – Port of Oakland vessel age distribution in 2020.

Model Year[a] – Tier Level	Count of Voyages	Individual % of Voyages	Model Year	Count of Voyages	Individual % of Voyages
2019 – Tier III	12	1%	1997	18	1%
2018 – Tier III	25	2%	1996	0	0%
2017 – Tier III	0	0%	1995	0	0%
2016 – Tier III	0	0%	1994	0	0%
2015 – Tier II	95	8%	1993	0	0%
2014 – Tier II	76	6%	1992	0	0%
2013 – Tier II	71	6%	1991	13	1%
2012 – Tier II	69	6%	1990	0	0%
2011 – Tier II	78	6%	1989	0	0%
2010 – Tier I	84	7%	1988	0	0%
2009 – Tier I	61	5%	1987	0	0%
2008 – Tier I	107	9%	1986	0	0%
2007 – Tier I	141	11%	1985	0	0%
2006 – Tier I	74	6%	1984	0	0%
2005 – Tier I	63	5%	1983	0	0%
2004 – Tier I	9	1%	1982	0	0%
2003 – Tier I	14	1%	1981	32	3%
2002 – Tier I	39	3%	1980	0	0%
2001 – Tier I	38	3%	1979	0	0%
2000 – Tier I	52	4%	1978	0	0%
1999	6	0%	1977	47	4%
1998	7	1%			

[a]No 2020 model year vessels called at the Port in 2020.
Source: Marine Exchange of the San Francisco Bay Region (2018) and IHS Fairplay (2020)

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 (2020). 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. Transiting occurs at different speeds depending upon the navigational challenges as the ship maneuvers within the SF 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 spent in hotelling mode is critical to estimating the auxiliary engine emissions. OGV operating modes were characterized differently under the Best Estimate approach as compared to the Historic Estimate approach as described below.

2.2.3.1 OGV Operating Mode Characterization: Historic Method

Previous emissions inventories for the Port for years 2005, 2012, and 2015 used average speed estimates by transiting link. The 2017 inventory introduced a second methodology using AIS data as described in Section 2.2.3.2. The average speeds for each transiting link were based on discussions with the SFMX (2006, 2013),[16] and San Francisco Bar Pilots (2006).[17] A link-level description of the transit activity for vessels calling at the Port of Oakland is presented in Table 2-4. Entries in Table 2-4 correspond to the schematic link illustrations in Figures 2-1 and 2-2. Links listed in Table 2-4 were used to specify activity for each portion of the vessel's transit.

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 few navigational challenges and where ships typically operate at their design speed. Engines are most efficient when running at the vessel's design speed. The cruise mode occurs before the Bar Pilot boards and after the Bar 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 during shifts between berths.
- Hotelling or 'at berth' mode occurs when the vessel is tied up at berth or lying at anchor, usually at Anchorage 9 south of the Bay Bridge.

Shifts and anchorages were relatively infrequent Shifts (defined as movements from one berth to another or between anchorage and berth) were included with other maneuvering activity. The SFMX provided vessel voyage data which included date and time stamps for the 'first line on' and 'last line off' records at each Port berth, the beginning and end times for each shift, and the beginning and ending positions for each shift. Anchorage occurs when a ship lies at anchor and is similar to berthing in that the propulsion engine is not running and only auxiliary hotelling loads are demanded.

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. Emissions occurring seaward of the Precautionary zone are outside of the geographic scope of this inventory. Upon entering the Precautionary Zone, ships transit toward the Sea Buoy and slow to allow the Bar Pilot to board. After the Bar Pilot boards and takes command of the

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

vessel, the ship proceeds toward the Golden Gate crossing 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.

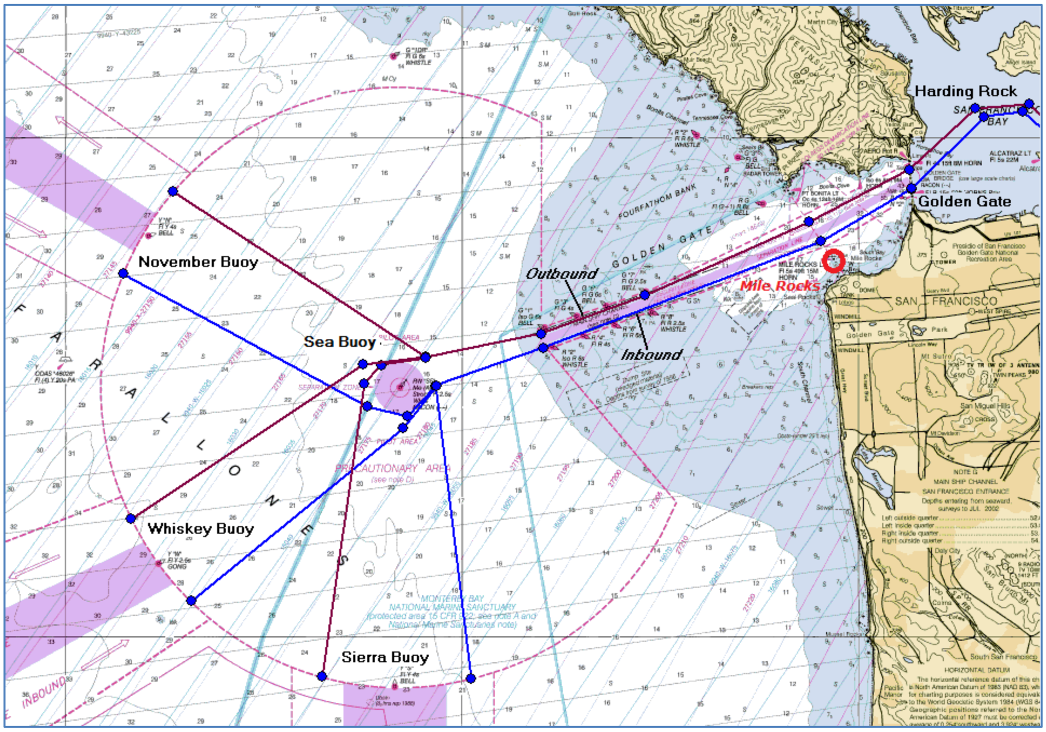


Figure 2-1. Link descriptions outside of the Golden Gate.

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 SF Bay. The SF Bar Pilots (2013) indicated that the primary or exclusive inbound transit route between the Golden Gate and Bay Bridges is south of Alcatraz unless the vessel draws more than 45 feet in which case it should use the deep water route north of Harding Rock. Only twenty vessel voyages exceeding a draft of 45 feet called on the Port in 2020; the maximum draft was 47.9 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 always be available due to traffic concerns. Because nearly all ships outbound from Oakland draw more than 28 feet and the route south of Alcatraz is rarely available for outbound transit, all vessels were assumed to use the route north of Harding Rock for outbound transit in the 2020 inventory as was the case in prior inventories. 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.

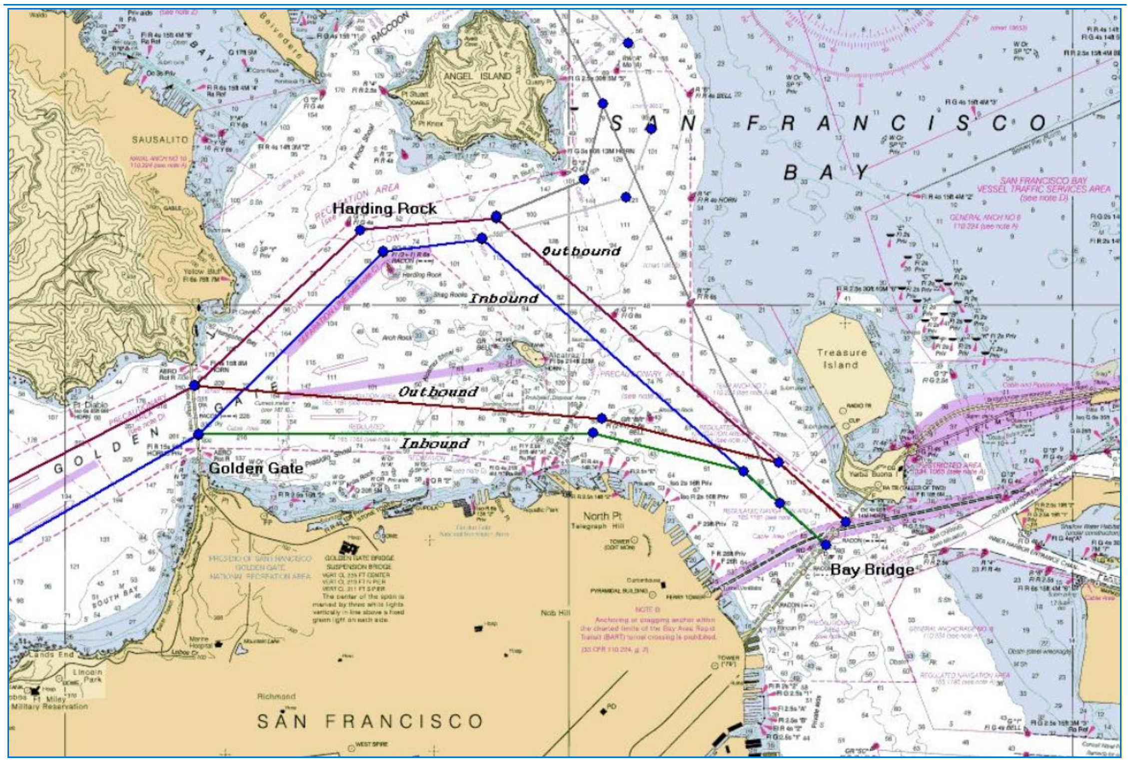


Figure 2-2. Transit link descriptions in San Francisco Bay (direct route primarily used inbound and less direct route outbound).

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.

For the Historic Method, the amount of time in each operating mode was estimated using the approach used in prior year inventories, i.e., 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 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 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.

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 inventory years prior to 2017, 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 and 2020 inventories, 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 OGV Operating Mode Characterization: Best Estimate Method

Under the Best Estimate method, Automatic Identification Systems (AIS) data were used to more accurately characterize vessel speeds. 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 have become widely available to investigators allowing average ship speed profiles to be estimated. The Port contracted with SFMX to collect AIS ship speed data for the period June – December 2017, which Ramboll used to estimate typical ship speed profiles for different transiting modes within the geographic scope of this emissions inventory. AIS represents a more robust and accurate estimate of ship speeds rather than relying on estimated average speeds from interviews with pilots or based on regulatory speed limits as was done under the Historic Method.

AIS data provided by SFMX were 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 cruise, Bar 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 can recommend alternative speeds at their discretion.

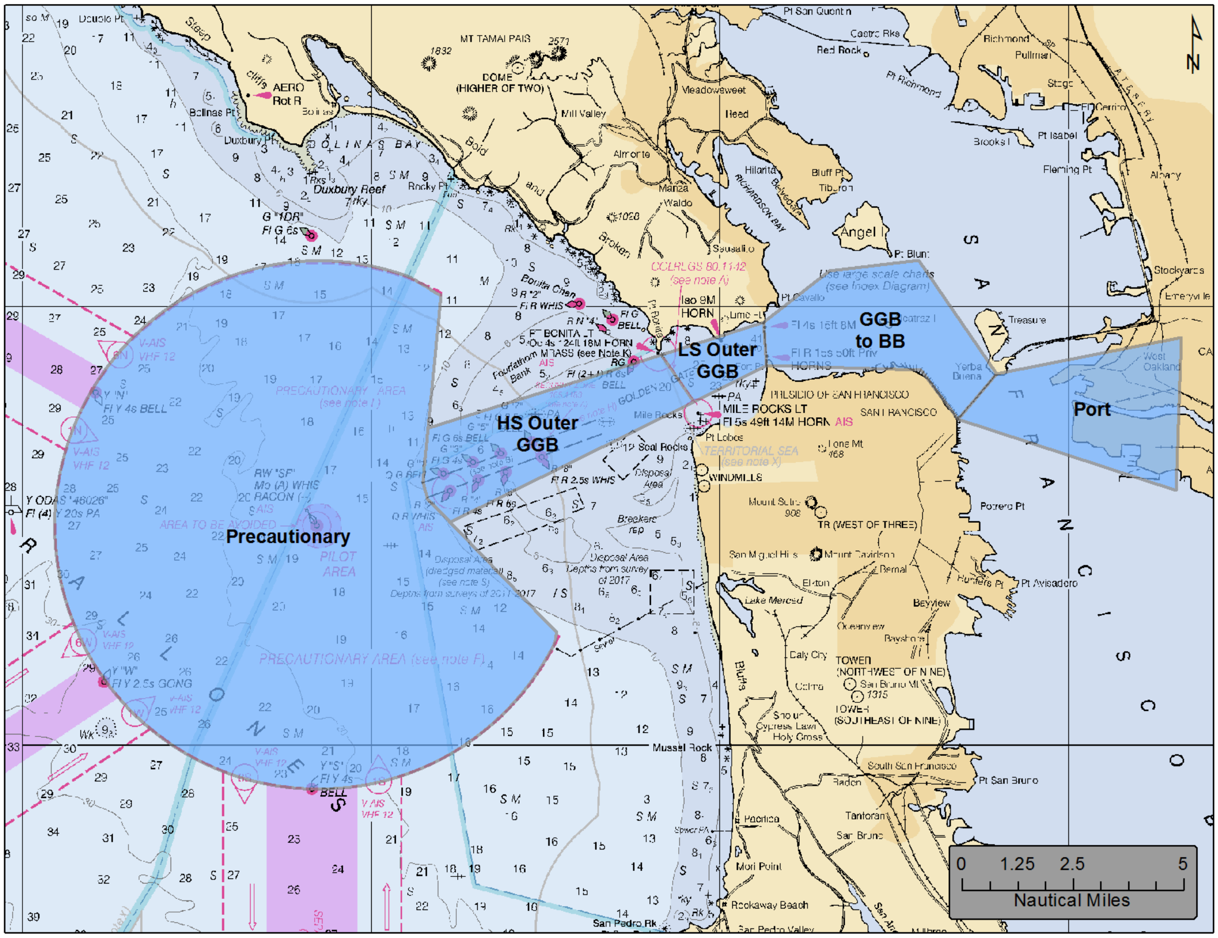


Figure 2-3. Mode descriptions in San Francisco Bay (with AIS data).

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 observed for the other zones. For the Precautionary Zone, the ship must slow to at least 10 knots to allow the Bar Pilot to transfer between the ship and the pilot boat, so a significant amount of time is spent below 10 knots. After the Pilot has disembarked there is no speed restriction, which explains the higher speeds for outbound trips.

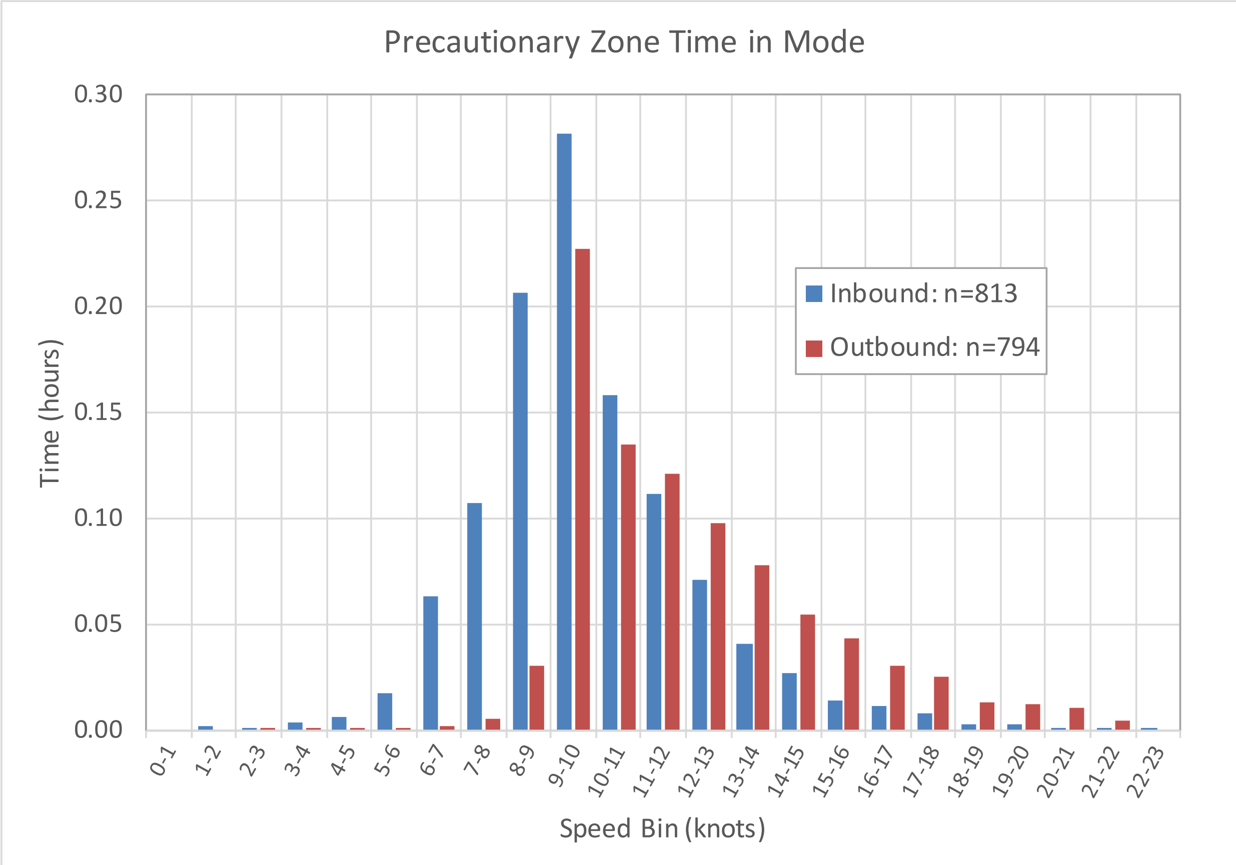


Figure 2-4. Precautionary zone speed profiles (from AIS data samples).

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. In this way, AIS-based ship speed profiles provide a more accurate representation of ship activity within the study area.

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 CARB (2019a,b).

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 (using either Historic Method or Best Estimate for speeds, as discussed in previous section). The load factor was calculated on the basis of the vessel's maximum speed and the actual vessel speed in each mode.

Emission factors depend on the type of engine and fuel being burned. 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 2020 data that the most common propulsion engines used on vessels calling the Port of Oakland in 2020 were slow speed engines (1,177 vessel voyages) with medium speed engines and steam engines powered by boilers accounting for the remainder (7 and 47 vessel voyages, respectively). Emission factors for these engines are shown in Table 2-5 (CARB 2019a,b).

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+) diesel and steam engines as noted. (Source: CARB 2019a,b).

Engine Type	Fuel Type	ROG	CO	NOx	PM_{10}	$PM_{2.5}$
Slow Speed	Marine Distillate (0.1% S)	0.78	1.38	17.0 Pre-controlled 16.0 Tier I 14.4 Tier II 3.4 Tier III[a]	0.189	0.174
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]	0.185	0.170
Steam	Marine Distillate (2.7% S)	0.11	0.2	1.995	0.164	0.151
Auxiliary	Marine Distillate (0.1% S)	0.52	1.10	13.8 Pre-controlled 12.2 Tier I 10.5 Tier II 2.6 Tier III[a]	0.182	0.168
Auxiliary Boiler	Marine Distillate (0.1% S)	0.11	0.2	1.995	0.164	0.151

[a]37 voyages to the Port of Oakland were made by vessels with Tier III engines in 2020.

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 CARB (2019a,b).

Emission rates corresponding to 0.1% fuel sulfur content were used based on the CARB fuel regulation. Although actual in-use fuel sulfur content may be lower, this maximum 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 estimated speed during each transiting mode.

Propulsion power and vessel design speed were derived from the IHS Fairplay (2020) 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 CARB's methodology (CARB, 2019a,b).

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 depends on 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. Under the Historic Method, low load adjustment factors previously recommended by CARB (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 and in the Port of Oakland's previous emission inventories. Low load adjustment factors for PM listed in Table 2-6 are from CARB (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 Historic Method, which uses average link speeds, 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 the Port of 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 Best Estimate, which uses speed profiles derived from AIS data, the calculated engine load was different for each speed bin to account for the variability in speeds within each transiting 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.

For the Best Estimate, updated low load adjustment factors were used in place of the Historic Method values shown in Table 2-6. The updated low load adjustment factors are based on 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.[18] These alternative load adjustment factors are provided in Appendix B. Most recently, CARB[19] has used the new Starcrest low load adjustment factors for MAN engines with slide valves and applied the new Starcrest low load adjustment factors for MAN engines without slide valves to all other propulsion engines. MAN introduced slide valves in 2000 and Wartsila adopted the technology around the same time so nearly all diesel-powered cargo vessels built since then can be expected to have slide valves (only 6% of voyages to Oakland in 2020 were made by diesel vessels built before 2000 and many older vessels have been retrofitted with slide valves to take advantage of the resulting fuel savings and other benefits).

2.3.2.2 Transiting

Each voyage includes one inbound and one outbound trip through the Golden Gate. The vessel speed and time for each mode (based on distance using either the Historic Method average speeds by leg or the Best Estimate method using 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.

2.3.2.3 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 2020, there were 256 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.

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 CARB (2011a) and are used here under the Historic Method for consistency with the Port's prior year inventories. For the Best Estimate emissions, more realistic at-berth auxiliary engine load factors were derived from shoreside power consumption records as described in Section 2.3.3.3.

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

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

Source: CARB, 2011a.

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

For each vessel call, the time when the auxiliary engine was running was estimated from the berth report and the shore power report and used in the emission calculations as described below.

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 2020 was 31.9 hours per call, which is higher than in 2017 (25 hours), lower than the 44 hours in 2015, but higher than the average of 21 hours per call in 2012 and 2005. The overall trend towards longer berthing times is consistent with the trend towards fewer calls by larger vessels and gradual increase in annual TEU throughput.

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 for 2020. There were over 926 calls averaging 27.8 hours on shore power per call during 2020. This represents a greater than 65% reduction in auxiliary engine operating hours at berth overall.

Shore power usage in 2020 was negatively impacted by circumstances surrounding the COVID-19 pandemic and extreme heat advisories that impacted the California electrical grid. Circumstances due to the pandemic resulted in 71 non-shore power calls which might otherwise have used shore power, and emergency electrical power demand reductions due to the extreme heat advisories resulted in 15 additional missed shore power connections. If these abnormal events had not occurred in 2020, there would potentially have been 86 calls averaging 27.8 hours per call[20] on shore power and the reduction in auxiliary engine operating hours at berth would potentially have been 72%.

Data on shore power usage during 2020 provide a comparison of actual auxiliary engine load as measured by power consumption with the default 18% load factor assumed by CARB that was used to develop the Historical Method emission estimates. When shore power is connected, the kW-hr billed and connection time (hours) are recorded, thus affording an estimate of average load demanded. The average load for all calls using shore power in 2020 was 1,248 +/- 24 kW (95% confidence interval). For the Best Estimate emissions method, Ramboll calculated auxiliary emissions based on the actual power demanded for the vessels using shore power when unconnected and used the 1,248 kW average for vessels that did not use shore power.

[20] Based on the overall 2020 average shore power usage per call.

This average load represents an average 11% load factor, 40% lower than the 18% assumed by CARB.

For each vessel call, the time when the auxiliary engine was running was estimated and used in the emission calculations. For those calls without shore power, the hotelling time was set equal to the time at berth. For calls that used shore power, the hoteling time with auxiliary engines running was equal to the at berth time minus the time when shore power was in use.

2.3.3.4 At Anchor

For 2020, there were 249 calls (coinciding with 245 voyages) averaging 27 hours each at anchorage either before or after calling at a Port berth. More than two thirds of the vessel anchorages occurred in the last third of the year from September through the end of December. Table 2-8 shows the historic trend in anchorage for ships calling the Port.

Table 2-8. Historic Anchorage Activity.

Calendar Year:	2020	2017	2015	2012	2005
Calls	249	149	307	37	99
Average Time (hours)	27.4	27.0	57.2	13.9	15.2
Total Time (hours)	6,815	4,023	17,560	514	1,505

The increase in anchorage in 2020 can be attributed to port congestion experienced along the entire West Coast. The congestion decreased noticeably by Summer of 2021 and anchorage is expected to decrease to more normal levels in the future.

2.3.4 Boilers

In-use boiler power estimates of 604 kW for container ships were assumed based on CARB modeling (2019a,b) using the size and voyage-weighted average for the Port's 2020 activity. Boiler emission factors shown in Table 2-9 were used; these are consistent with emission factors used in CARB (2019b). 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	0.164	0.59	934.2	0.002	0.045

Source: CARB, 2011a

2.4 Summary of OGV Emission Results

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

1) Historic Method: average ("static") leg speeds, historic low load adjustment factors, and standard CARB at-berth auxiliary engine load (18%) as in previous Port inventories,

2) Best Estimate: AIS-based speed profiles with revised low-load adjustment factors and at-berth auxiliary engine load factors based on shore power records.

Emissions by operating mode calculated by each method are provided in Tables 2-10 and 2-11. Table 2-10 shows emissions from OGVs using the Historic Method, which is the same methodology used in the 2005, 2012, 2015, and 2017 emission inventories. Table 2-11 shows Best Estimate emissions from OGVs using AIS-based speed profiles, the revised low load adjustment factors that were used in the Port of Los Angeles 2014 and subsequent inventories, and at-berth auxiliary engine load factors based on shore power records. As a result, emissions in Table 2-11 represent the current best estimate of 2020 OGV emissions. Total DPM emissions from main and auxiliary diesel engines are provided in both 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 in 2020 resulted in a greater than 65% reduction in auxiliary engine operating hours at berth overall. This reduction in auxiliary engine operating hours in turn resulted in a 50-67% reduction in pollutant emissions based on the Historic Method (39 – 66% based on the Best Estimate method). 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 and 2-11 do not account for GHG emissions from generation and transmission (G&T) of electricity used for shore power. G&T emissions for both the Historic Method (assuming 18% auxiliary engine loads at berth) and the Best Estimate method (using actual shore power consumption) are summarized in Table 2-12. These emissions take into account use of Port-supplied 100% renewable, zero carbon intensity (CI) electricity starting in October 2020 at all terminals except Berths 61-63 (where power is supplied by PG&E). Based on the Port's 2020 Power Content Label[21], Port-supplied electricity used to meet shore power demand for January – September was assumed have a CI of 194 lb CO2e/MW-hr while PG&E-supplied power was assumed to have a California grid-average G&T CI of 466 lb/CO2e/MW-hr. With G&T emissions included, the reductions in CO2e emissions resulting from shore power use are 45% and 35% for the Historic and Best Estimate methods, respectively.

Using the more accurate Best Estimate approach, OGV emissions are substantially less than under the more conservative Historic Method approach. For DPM, the Best Estimate emissions are 46% of the Historic Method value; for NOx the Best Estimate is 81% of the Historic Method value (Figure 2-5). However, the Historic Method results provide for a more consistent, "apples to apples" comparison with prior Port inventories. The lower Best Estimate values primarily result from: a) the interplay of AIS-based speeds and revised low-load adjustment factors, and b) actual at-berth auxiliary engine loads which are substantially less than the 18% load assumed in the Historic Method. As shown in Figure 2-5, the contribution of transiting and especially maneuvering modes to the OGV emissions total is greatly reduced under the Best Estimate

[21] Personal communication, J. Carpenter and T. Fidell, Port of Oakland, August 13, 2021.

approach. As discussed in (Ramboll, 2018), the use of AIS data in the Best Estimate method shows that actual vessel maneuvering times are significantly less than the assumptions used in the Historic Method.

Table 2-10. Emissions totals for OGV calling at the Port of Oakland in 2020 by mode for main and auxiliary engines and boilers – tons. Historic Method: static (average) speeds and historic load and low-load adjustment factors.

2020 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[b]	25.22	44.75	491.62	6.23	5.73	6.16	12.10	19,274	0.39	0.93	19,560
OGV – RSZ[c]	31.30	51.83	455.96	6.56	6.04	6.17	12.09	19,261	0.33	0.93	19,545
OGV – Maneuver	60.58	60.67	415.25	6.70	6.17	6.40	9.32	14,839	0.18	0.71	15,057
OGV – Berth[d]	18.38	3899	378.99	9.23	8.49	5.63	25.34	41,898	0.34	1.96	42,492
OGV – Shifts	1.50	3.16	32.67	0.56	0.51	0.51	1.35	2,150	0.02	0.10	2,182
OGV – Anchorage	8.45	17.75	179.71	3.44	3.16	2.81	8.79	13,996	0.13	0.67	14,200
Container Subtotal	**145.42**	**217.14**	**1954.20**	**32.72**	**30.11**	**27.69**	**68.99**	**111,418**	**1.39**	**5.31**	**113,036**
Emissions avoided by shore power (tons)[d]	31.60	66.85	678.91	11.07	10.19	11.06	25.78	41,066	0.49	1.98	41,668
Berthing % reduction due to shore power[d]	64%	65%	65%	55%	55%	67%	50%	50%	64%	50%	50%

[a]Excludes GHG emissions from electricity generation and transmission for shore power (see text).
[b]Cruise mode extends from the outer edge of the Precautionary zone to the Sea Buoy (see Table 2-4).
[c]RSZ extends from the Sea Buoy to the Bay Bridge (see Table 2-4).
[d]Includes cargo ship lay berth shore power diesel generator emissions.

Table 2-11. Emissions totals for OGV calling at the Port of Oakland in 2020 by mode for main and auxiliary engines and boilers – tons: Best Estimate method (AIS Time in Speed Bin and updated Load factors (including actual at-berth auxiliary engine loads).

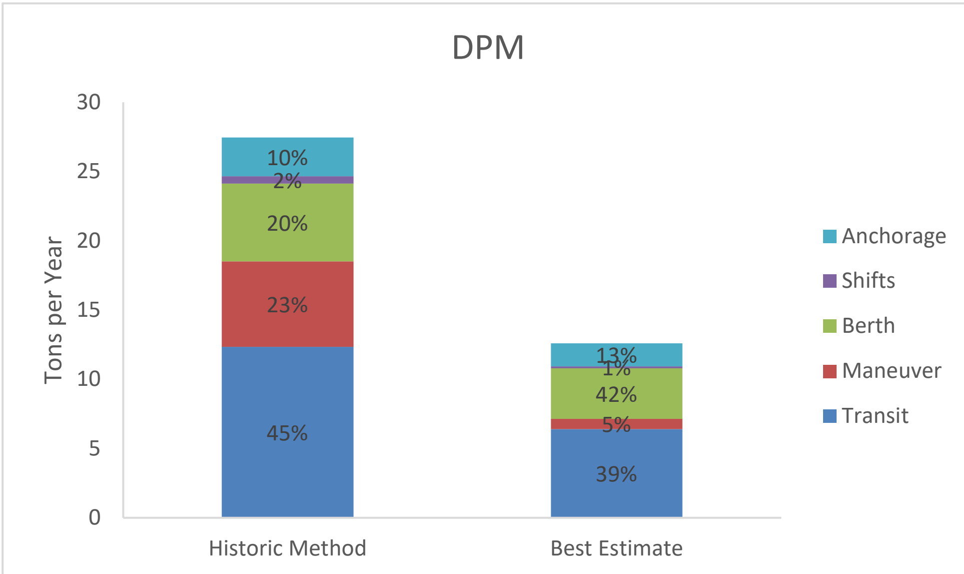
2020 Inventory	Criteria Air Pollutants							Greenhouse Gas[a] CO_2e = GWP-weighted sum of CO_2, CH_4, N_2O			
	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
OGV – Cruise[b]	26.23	48.96	630.87	4.80	4.42	4.25	14.99	23,877	0.40	1.35	24,290
OGV – RSZ[c]	13.74	25.44	333.32	2.43	2.24	2.15	7.81	12,447	0.21	0.71	12,664
OGV – Maneuver	4.12	5.14	92.11	1.00	0.92	0.74	2.97	4,727	0.06	0.26	4,807
OGV – Berth[d]	13.15	27.79	269.60	7.93	7.30	3.64	23.18	38,463	0.26	1.80	39,006
OGV – Shifts	0.99	1.02	22.60	0.21	0.19	0.16	0.65	1,034	0.02	0.06	1,053
OGV – Anchorage	5.24	10.94	113.36	2.41	2.21	1.66	6.53	10,409	0.08	0.50	10,560
OGV Subtotal	**63.47**	**119.28**	**1461.85**	**18.79**	**17.28**	**12.59**	**56.14**	**90,957**	**1.04**	**4.69**	**92,379**
Emissions avoided due to shore power (tons)	18.41	38.93	400.93	6.45	5.93	6.44	15.02	23,918	0.28	1.15	24,268
Berthing % reduction	60%	60%	60%	46%	46%	66%	39%	39%	59%	39%	39%

[a]Excludes GHG emissions from electricity generation and transmission for shore power (see text).
[b]Cruise defined as covering Precautionary and HS Outer zones (Fig. 2-3).
[c]RSZ defined as covering LS Outer to Bay Bridge zones, inclusive (Fig. 2-3).
[d]Includes cargo ship lay berth shore power diesel generator emissions.

Table 2-12. GHG emissions as CO2e from OGV berthing at the Port of Oakland in 2020 including electricity generation and transmission.

	Based on Default 18% Aux. Eng. Load	**Based on Actual Power Demand**
Shore Power Electricity Consumption	55,131,521 kW-hrs	32,087,330 kW-hrs
G&T Emissions[a]	3,903 tpy	2,401
OGV Berthing Emissions (Aux. Eng. and Boilers)	42,492 tpy	39,006 tpy
Total Emissions	**46,395 tpy**	**41,407 tpy**
Aux. Eng. Emissions Avoided due to Shore Power	41,668	24,268
Berthing Emissions Reduction	45%	35%

[a] For Berths 61-63 based on 2020 California average grid electricity generation and transmission carbon intensity (CI) of 466 lb CO2e/MW-hr. For all other terminals, January-September based on Port of Oakland 2020 average grid power CI of 194 lb CO2e/MW-hr and October-December assumed zero CI based on use of 100% renewable electricity.



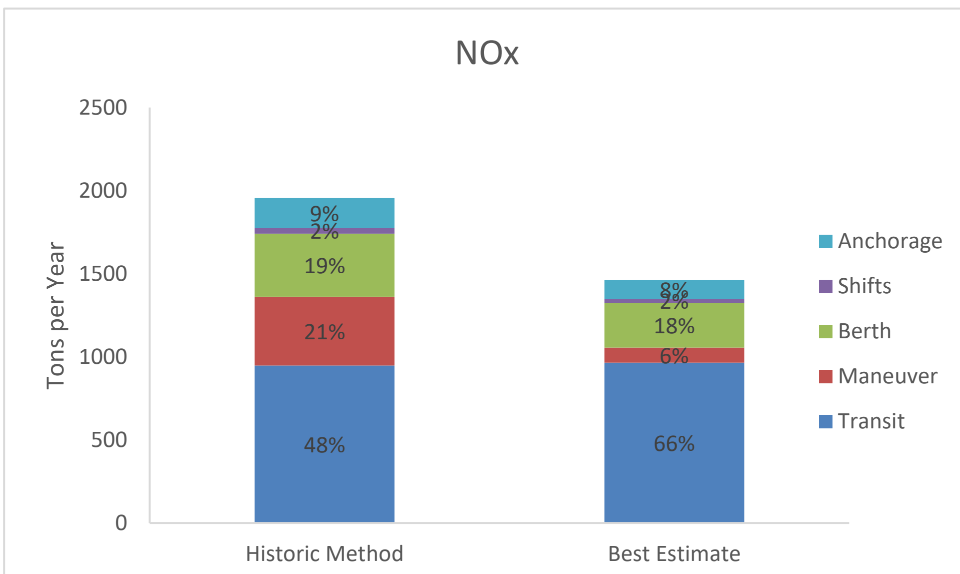


Figure 2-5. Summary of OGV DPM (top) and NOx (bottom) emissions for 2020 under the Historic Method and Best Estimate approaches.

2.4.1 Extraordinary Events in 2020

As noted above, two extraordinary events occurred in 2020 which resulted in releases of emissions that are not expected to occur in a normal year: the COVID-19 worldwide pandemic and the intense heat waves during August and September. These events fell into two categories:

- Suspension of shore power use for some calls due either to COVID-related labor issues or the Governor's heat emergency declarations.
- Suspension of cruise ship operations due to the pandemic resulting in lay berthing (berthing for extended periods with minimal activity) of cruise ships at the Port (cruise ships do not ordinarily call the Port, and the Port does not have any cruise ship passenger terminals); cruise ship lay berthing at the Port in 2020 is summarized in Table 2-13.

In addition, pandemic-related labor restrictions and surges in cargo shipments contributed to an increase in anchoring activity during the latter portion of 2020 beyond that seen in typical years.

Table 2-13. Extraordinary lay berthing calls at the Port of Oakland in 2020.

IMO	Ship	Berth Time (hrs)
9104005	GRAND PRINCESS	163.45
9304045	NORWEGIAN JEWEL	742.97
9156474	REGATTA	358.03
9210139	SEVEN SEAS MARINER	812.90
9156474	REGATTA	410.17
9304045	NORWEGIAN JEWEL	581.13
9156474	REGATTA	527.12
9210139	SEVEN SEAS MARINER	599.30

As a result of the extraordinary events in 2020, comparisons of emissions in 2020 with prior years do not fully reflect progress that has been made in reducing emissions at the Port. This bias has been partly reduced by not including emissions from the cruise ship lay berthing visits in 2020 in the OGV emission summary tables above (Tables 2-10, 2-11, and 2-12). The cruise ship visit emissions are tabulated in Table 2-14. The bulk of emissions from these visits occurred while at berth, with a small amount of additional emissions from transiting to and from the Port. DPM emissions from these extraordinary visits (3.18 tons) account for 20% of total 2020 Seaport DPM emissions while NOx emissions from cruise ship visits were 13% of total 2020 NOx emissions. No adjustments to the 2020 emissions were made for the potentially missed shore power connections associated with the pandemic or the heat emergencies as it is not possible to know with any certainty how many of the missed connections might actually have been made but for the unusual conditions in 2020.

Table 2-14. Emissions totals for extraordinary OGV lay berthing events in 2020 at the Port of Oakland in 2020 – tons. Based on AIS Time in Speed Bin and updated Load factors (including actual at-berth auxiliary engine loads).

2020 Cruise Ship Visits	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
Berthing	8.95	18.85	213.03	3.51	3.23	3.02	8.76	13,958	0.14	0.67	14,161
Total: All Modes	9.50	19.76	223.53	3.67	3.37	3.18	9.12	14,528	0.15	0.70	14,740
OGV Subtotal from Table 2-11	63.47	119.28	1461.85	18.79	17.28	12.59	56.14	90,957	1.04	4.69	92,379
Total 2020 Emissions	**72.96**	**139.05**	**1685.38**	**22.45**	**20.66**	**15.77**	**65.26**	**105,485**	**1.18**	**5.39**	**107,120**
Lay Berthing % of Total 2020 Emissions	13%	14%	13%	16%	16%	20%	14%	14%	12%	13%	14%

[a]Excludes GHG emissions from electricity generation and transmission for shore power (see text).
[b]Cruise defined as covering Precautionary and HS Outer zones (Fig. 2-3)
[c]RSZ defined as covering LS Outer to Bay Bridge zones, inclusive (Fig. 2-3)

2.4.2 Comparisons with Prior Year Inventories

Changes in OGV DPM and NOx emissions at the Port of Oakland since 2005 based on the Historic Method are shown in Figure 2-6. While use of the Historic Method for these results ensures a reasonable representation of OGV emission trends over the years, year-to-year comparisons are also influenced by other factors including changes in CARB-recommended emission factors. While CARB revised diesel engine DPM (i.e., PM10) emission factors downward by about 25% in 2019 for engines using CARB-compliant 0.1% sulfur fuel[22], comparisons with the previously published emissions for 2005 as shown in Figure 2-6 remain valid as the revised CARB DPM and NOx emission factors applicable to the higher sulfur residual fuel oil most commonly used in 2005 remained largely unchanged (a minimal 5% reduction for DPM and no change for NOx).[23]

Both NOx and DPM emissions have been substantially reduced since 2005, with DPM emissions 87% below 2005 levels. DPM and NOx emissions have been lowered through increasing use of shore power and the continuing trend towards fewer vessel calls and an increase in vessel size despite increases in TEU throughput as illustrated in Figure 2-7. DPM emissions also decreased due to the switch to low sulfur fuel starting in 2009 (maximum of 1.5% S), 2012 (maximum of 1%) and 2014 (maximum 0f 0.1%).[24] NOx emission reductions resulted both from the use of shore power and gradual turnover of the vessel fleet to newer ships with engines designed to meet lower NOx emission standards. Shore power use contributed to larger reductions in

[22] The 2019 revised NOx emission factors for 0.1% S fuel remained unchanged except for a 6% reduction for 2010 – 2014 model year engines.
[23] The 2005 inventory assumed residual fuel oil was used in all main engines and in 71% of container vessel auxiliary engines with the remaining 29% using 0.5% S marine distillate oil.
[24] 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.

berthing emissions between 2005 and 2020 (91% for DPM and 51% for NOx) as compared to total OGV emissions.

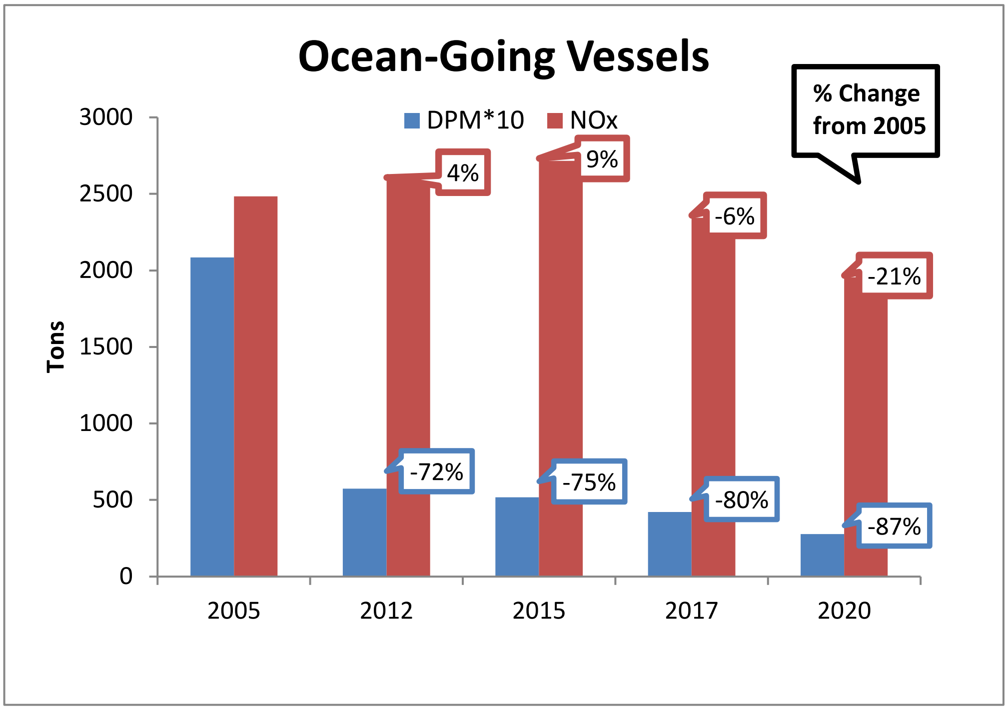


Figure 2-6. Trends in annual OGV DPM and NOx emissions (2020 emissions do not include cruise ship lay berthing events).

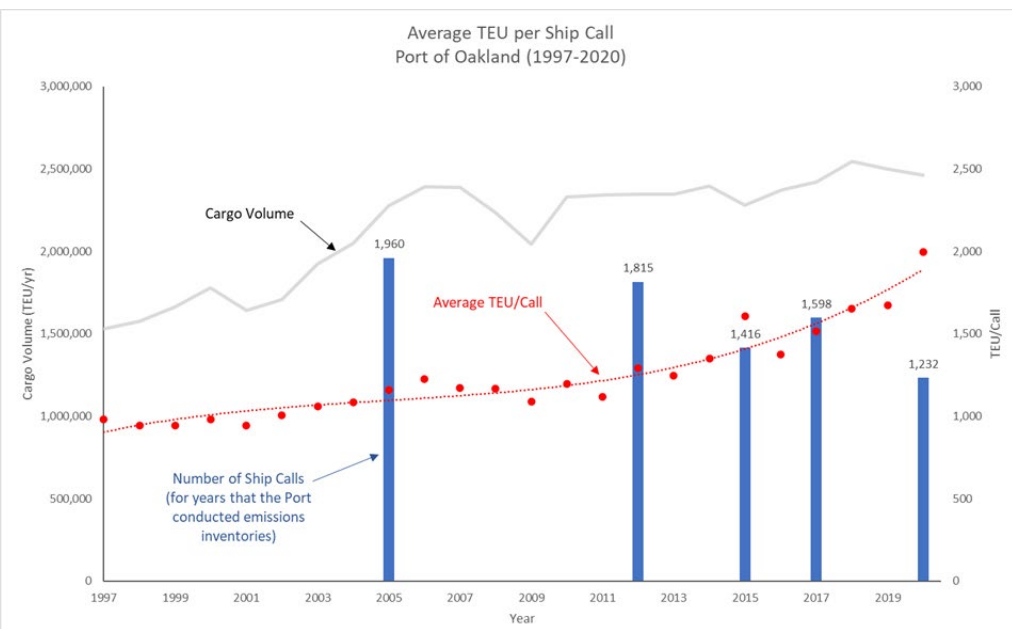


Figure 2-7. Trends in cargo volume (TEUs), vessel calls, and average TEU per call at the Port of Oakland.

3.0 COMMERCIAL HARBOR CRAFT

This section describes emissions estimation methodologies and results for three regularly occurring activities at the Port of Oakland involving commercial harbor craft (CHC):

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.

As in the case of the 2017 inventory, the bunker refueling activity has been added to the harbor craft emission inventory for 2020; this activity was not part of the prior Port Seaport 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 Seaport 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 proper depth of channels and berths and ensure safe navigation. O&M dredging removes material that is deposited into the SF 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." During 2020, channel dredging was conducted from June through November, while berth dredging was conducted during October and one week in November.

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 2020, dredging was performed by a diesel-powered derrick barge (clamshell) dredge, accompanied by tender tugs and work boats needed to assist the dredge. 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 scow to pick up a new load.

During 2020, Dutra was the contractor working to dredge the berths for the Port while Manson was hired by USACE to perform dredging of the federal channels. The material excavated from the berths and channels was primarily disposed of at the San Francisco Deep Ocean Disposal Site (SF-DODS) with a small fraction of material disposed at the SF-11 site near Alcatraz. SF-DODS is an open water site located approximately 49 nautical miles west of the Golden Gate.

3.1.2 Dredging Emissions Estimation Method

Dredging contractors Dutra and Manson provided lists of equipment used for O&M and channel dredging in 2020:

- Clamshell dredges on a dredge barge
- Dredge tenders and work support boats
- Towboats for use in dredge spoils disposal

The basic equation used to calculate emissions from each of the main propulsion or auxiliary 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 sum of the operating hours during the project,
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.

In a typical disposal 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 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 and SF-11 was accomplished by gravity - that is, by opening the bottom of the scow and allowing material to flow out.

3.1.3 Input Data

Key input data for estimating dredging emissions include the physical characteristics of the vessels and equipment used by the dredging contractors, equipment emission factors, engine load factors, the volume of material removed, and the hours of operation. Dutra provided the engine characteristic data and activity in hours of use (Dutra, 2018, 2020). USACE and Manson provided disposal trip records and indicated dredging operations proceeded on a 24/7 schedule between June 19 – November 20, 2020. Manson dredge hours of operation were therefore assumed to be 3,696 hours total (154 days times 24-hours per day). CARB vessel emission, deterioration, fuel correction, and load factors were used to estimate emissions for all engines used on the dredging and support vessels (CARB 2011b).

During 2020, berth dredging occurred in October and November, and channel dredging took place from June through November. Dredged material from both projects was sent to the deep ocean disposal site, SF-DODS, with a small fraction going to the SF-11 Alcatraz sites. Dutra and USACE/Manson provided the collected dredging volume and tug and barge trip log data. Because the SF-DODS disposal site is located outside the geographic scope of the Port of Oakland emission inventory, only the portion of the SF-DODS 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 (the distance from the West buoy to the disposal site is an additional 24.4 nautical miles). Ramboll estimated the one-way trip distance from the Port to SF-11 at 6 nautical miles on average. Dutra (2018) estimated 8 knots as a representative average speed for the tug and barge trips.

Dredging by Dutra was accomplished using barge mounted derricks which were positioned using the tender tug *Becky T*. The Dutra dredgers resemble clamshell excavators or cranes and are not on self-propelled barges. The Manson dredger was described as a walking clamshell dredge that can move by lowering cylindrical poles (also called a ‘spuds’ or ‘piles’) to push / pull the barge into the next position and did not require a tender tug.[25] For purposes of emissions calculations, all channel dredging disposal trips were assumed to be carried out by the tug *Heidi Brusco* in 2020. Although USACE reported that two other tugs with lower horsepower engines *(Peter M.* and *Arthur Brusco*) were also used for disposal trips, information on which tug made each trip was not available. Given the higher horsepower of the *Heidi Brusco*, disposal tug emissions reported here may be slightly higher than actual emissions in 2020.

[25] Walking Spud Clamshell Dredge - YouTube; https://www.youtube.com/watch?v=fC7spZe7N3I

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 2020. Emission factors for diesel engines used in tugs and tenders were calculated based on engine load, zero-hour emission factors, and deterioration factors obtained from the CARB (2011b) harbor craft emission inventory database tool. Emission factors in Table 3-1b include adjustments for deterioration to account for the increase in emissions with engine age. A fuel correction factor was applied to account for use of 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
Barge 24[1]	Dredge	Main	2019	755	0.42	490	0
		Aux.	2006	325	0.31	490	0
		Main	2007	300	0.42	490	0
		Main	2007	300	0.42	490	0
		Main	2007	127	0.42	490	0
Becky T [2]	Tender	Main (2)	2017	350	0.45	196	0
		Aux.	2018	162	0.43	196	0
		Aux.	2002	25	0.43	196	0
Njord	Dredge	Main	2005	2,934	0.51	0	3,696
		Aux.	2017	280	0.42	0	3,696
		Aux.	2017	280	0.42	0	3,696

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

Table 3-1(b).Operation & maintenance dredging off-road engine in-use emission factors. [a]

Vessel	Type	Emission Factors in g/bhp-hr							
		ROG	CO	NOx	PM_{10}	$PM_{2.5}$	CO_2	CH_4	N_2O[b]
Barge 24	Main	0.06	0.95	2.29	0.018	0.017	530	0.005	0
Barge 24	Aux,	0.27	1.06	2.53	0.123	0.113	518	0.024	0
Barge 24	Main	0.27	1.077	2.59	0.118	0.109	531	0.024	0
Barge 24	Main	0.27	1.077	2.59	0.118	0.109	531	0.024	0
Barge 24	Aux.	0.27	3.31	2.59	0.179	0.165	532	0.024	0
Becky T	Main	0.82	3.73	3.99	0.080	0.078	670	0.073	0.02
Becky T	Aux.	0.81	3.73	3.80	0.090	0.087	670	0.073	0.02
Becky T	Aux.	0.81	2.78	7.31	0.319	0.310	587	0.073	0.02
Njord	Main	0.28	1.09	4.28	0.125	0.115	529	0.026	0
Njord	Aux.	0.07	1.00	0.27	0.010	0.009	531	0.007	0
Njord	Aux.	0.07	1.00	0.27	0.010	0.009	531	0.007	0

[a] All values are rounded to indicated number of significant figures.
[b] N_2O emission factors shown as 0 are not available and assumed to be approximately equal to zero.

Table 3-2. Operation & maintenance dredging emissions - 2020 (tons/yr).[a]

	Equipment	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
POAK	Dredger	0.08	0.50	1.10	0.03	0.03	0.03	0.00	238	0.01	0.00	238
	Tenders	0.08	0.33	0.34	0.01	0.01	0.01	0.00	52	0.01	0.00	52
	Annual Tons	*0.15*	*0.83*	*1.43*	*0.04*	*0.04*	*0.04*	*0.00*	*289*	*0.01*	*0.00*	*290*
USACE	Dredger	1.80	7.57	26.3	0.77	0.71	0.77	0.03	3,732	0.16	0.00	3,736
	Tenders	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Annual Tons	*1.80*	*7.57*	*26.32*	*0.77*	*0.71*	*0.77*	*0.03*	*3,732*	*0.16*	*0.00*	*3,736*
	Total	**1.95**	**8.40**	**27.76**	**0.81**	**0.75**	**0.81**	**0.04**	**4,021**	**0.18**	**0.00**	**4,026**

[a] All values are rounded to indicated number of significant figures.

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 material 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 (based Heidi Brusco, 2008 model year main engines 3000 hp total, and 161 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	670	0.073	0.02

Table 3-4. Dredged material transport activities in 2020.

	Destination	Round Trip Distance (nautical miles)	Speed (knot)	Time (hours)	Trips
USACE	SF-DODS[1]	49	8	6.1	267
POAK	SF-11 Alcatraz	12	8	1.5	8
POAK	SF-DODS[1]	49	8	6.1	15

[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 2020 (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	0.20	1.00	1.38	0.051	0.049	0.051	0.00	142	0.02	0.00	144
USACE Total	3.12	15.76	21.72	0.796	0.772	0.796	0.02	2,234	0.28	0.08	2,263
Total	**3.32**	**16.76**	**23.10**	**0.847**	**0.821**	**0.847**	**0.02**	**2,376**	**0.30**	**0.08**	**2,407**

[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 2020 (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	1.95	8.40	27.76	0.812	0.747	0.812	0.04	4,021	0.18	0.00	4,026
Disposal	3.32	16.76	23.10	0.847	0.821	0.847	0.02	2,376	0.30	0.08	2,407
Total	**5.27**	**25.16**	**50.86**	**1.66**	**1.57**	**1.66**	**0.06**	**6,397**	**0.47**	**0.08**	**6,433**

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 home bases to conduct the assists.

The role of the assist tugs is to ensure safe navigation, which is particularly important in windy weather, strong currents, 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 SF Bay including vessel escort, berthing and departure assists at SF 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, bollard pull, 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 voyage data specific to the Port of Oakland was provided by the San Francisco 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 tugs are domiciled at Berth 9 at the Port, and Starlight tugs were domiciled on the Alameda side of the Inner Harbor Turning Basin in 2020 (in 2021 Starlight moved to Berth 10 at the Port). Together, these two companies accounted for about 83% of assist tug activity for Port of Oakland in 2020. BayDelta and Crowley (which accounted for 5% and 7% of calls, respectively) are based in San Francisco near the Bay Bridge, and Foss tugs (5% of calls) are based in Richmond. Ramboll 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 not 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 SF Bay, but the activity estimated in this study included only activity related to Port of Oakland ship calls.

3.2.2 Emissions Estimation Method

Assist tug emissions were estimated using an approach based on the methodology developed for CARB's Commercial Harbor Craft Emission Inventory Database (CARB, 2011b). The CARB 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 CARB 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 on the tugs.

The Bay Area Air Quality Management District (BAAQMD)[26] researched a list of the fleet of tugs that were operating in 2020 and verified the vessel characteristics with the operators and determined their relative activity. 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 of each company to each tug based on its relative activity within each company.

Table 3-7. Assist tug fleet characteristics in 2020.

Company	Name	Engines				Relative Tug Activity by Company
		Model Year	Main Total (HP)	Aux. kW	Main Engine Tier	
AMNAV Maritime	Patricia Ann	2008	5,100	250	Tier 2	11.2%
AMNAV Maritime	Independence	2007	5,080	250	Tier 2	6.8%
AMNAV Maritime	Revolution	2015	5,080	250	Tier 3[a]	26.3%
AMNAV Maritime	Sandra Hugh	2015	5,080	250	Tier 3[a]	19.4%
AMNAV Maritime	Liberty	2008	3,300	150	Tier 2	13.7%
AMNAV Maritime	Patriot	2006	4,300	210	Tier 1	2.1%
AMNAV Maritime	Dr. Hank Kaplan	2015	5,350	236	Tier 3	20.5%
BayDelta	Delta Billie	2009	6,712	215	Tier 2	28.3%
BayDelta	Delta Cathryn	2009	6,712	215	Tier 2	21.5%
BayDelta	Delta Audrey	2014	6,712	215	Tier 3	50.2%
Crowley (BayDelta)	Valor	2007	6,772	215	Tier 1	100%
Foss (AMNAV)[b]	Delta Lindsey	2010	6,800	215	Tier 2 Low NOx	36.6%
Foss (AMNAV)[b]	Sarah	2015	4,750	198	Tier 3	29.0%
Foss (AMNAV)[b]	Caden Foss	2017	6,772	365	Tier 4	33.5%
Foss (AMNAV)[b]	Keegan Foss	2008	3,900	198	Tier 2 Low NOx	0.9%

[26] Personal communication with Michael Murphy and Tan Dinh, BAAQMD, June 22, 2020.

Company	Name	Engines				Relative Tug Activity by Company
		Model Year	Main Total (HP)	Aux. kW	Main Engine Tier	
Foss (AMNAV)[b]	Point Fermin	2006	3,500	198	Bunkering, Tier 1	Bunker only
Starlight Marine	Ahbra Franco	2013	6,850	290	Tier 3	34.5%
Starlight Marine	Z-3	2012	4,000	204	Tier 2	23.1%
Starlight Marine	Z-4	2012	4,000	204	Tier 2	21.5%
Starlight Marine	Z-5	2012	4,000	204	Tier 2	20.8%

[a]AMNAV was awarded funding under the Carl Moyer Program to retrofit the *Sandra Hughes* and *Revolution* with Tier 3 engines. This is reflected here by selecting a model year consistent with Tier 3.
[b]AMNAV is wholly owned by Foss; Foss tugs are assumed to use the AMNAV home base between jobs (see text).

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 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 SFMX 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 2.44 inbound and 2.03 outbound per ship move in 2020.
- 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 CARB's database emission inventory tool (CARB, 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, 2015, and 2017 Seaport Air Emissions inventories (ENVIRON, 2008a, 2013; Ramboll Environ, 2016; Ramboll 2018) and the Port of Los Angeles Inventory of Air Emissions (Starcrest, 2012).[27]

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 2020.

# of Inner Harbor Assists		# of Outer Harbor Assists		Assist Hours	Transit Hours	Total Hours
Inbound	Outbound	Inbound	Outbound			
2,137	1,669	904	827	6,810	3,252	10,062

Table 3-9. Tug assist emissions for 2020 (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	13.92	68.69	96.42	3.39	3.29	3.39	0.10	11,874	1	0	12,011
Auxiliary	1.41	6.22	7.10	0.24	0.23	0.24	0.01	1,053	0	0	1,066
Total	15.33	74.91	103.52	3.63	3.52	3.63	0.11	12,928	1	0	13,077

[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

3.3 Tanker Barge Calls

Eleven tug and tanker barge calls were made to the Port during 2020. These vessels also called at other SF Bay Area terminals either before or after calling at the Port. The tugs either shut

[27] CARB recently revised their methods for calculating CHC emissions, including revised emissions and deterioration factors and, most significantly, much lower load factors (CARB, 2021b). Based on the load factor changes alone, using the revised CARB approach would have reduced CHC emissions by about 50% from the values reported here.

down while in Port or performed other work around the SF Bay while the tanker barge was berthed. Filling or emptying of tanker barges was not conducted at the Port.

The tugs used in each case were part of the Centerline[28] fleet, which provided tugs' engine characteristics shown in Table 3-10.

Table 3-10. Tugs with tanker barges fleet characteristics in 2020.

Name	Engines		
	Model Year	Main Total (hp)	Aux. (kW)
Jake Shearer	2015	4522	198
Bill Gobel	2017	4492	198
Min Zidell	2017	4522	198
Emery Zidell	2012	4070	242
Ann T Cheramie	2003	4750	200
Barbara Jean Mulholland	2013	4058	280
James T. Quigg	2005	3000	198
Eagle	2015	3000	198
Millennium Falcon	2012	4200	198
Millennium Dawn	2012	4400	291

The SF Marine Exchange Berth report showed that the time between the Pilot on or off and the first line or last line was cast at the berth was about 3 hours. Ramboll used 4 hours operating time for each inbound or outbound move (8 hours per call) to account for total time within the Precautionary Zone and any carryover after the first line or before the last line was cast.

Emissions were calculated using the same approach as for assist tugs except to use a higher (0.68) load factor for propulsion engines.

Table 3-11. Emissions from tugs with tanker barges for 2020 (tons).

	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx	CO_2	CH_4	N_2O	CO_2e
Total	0.25	1.45	1.63	0.057	0.056	0.057	0.00	259	0.02	0.01	262

3.4 Bunkering Barges

3.4.1 Introduction

The Port and Ramboll collected the date and fuel cost for bunkering events in 2020.[29] 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.

[28] https://www.centerlinelogistics.com/fleet

[29] Port of Oakland. Personal communication from Tracy Fidell, March 2021.

3.4.2 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 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 CARB OFFROAD model emission rates for pumps.

3.4.3 Input Data and Emissions

A total of 239 bunkering events occurred in 2020. Of these, 49 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 190 round trips to and from Richmond in 2020.

Propulsion and auxiliary engine model year and power data for the *Point Fermin* tug 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 950 bunker barge towing hours in 2020.

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, the average bunkering event would take five hours of pumping or about 1,198 total hours of pumping for all 239 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 2020 bunkering operation tow boats and barge pumps are shown in Table 3-12. Bunkering emissions were not quantified in 2005.

Table 3-12. Tug towboat and barge pump emissions for bunkering events during 2020 (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[b]	CO_2e
Tug (all engines)	2.31	6.25	20.36	1.07	1.04	1.07	0.01	1,755	0.2	0.05	1,776
Pumps	0.15	1.17	2.16	0.08	0.07	0.08	0.00	301	0.03	0	302
Total	**2.47**	**7.42**	**22.52**	**1.15**	**1.11**	**1.15**	**0.02**	**2,056**	**0.23**	**0.05**	**2,077**

[a] All values are rounded to indicated number of significant figures.

[b] N_2O emission factors shown as 0 are not available and assumed to be approximately equal to zero.

3.5 Summary of Commercial Harbor Craft Emissions

Table 3-13 summarizes harbor craft emissions for 2020. Note that emissions from bunkering were not reported in Port of Oakland inventories prior to 2017. All of the PM_{10} emissions listed here come from diesel engines and are therefore DPM.

Table 3-13. Total harbor craft & dredge emissions, 2020 (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	5.27	25.16	50.86	1.66	1.57	1.66	0.06	6,397	0.47	0.08	6,433
Assist Tug	15.33	74.91	103.52	3.63	3.52	3.63	0.11	12,928	1.38	0.39	13,077
Tug & Barge	0.25	1.45	1.63	0.057	0.056	0.057	0.002	259	0.02	0.01	262
Subtotal	***20.85***	***101.52***	***156.01***	***5.35***	***5.15***	***5.35***	***0.17***	***19,583***	***1.88***	***0.48***	***19,772***
Bunkering Barges	2.47	7.42	22.52	1.15	1.11	1.15	0.02	2,056	0.23	0.05	2,077
Total	***23.32***	***108.94***	***178.53***	***6.49***	***6.25***	***6.49***	***0.18***	***21,639***	***2.11***	***0.53***	***21,850***

[a] All values are rounded to indicated number of significant figures.

Trends in harbor craft NOx and DPM emissions estimates since 2005 are shown in Figure 3-1. Bunkering emissions are not included in this comparison as bunkering activity data were not available prior to 2017. DPM and NOx emissions have decreased over the years primarily due to replacement of older engines with newer, lower emitting models.

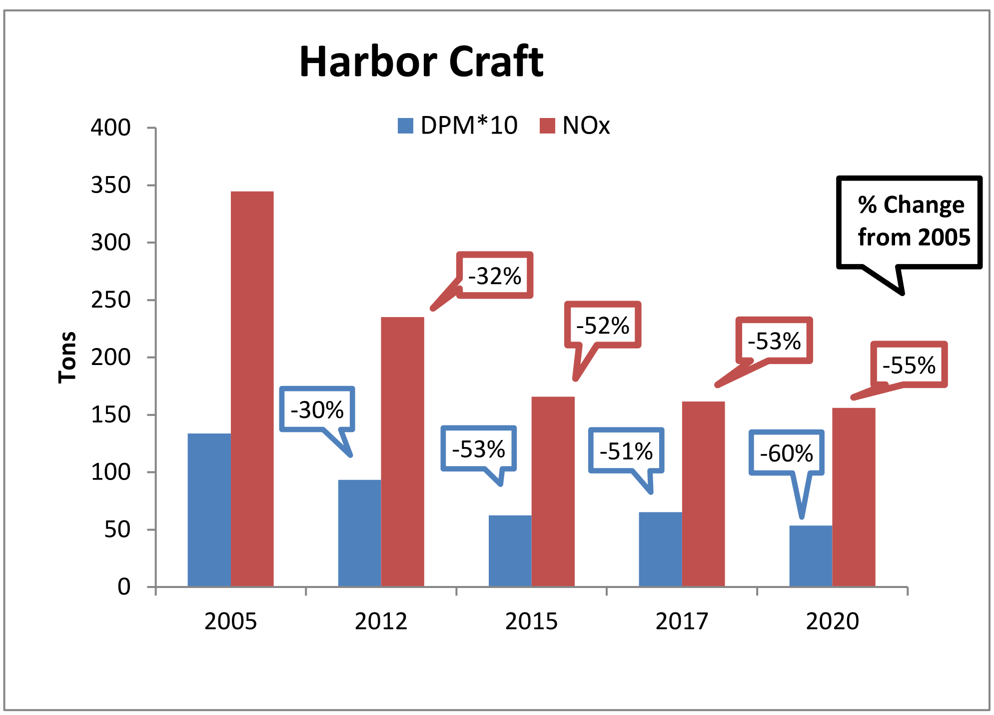


Figure 3-1. DPM and NOx emissions from harbor craft activity (exclusive of bunkering).

4.0 CARGO HANDLING EQUIPMENT

This section documents emission estimation methods and results for cargo handling equipment (CHE) operated at Port of Oakland. The 2020 Port of Oakland CHE emission inventory includes on-dock and off-dock terminals and the OIG rail yard (no CHE operated at the OHIT rail yard). Port of Oakland CHE emission inventories prior to 2017 did not include CHE operated at off-dock terminals because activities at off-dock terminals may include transloading activity not related to Port imports and exports. Nevertheless, in an effort to expand the Seaport inventory to include activities at all maritime tenant facilities, emissions from CHE at off-dock terminals were included in the 2017 emission inventory and are also included in this 2020 inventory. As in past years, the 2020 Port Seaport 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 storage areas, between storage areas and trucks, or between storage areas and trains. 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.[30] 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 2020 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 operating hours estimates were based on on-dock terminal, off-dock terminal and rail yard surveys conducted by the Port of Oakland in March 2021.

Per CARB (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

[30] An exception came to the author's attention after completion of the emissions calculations for this report: a log handler was used at times during 2020 to place logs into containers at one of the off-dock facilities. However, emissions from this operation were minor within the context of total Port-wide CHE emissions.

- 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 maritime 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 terminals operating in 2020, the OIG and OHIT railyards, and nine off-dock facilities. Response rates to the survey questions were high overall with hours of use in 2020 included for each piece of equipment listed. Engine model year and rated horsepower were filled in for 84% and 83% of all equipment, respectively. However, cumulative engine hours were only reported for 30% of equipment. Where equipment-specific horsepower, engine model year, or fuel type were not provided, values were filled in based on results from the 2017 survey, web search, or via comparison with values for similar equipment included in the 2020 survey responses. For some equipment, the missing engine model year was assumed to be the same as the reported chassis model year. In cases of missing annual activity, average annual operating hours for similar equipment types from the 2017 Port of Oakland surveys was used. Missing cumulative hour values were then filled in based on engine model year and annual average hours of use.

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 CARB*'s 2017 Off-road Diesel emission Factors*.[31] Diesel-powered equipment SO_2 emission factors were estimated based on brake specific fuel consumption (BSFC) estimates from CARB's *2017 Off-road Diesel emission Factors* and a 15 ppm diesel fuel sulfur content based on use of ultra-low sulfur diesel (ULSD). Diesel-powered equipment GHG (CO_2, CH_4, and N_2O) emission rates per unit of fuel consumption were taken from California's 2000-2018 GHG Inventory.[32]

Criteria air pollutant (HC, CO, NOx, SO_2, and PM) emission factors for gasoline and propane powered equipment were obtained from a compilation of emission factors provided by CARB (2021a). 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 2000-2018 GHG Inventory.

CHE were grouped into equipment type categories as defined by CARB (2011c). The resulting 2020 populations by equipment type for the Port of Oakland are summarized in Table 4-1. Out of 408 total pieces of cargo handling equipment, 380 were diesel powered, 27 were gasoline powered, and 1 was battery electric. 90% of CHE operates at marine terminals or railyard facilities and 10% 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)	117	29%
Forklift	28	7%
RTG Crane	28	7%
Yard Tractor	95	23%
Yard Tractor (On-road)	140	34%
Total	**408**	**100%**

[31] https://www.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017_v7.xlsx
[32] Documentation of California's 2000-2018 GHG Inventory, https://ww2.arb.ca.gov/ghg-inventory-data

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
Top or Side Pick	300	45	239	1,330	0.59
	600	72	376	1,641	
Forklift	175	22	162	1,305	0.30
	300	5	205	560	
	600	1	370	900	
RTG Crane	175	17	110	657	0.20
	600	7	512	2,767	
	750	4	618	303	
Yard Tractor[a]	175	13	166	405	0.39
	300	194	227	1,609	
	500[b]	27	220	1,400	

[a] Excludes electric yard tractors
[b] Includes gas yard tractors

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 2020 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 CARB (2013).

As mentioned above, the 2020 Port of Oakland CHE emission inventory (summarized in Table 4-3 and Table 4-4 below) includes CHE at on-dock and off-dock terminals and the OIG (BNSF) rail yard. Port of Oakland CHE emission inventories prior to 2017 included on-dock terminals and the rail yard, but not CHE operated at off-dock terminals. In 2020, off-dock terminals accounted for 0.08 tons per year (3%) of total CHE DPM emissions and 4.7 tons per year (2%) of total CHE NOx emissions.

Table 4-3. 2020 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	21.16	53.74	124.03	1.41	1.30	1.41	0.20	21,542	0.87	0.17	21,616
Forklift	1.30	6.80	6.46	0.07	0.07	0.07	0.01	943	0.04	0.01	946
RTG Crane[b]	1.28	4.16	6.34	0.12	0.11	0.12	0.01	1,399	0.06	0.01	1,404
Yard Tractor	15.92	51.47	59.04	1.15	1.05	0.93	0.19	20,470	0.83	0.17	20,540
Total	**39.66**	**116.16**	**195.87**	**2.76**	**2.54**	**2.54**	**0.41**	**44,353**	**1.80**	**0.36**	**44,506**

[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 4-4. 2020 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	36.48	107.09	189.82	2.54	2.34	2.54	0.38	41,297	1.67	0.33	41,436
Gasoline	3.18	9.08	6.05	0.22	0.20	--	0.03	3,057	0.13	0.03	3,067
Total	**39.66**	**116.16**	**195.87**	**2.76**	**2.54**	**2.54**	**0.41**	**44,353**	**1.80**	**0.36**	**44,503**

[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 2005 with 2020. NOx and DPM emissions declined as the CHE fleet turned over to lower emitting engines: DPM emissions in 2020 were 88% below 2005 levels while NOx emissions were 74% below 2005 levels. The increase in DPM emissions in 2020 relative to 2017 is due to a combination of higher reported activity levels and updated PM emission factors for some model years. As noted above, while emissions shown in Figure 4-1 for 2017 and 2020 include CHE at marine terminals and off-dock terminals, off-dock terminals were not included in the 2005, 2012, or 2015 emission inventories.

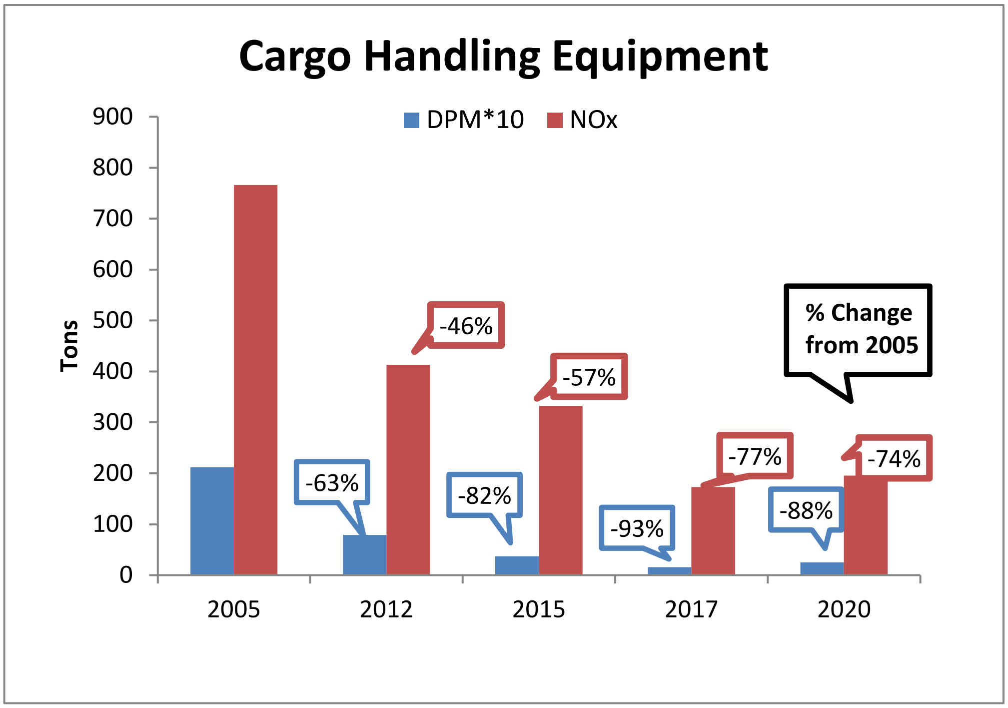


Figure 4-1. **DPM and NOx emissions estimates for Cargo Handling Equipment, 2005 - 2020.**

5.0 ON-ROAD HEAVY-DUTY TRUCKS

Trucks transport containers between marine terminals, freeway interchanges, and nearby rail yards. Historically, emissions from on-road trucks servicing the Port (drayage trucks) have been a large contributor to diesel exhaust emissions at the Port. Prior to implementation of the CARB'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 (CARB, 2009) in an effort to reduce emissions from the 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, to be replaced by the Advanced Clean Truck and Advanced Clean Fleet Rules.

The geographical boundaries of this Port of Oakland air emissions inventory include truck travel between the marine terminals and three nearby freeway interchanges and between the marine terminals and the two port area rail yards: the Port's OIG operated by BNSF and the Union Pacific rail yard. Trucks mainly arrive at or depart from the Port area via the three freeway interchange intersections: Maritime/West Grand Street, Seventh Street, and Adeline/Market Street. Trucks arriving by surface streets also pass through one of these three intersections to enter the Port area.

The following sections describe the activity and emissions calculation methods for the 2020 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 CARB's on-road emissions factor model (EMFAC2021, v1.0.1[33]) to estimate emissions from the drayage trucks moving and idling within the Port area. A summary of the 2020 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.

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

[33] http://www.arb.ca.gov/emfac

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 EMFAC2021 model based on
   a. Age distribution
   b. Individual link speeds comprising a trip
   c. Idle emission rate

5.2 Truck Trip Counts

Three data sources are available for estimating the number of truck trips: 1) Automated gate counts collected by the Port's eModal system, 2) a survey of gate transaction records completed by terminal operators, and 3) counts of the number of container lifts (defined as movement of one container, whether a 20-foot or 40-foot container). Available through the Oakland Portal on-line gateway,[34] eModal is the Port's real-time electronic system for tracking cargo activities at all four marine terminals, including truck entry and exit times. Alternatively, gate transactions reported by terminal operators rely on the terminal recordkeeping of gate activity. Gate transaction counts do not usually include bobtail trips (where the truck either arrives or departs without a container or chassis) because those trips do not generate a transaction with a gate clerk. Lastly, container lifts (i.e., the number of containers discharged from or loaded onto a ship) provide a third source of data on 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 with 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.

Based on a review of 2020 data from the three data sources described above and discussions with the Port, it was determined that the eModal automated gate count data best represents the actual number of truck visits[35] to and from the marine terminals during 2020. For the OIG rail terminal, the number of truck trips was assumed to be equal to double the number of lifts (i.e., one lift per truck visit) with the number of lifts for 2020 obtained from the rail yard operator. Table 5-1 summarizes the resulting estimated total number of truck visits for the Port area in 2020 and compares this with the number of lifts. If each truck transports one container either to or from the terminal, and no containers on the opposite leg, then the number of trips would be equal to exactly twice the number of lifts or, equivalently, the number of truck visits would be exactly equal to the number of lifts. The "excess" truck visits to marine terminals shown in Table 5-1 could be due to a combination of truck visits without loaded containers or a net change over the year in the number of empty containers or chassis stored at the terminal.

Table 5-1. On-road trucking – estimated truck visits in 2020.

Terminal Type	Truck Visits[a]	Lifts
Marine	1,391,171	1,377,296
Rail[b]	54,855	54,855

[a] One truck visit consists of two one-way truck trips.
[b] Rail results are only reported here for the intermodal rail yard located within the Port boundary (the OIG yard operated by BNSF). Trips to the Union Pacific rail yard were assumed to be twice the number to the OIG rail yard.

[34] http://portofoakland.emodal.com/
[35] A truck visit represents a roundtrip. Thus, the total number of one-way trips is equal to twice the number of visits.

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 interchange intersections. 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 within the Port (located at the former Ports America Outer Harbor terminal and the Howard Terminal in 2020) are not included, since trips to and from the parking areas at the beginning or end of the day are roughly similar to trips to and from freeway interchanges. There may also have been some trips to and from the parking areas for short-term stopovers during the day. In either case, 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

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

Rail yard
OIG (BNSF)
Union Pacific

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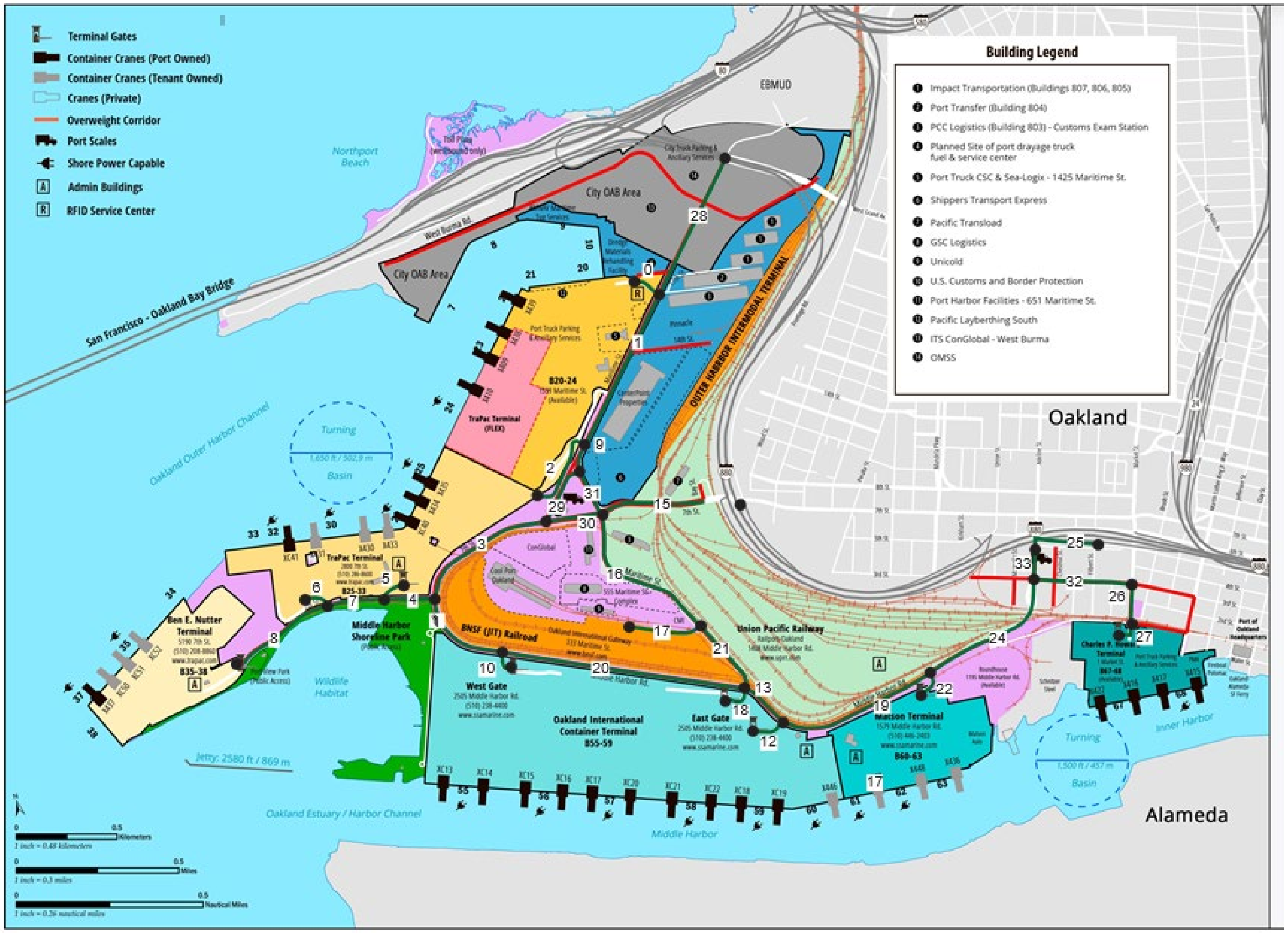


Figure 5-1. On-road trucking – roadway links within the Port of Oakland (2020 Terminal Configuration).

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 have since 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 route estimates may be updated in future inventories if new terminal-specific data become available.

Table 5-3. Distribution of truck trips between freeway and Port Terminals.

Berths	Terminal	Assumed Fraction of Traffic		
		Adeline/Market	7th Street	West Grand/ Maritime
B 20-24	former Ports America Outer Harbor	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	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 make up the trip. Average speeds for each trip in Table 5-4 are the VMT-weighted averages of the speeds for each listed link. Link-level speeds were determined from a previous study (Environ 2008a, Appendix E).

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

Trip ID	Terminal	Berth	Trip Beginning/ End	Road Link Segments, One-way	One-way Trip Length (feet)	Average Speed (mph)
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
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 (Ramboll, 2018). These previous survey data were used to estimate 2020 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 (min)	8
Idling in terminal (min)	20
Distance traveled (mi)	2.54
Speed (mph)	13.5

[a]Based on 2012 and 2005 survey data and 2020 by terminal trip activity

Data on terminal turn times obtained through the Port's eModal system shows that the average turn time in 2020 was 76 minutes (which does not include any time spent queuing outside the terminal gates). This is inconsistent with the speed, distance, and in-terminal idling parameters listed in Table 5-5 which together imply a turn time of 31 minutes. Unfortunately, data needed reconcile this difference are not currently available and updated estimates of average queuing times outside the terminal gates are also not available. Accordingly, and to maintain consistency with prior Seaport inventories, 2020 truck emissions were estimated using the activity parameters shown in Table 5-5.

5.5 Emission Factors and Age Distribution

Ramboll used the most recent version of CARB's on-road emission factor model, EMFAC2021, to calculate emission factors for trucks idling and driving at various speeds. 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 CARB's Drayage Truck Regulation, which affects specific model years, causing sharp declines in NOx and PM emission rates for EMFAC vehicle category Class 8 POAK Drayage Trucks as shown in Figure 5-2. The EMFAC2021 model accounts for the benefits of the Drayage Truck Regulation applicable to calendar year 2020, including:

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.

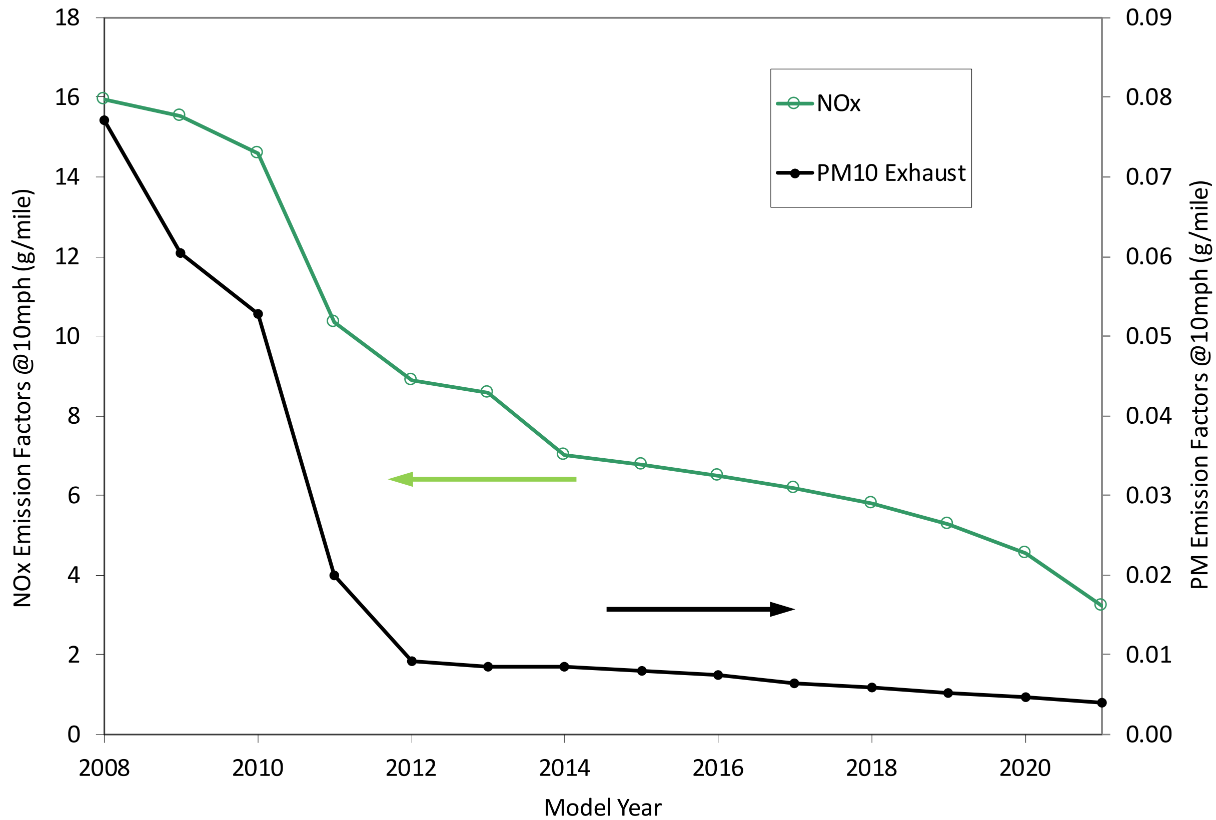


Figure 5-2. 2020 calendar year POAK drayage truck EMFAC2021 emission factors by model year for PM and NOx at 10 mph (NOx plotted on left vertical axis, PM10 on right vertical axis as indicated by the colored arrows).

The truck age distribution used in this analysis was based on the 2020 calendar year Alameda County (Port of Oakland) drayage truck VMT-weighted age distribution in EMFAC2021 v1.0.1. 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 CARB rule. Based on checks incorporated into the Port's Secure Truck Enrollment Program (STEP) to assure compliance with the CARB rule, Ramboll 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).

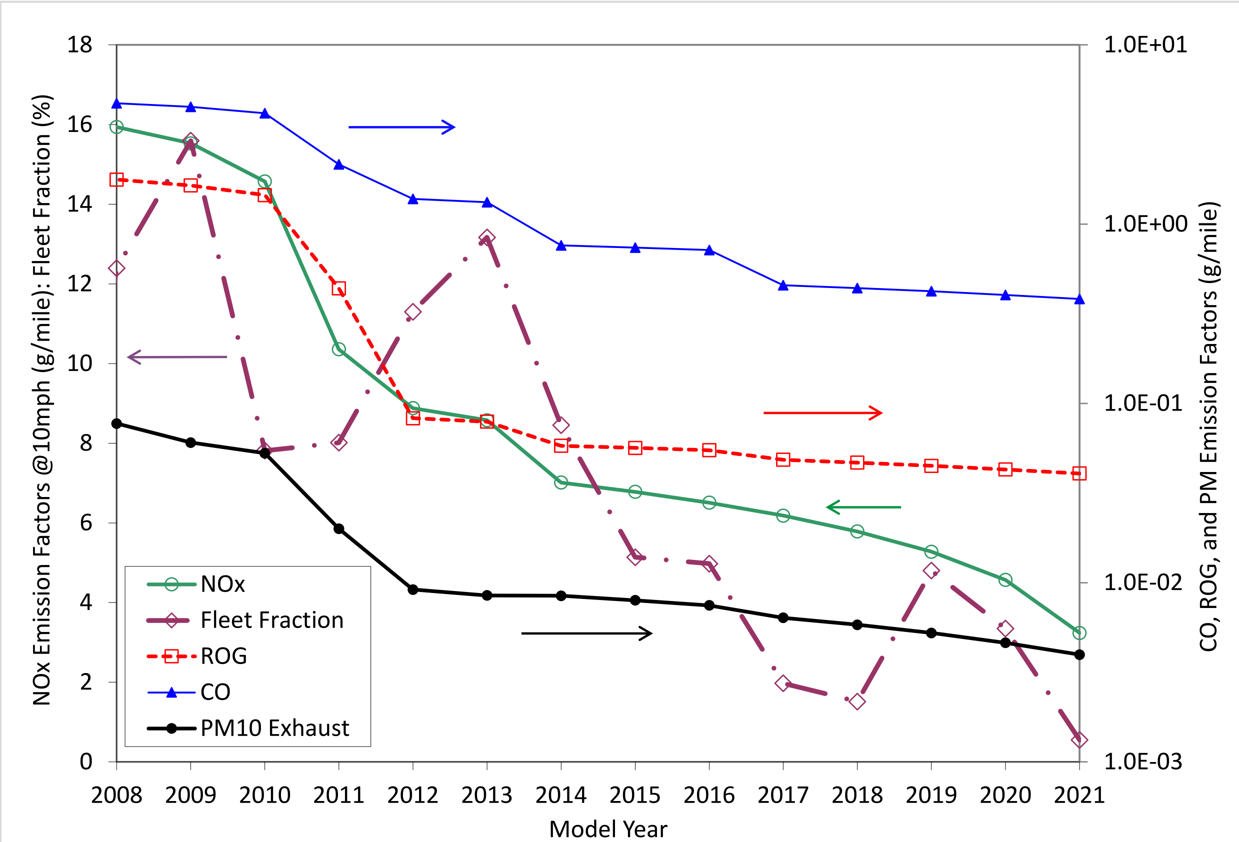


Figure 5-3. Port of Oakland drayage truck age distribution as fraction of fleet by model year (diamond symbols connected by dash-dot line) and NOx, ROG, CO and PM_{10} exhaust emission factors at 10 mph by model year (NOx plotted on left vertical axis, CO, ROG, and PM plotted on right axis as indicated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

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, 2012, and 2013 (using engine model years 2007, 2008, 2011, and 2012 respectively) made up just over half (51% together) of the Port's truck fleet in 2020. The 2007 and 2008 truck engines produce higher emissions than 2011 and later trucks.

Table 5-6 lists all emission factors for the Port's truck fleet in 2020, including idling (grams/hour) and driving (grams/mile) by speed. Speed effects on emission rates are based on pollutant specific EMFAC2021 speed correction factors. As shown in Table 5-6, emission factors are generally highest at low speeds and lowest at high speeds.

Table 5-6. Port of Oakland specific average drayage truck emission factors in 2020 for speeds 0 to 45 mph.[36]

Speed (mph)	ROG	CO	NOx	PM_{10} Total	PM_{10} Exhaust	$PM_{2.5}$ Total	Unit
0	2.37	25.58	41.07	0.014	0.014	0.01	g/hr
5	0.68	2.35	10.55	0.217	0.030	0.09	g/mile
10	0.68	2.35	10.55	0.217	0.030	0.09	g/mile
15	0.46	1.54	8.03	0.210	0.025	0.09	g/mile
20	0.33	1.09	6.60	0.204	0.022	0.08	g/mile
25	0.24	0.81	5.65	0.199	0.021	0.08	g/mile
30	0.18	0.60	4.92	0.196	0.020	0.08	g/mile
35	0.14	0.45	4.35	0.174	0.020	0.07	g/mile
40	0.10	0.34	3.94	0.159	0.020	0.06	g/mile
45	0.08	0.25	3.68	0.145	0.022	0.06	g/mile

Effects of emission control systems failures on truck emissions are incorporated into EMFAC2021 emission rates. As described in the 2017 Seaport inventory report (Ramboll, 2018), the EMFAC2017 modeled DPF failure rate for the Oakland drayage truck fleet was higher than the DPF failure rate observed via roadside measurements by Preble et al. (2016). For EMFAC2021, CARB modified the manner in which DPF failure rates were folded into the overall emissions deterioration rates but the EMFAC2021 deterioration rates are somewhat higher than those used in EMFAC2017, indicating a DPF failure rate at least as conservative as that used in EMFAC2017.

5.6 Summary of Drayage Truck Emissions Results

Drayage trucks that provided service to Port of Oakland marine terminals and rail yards emitted approximately 90 tons of NOx and just over 0.2 tons of DPM within the Port area during 2020 as shown in Table 5-7. Aside from the seven electric BYD demonstration trucks (four at SeaLogix and three at GSC), all trucks used diesel engines in 2020, 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). Truck travel on surface roads and in-terminal driving accounted for 78% of total fuel consumption (based on CO2 emissions) but over 95% of PM emissions while accounting for only 63% of NOx emissions. Thus, just over a third of NOx emissions are from idling. Note that idling emissions are proportional to the idling times derived from 2012 and 2005 survey data (Table 5-5) which may not be fully representative of current port operations (see discussion in Section 5.4 above).

[36] Based on EMFAC2021 vehicle category: Port of Oakland Drayage Trucks

Table 5-7. 2020 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	0.97	3.22	25.30	0.937	0.104	0.373	0.104	0.09	9498	0.04	1.50	9,945
Gate idling in queue	0.59	6.34	10.19	0.003	0.003	0.003	0.003	0.02	1657	0.03	0.26	1,735
In terminal idling	1.32	14.22	22.83	0.008	0.008	0.007	0.008	0.04	3715	0.06	0.58	3,890
In terminal driving	1.85	6.26	30.95	0.749	0.094	0.307	0.094	0.09	9751	0.09	1.54	10,211
Truck totals	**4.72**	**30.04**	**89.28**	**1.698**	**0.209**	**0.690**	**0.209**	**0.23**	**24621**	**0.22**	**3.87**	**25,782**

Drayage truck NOx and DPM emission estimates for 2005 – 2020 are shown in Figure 5-4.[37] DPM emissions in 2020 were 99% below 2005 levels. Changes in emissions from year to year are a result of 1) changes in the reported number of truck trips, 2) modernization of the truck fleet due to the introduction of restrictions on older trucks and fleet turnover[38], and 3) revisions to emission rates associated with updates to CARB'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), EMFAC2017 (used to prepare the 2017 inventory), and EMFAC2021 (used to prepare the 2020 inventory) also contributed to the changes in reported emissions. In particular, brake dust emission factors were revised upward in EMFAC2021 while trip-average PM10 exhaust emission factors were revised downward.

Comparisons of drayage truck CO2 emissions between 2017 and 2020 are consistent with the roughly 30% increase in reported truck activity (i.e., trips) in 2020 despite the minimal (1.7%) increase in TEU throughput and a slight (0.4%) reduction in report lifts (the change in CO2 emissions per trip was a minimal 0.3%). This is most likely a result of using the eModal gate counts to determine the number of trips for 2020 instead of the gate transaction surveys used for 2017 (see Section 5.2 above), rather than an actual increase in truck trips. Truck visits per lift were 0.8 in 2017 as compared to 1.0 in 2020 and 0.98 in 2005[39], which further supports the hypothesis that truck trips were underestimated in the 2017 inventory. Nevertheless, the large

[37] 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.
[38] Emission reductions due to turnover to newer, cleaner trucks is offset to some extent by gradual increases in emissions as the first batch of new trucks purchased to meet the new drayage truck rule age and EMFAC deterioration factors are applied.
[39] The 2005 lift count is estimated by multiplying the 2005 TEU throughput by the 2017 and 2020 average of 0.59 lifts per TEU.

percentage emission reductions since 2005 shown in Figure 5-4 can be expected to have a high relative accuracy.

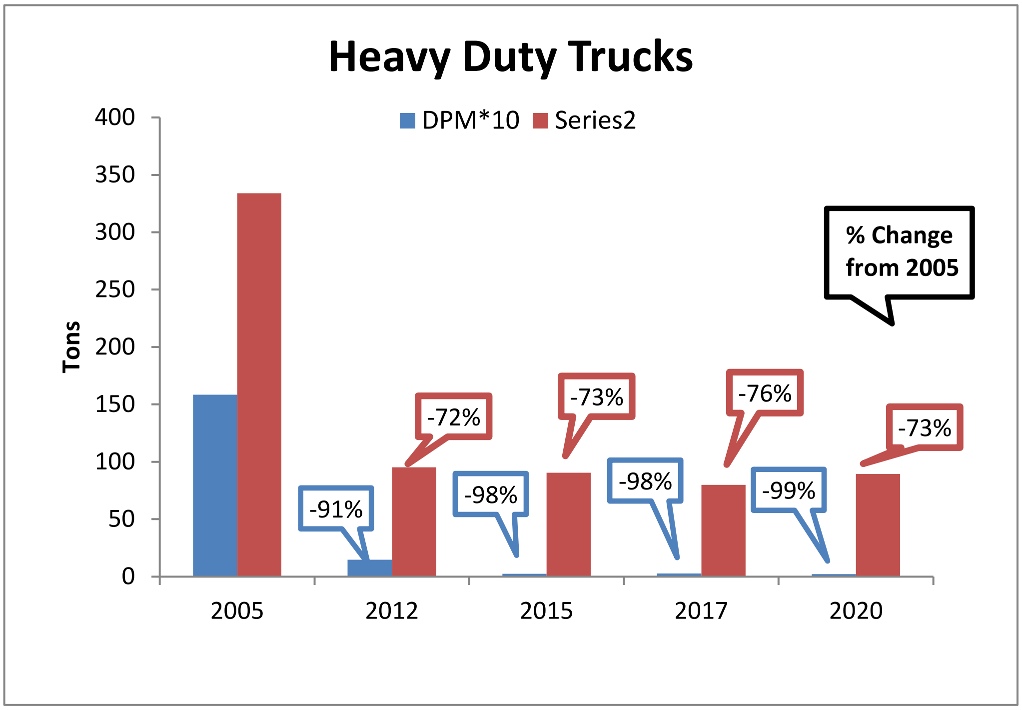


Figure 5-4. Drayage truck NOx emission estimates for 2005 - 2020.

6.0 RAIL LOCOMOTIVE

6.1 Introduction

This section describes the data and methods used in estimating emissions from locomotives at the two rail yards on Port property: the Oakland International Gateway (OIG) rail yard and the Outer Harbor Intermodal Terminal (OHIT). The Burlington Northern Santa Fe (BNSF) railway leases and operates the OIG rail yard. 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 included in this inventory because the UP yard is privately owned and not leased from the Port. Union Pacific previously provided CARB an independent analysis of the emissions at their Oakland facility (Sierra Research, 2007). And the BAAQMD and the West Oakland Environmental Indicators Project (WOEIP) included emissions from the UP Railport in its West Oakland air quality study (BAAQMD and WOEIP, 2019).

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 or at OHIT. 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 CARB (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 (Ramboll 2018). 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 CARB (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, CARB (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[40] 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.

[40] https://www.epa.gov/emission-standards-reference-guide

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 CARB SPECIATE[41] TOG profile number 818 for diesel engines, which provides the weight fraction of methane and other 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 CARB's Marine Emissions Model emission inventory tool for ocean-going vessels[42] 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 2020 made available by BNSF (2021).[43] BNSF usually assigns one switching locomotive to OIG at any given time. Switching locomotives assigned to OIG rotate in and out of service; the percentage of hours on-site by type are shown in Table 6-2. Average emission rates of typical locomotive engine surrogates for which data are available and which

[41] CARB, Speciation Profiles Used in ARB Modeling, https://www.arb.ca.gov/ei/speciate/speciate.htm
[42] CARB, 2019a. OGV At Berth Emissions Inventory Model (https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road)
[43] BNSF 2021, Personal communication with Edward Phillips, May 5 2021.

bracket the power of the locomotive used at the yard were used to estimate emissions of the in-use switching locomotive.

Table 6-2. Locomotive – Switching engine characterization for the OIG facility in 2020.

Locomotive Model	Certification Tier	HP	Number of Engines	Percent Hours on Site	Engine Surrogate
GP60	Precontrolled	3800	2	11.54%	GP-60 precontrolled
SD40-2	Precontrolled	3000	1	0.72%	GP-4x precontrolled
SD40-2	Tier 0	3000	2	5.74%	GP-4x precontrolled
GP60	Tier 0	3800	1	0.12%	GP-60 Tier 0
B40-8W	Tier 0	3999	4	8.95%	Dash 8 Tier 0
SD40-2	Tier 0+	3000	2	11.24%	Dash 9 Tier 0
GP60M	Tier 0+	3800	5	8.72%	Dash 9 Tier 0
B40-8W	Tier 0+	3999	8	10.57%	Dash 8 Tier 0
B40-8W	Tier 1+	3999	3	42.33%	Dash 8 Tier 0
3GS21B	Genset Tier 1+	2100	2	0.06%	ES-44 Tier 2+

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 time in mode at OIG have remained consistent since 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.[44] The lift count at OIG in 2020 was down about

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

44% from 2015, so for 2020, the switching locomotive activity was proportionally reduced to 1,528 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 2020 as shown in Table 6-4.

Table 6-4. Locomotive – Fleet characterization for locomotive arrival and departure at the OIG facility in the OIG facility in 2020.

Model	Tier	Surrogate	Count
SD75M	0+	Dash 9 Tier 0+	1
AC4400CW	1	Dash 9 Tier 1	1
AC4400CW	1+	Dash 9 Tier 1+	4
C44-9W	1+	Dash 9 Tier 1+	40
AC4400EV	2	ES44 Tier 2	1
ES44DC	2	ES44 Tier 2	3
ES44C4	2	ES44 Tier 2	4
ES44AC	2+	ES44 Tier 2+	17
ES44C4	2+	ES44 Tier 2+	13
ES44DC	2+	ES44 Tier 2+	35
SD70ACE	2+	ES44 Tier 2+	3
ES44C4	3	ES44 Tier 3	51
SD70ACE	3	SD70 Tier 3	4
ES44C4	4	ES44 Tier 4	24
ET44C4	4	ES44 Tier 4	31

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[45] and restrict idling to 15 minutes per event per agreement with CARB,[46] the idle time was adjusted to 1.0 hour assuming four in-yard movements per arrival and departure as in the 2015 and 2017 inventories. The average time in mode data are summarized in Table 6-5.

[45] https://www.businesswire.com/news/home/20030421005337/en/GE-Transportation-Systems-Launches-New-Fuel-Saving

[46] https://www.arb.ca.gov/msprog/offroad/loco/loco.htm

Table 6-5. Locomotive – Time in mode per trip for arriving and departing locomotives at the OIG facility in 2020.

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

The fleet characterization for locomotives, provided in Table 6-4, was derived from all engines entering the site in 2020, 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 - 2020.[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	0.57	1.08	6.05	0.114	0.105	0.00	350	0.03	0.01	353
Train Arrival / Departure	0.01	0.04	0.27	0.005	0.004	0.00	38	0.00	0.00	39
Total	**0.58**	**1.12**	**6.32**	**0.119**	**0.109**	**0.00**	**388**	**0.03**	**0.01**	**392**

[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] Based on ROG to THC ratio of 1.21 for diesel engines
[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 CARB (2015) Vision Locomotive Module

6.4 Oakland Global Rail Enterprises (OGRE)

6.4.1 Overview

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 2020, 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

OGRE used only one locomotive during 2020[47]: a new EMD 24B locomotive that meets Tier 4 standards with specifications described by Progress Rail (a division of Caterpillar),[48] for a total of 598 hours. Ramboll used emission rates for a Tier 4, 4400 hp line-haul locomotive adjusting for the rated power to 2000 hp for the EMD 24B model. Emissions from the OGRE switching engine activities are included in the summary of all locomotive emissions results below.

6.5 Summary of Locomotive Emission Results

Total 2020 locomotive emissions at the Port of Oakland are summarized in Table 6-9.

Table 6-9. Estimated total annual locomotive emissions (tons) - 2020.[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	0.57	1.08	6.05	0.114	0.105	0.114	0.00	350	0.03	0.01	353
OIG Train Arrival / Departure	0.01	0.04	0.27	0.005	0.004	0.005	0.00	38	0.00	0.00	39
Subtotal: OIG	**0.58**	**1.12**	**6.32**	**0.12**	**0.11**	**0.12**	**0.00**	**388**	**0.03**	**0.01**	**392**
OGRE	0.01	0.06	0.14	0.002	0.002	0.002	0.00	96	0.00	0.00	96
Total	**0.59**	**1.18**	**6.46**	**0.12**	**0.11**	**0.12**	**0.00**	**483**	**0.03**	**0.01**	**488**

[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 CARB (2015) Vision Locomotive Module

Locomotive DPM and NOx emissions for 2005 – 2020 are summarized in Figure 6-1. Locomotive DPM emissions in 2020 were 94% below 2005 levels and NOx emissions were 92% below 2005 levels. These reductions are due to turnover of locomotive engines to newer, cleaner models, nation-wide use of ultra-low sulfur diesel fuel, introduction of idle reduction measures, and reductions in activity levels.

[47] Personal communication with Lance Jenkins, April 5, 2021.
[48] https://www.progressrail.com/en/Segments/RollingStock/Locomotives/RepoweredLocomotives/EMD24B.html

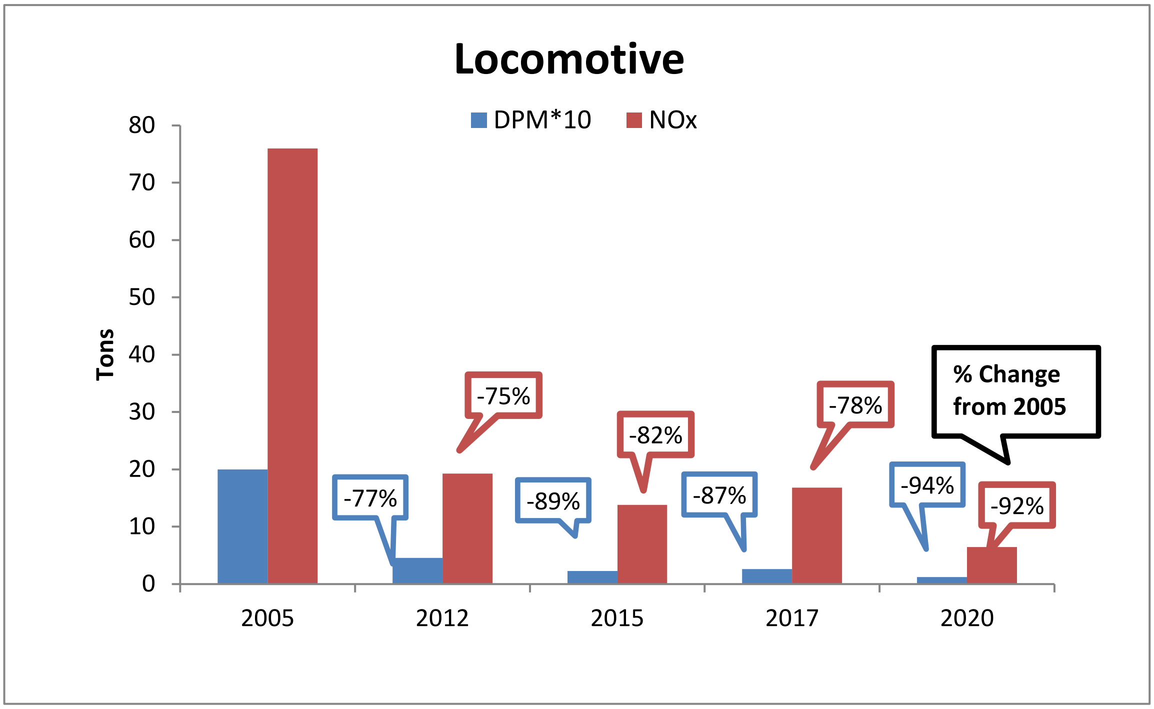


Figure 6-1. Locomotive DPM and NOx emissions.

7.0 OTHER OFF-ROAD EQUIPMENT

This section documents emission estimation methods and results for construction and maintenance equipment operated at the Port of Oakland. The 2020 Port of Oakland other off-road equipment emission inventory includes non-CHE equipment operating at on-dock and off-dock terminals and the OIG (BNSF) rail yard and paving of a 13.5 acre parking lot. Prior to 2017, Port of Oakland Seaport 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 Seaport inventory to include activities at all Port maritime tenant facilities, emissions from other off-road equipment at off-dock terminals were included in the 2017 emission inventory and are included in the current (2020) inventory. As in past years, the Port 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 includes general industrial and construction equipment that is most often used for maintenance and construction activity occurring at the Port. This is not to be confused with CHE, which is used to transfer shipping containers or other intermodal freight cargo.[49] The CHE activities and emissions are discussed in this emission inventory under Section 4. Non-CHE offroad equipment inventoried below consist of three types: (1) facility maintenance and construction equipment at each terminal, (2) Port of Oakland general maintenance equipment, and (3) equipment used for other construction projects on Port property.

7.2 Emission Calculation Methodology

To estimate 2020 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 construction were provided by the Port.

[49] California defines cargo handling equipment as "any off-road, self-propelled vehicle or equipment used at a port or intermodal rail yard to lift or move container, bulk, or liquid cargo carried by ship, train, or another vehicle, or used to perform maintenance and repair activities that are routinely scheduled or that are due to predictable process upsets." (13 CCR § 2479).

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

- Aerial Lifts
- Air Compressors
- Cranes
- Excavators
- Forklifts
- Generator Sets
- Graders
- Lifts
- Other Construction Equipment
- Other General Industrial Equipment
- Pavers
- Paving Equipment
- Pumps
- Rollers
- Rubber Tired Dozers
- Rubber Tired Loaders
- Scrapers
- 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. Where equipment-specific horsepower was not provided, Ramboll assumed (i) horsepower of similar make and model provided in the Port survey or (ii) defaulted values used in CARB models or (iii) values obtained from a web search. Similarly, where gaps were found in reported annual activity, average annual operation of similar equipment from the Port inventory was used.

For diesel-powered equipment, emission factors for HC, CO, NOx, and PM were derived from CARB's *2017 Off-road Diesel Emission Factors*.[50] Diesel-powered equipment SO_2 emission factors were estimated based on fuel sulfur content and brake specific fuel consumption (BSFC) estimates obtained from CARB's *2017 Emission Off-road Diesel Emission Factors*. Diesel-powered equipment GHG (CO_2, CH_4, and N_2O) emission rates per unit of fuel consumption were taken from California's 2000-2018 GHG Inventory. For small (< 25 hp) gasoline and propane powered equipment, criteria air pollutant emission factors, including SO2 and CO2 emission factors, were obtained from CARB's Small Off-road Emissions (SORE) 2020 model (CARB, 2020). N2O and CH4 emission factors were obtained from CARB's GHG inventory. For gasoline and propane equipment greater than 25 hp, emission factors were obtained as described for CHE in Section 4.2. 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 2000-2018 GHG Inventory emission factors.

Emissions from paving of the 13.5 acre parking lot completed in 2020 were estimated using the CalEEMod emissions model.[51] This included emissions from off-road equipment and worker vehicles. Hydrocarbon emissions from pavement off-gassing were estimated using the CalEEMod default emission factor (2.62 lb VOC per acre).

Populations of off-road equipment evaluated in this section are summarized in Table 7-1 below. 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	148	326
Air Compressors	56	10	100
Excavators	1	173	90
Forklifts	67	162	768
Generator Sets	2	80	0

[50] https://www.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017_v7.xlsx
[51] http://www.aqmd.gov/caleemod/download-model

Equipment Type	Population	Average Horsepower	Average Annual Hours of Operation
Golf Carts	1	9	10
Graders	1	150	25
Lift	1	0	0
Light Tower	1	11.7	0
Off-Highway Trucks	1	710	49
Other General Industrial Equipment	2	147	60
Pallet Jack	2	0	10
Pavers	1	36	2
Paving Equipment	1	123	20
Pressure Washers	1	8	10
Rollers	2	39	97
Rubber Tired Loaders	1	260	20
Skid Steer Loaders	3	133	61
Sweepers/Scrubbers	1	66	192
Welders	56	10	100
Tractors/Loaders/Backhoes	6	106	106

7.4 Summary of Construction and Maintenance Equipment Emission Results

Table 7-2 presents emission estimates for 2020 construction and maintenance equipment. As mentioned above, Port of Oakland construction and maintenance equipment emission inventories prior to 2017 included on-dock terminals and the rail yards but did not include construction and maintenance equipment operated at off-dock terminals. Construction and maintenance equipment at off-dock terminals not included in previous emission inventories accounted for 0.38 tons of NOx and 0.0002 tons of DPM, representing 13% and 0.4%, respectively, of total Port-wide emissions from construction and maintenance equipment in 2020.

Table 7-2. 2020 Port of Oakland construction and maintenance equipment (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	SO_2	CO_2	CH_4	N_2O	CO_2e
Paving	0.05	0.14	0.15	0.01	0.01	0.01	0.00	21	0.01	0.00	21
Terminal Maintenance Equipment	1.29	39.71	2.52	0.07	0.07	0.03	0.01	565	0.03	0.01	5.67
Port Maintenance Equipment	0.04	0.23	0.38	0.01	0.01	0.01	0.00	49	0.00	0.00	49
Totals	**1.38**	**40.10**	**3.04**	**0.09**	**0.09**	**0.05**	**0.01**	**635**	**0.03**	**0.01**	**637**

8.0 SUMMARY AND COMPARISONS WITH PRIOR YEAR INVENTORIES

This section presents an overall summary of the 2020 Seaport Emissions Inventory and discusses comparisons of 2020 emissions with emissions previously estimated for 2005, 2012, 2015, and 2020.

8.1 Summary of 2020 Seaport Emissions

Seaport emissions for 2020 based on the Best Estimate methods described in previous sections (i.e., use of AIS-based speed data and revised load factors for OGVs) are summarized in Table 8.1a (for criteria pollutants) and 8.1b (for GHGs) and in Figure 8.1. This methodology has been refined since the methods used in the 2005 - 2015 inventories, in that it uses input data and methods that were not available prior to 2017. For the sake of comparison between inventory years, 2005, 2012, 2015, 2017, and 2020 emissions are compared below in Section 8.2 using consistent methods for OGVs for all years (i.e., the Historic Method), as discussed in Section 2. OGVs are the largest source of emissions and are the source for which the most refinements in methodology have been implemented. For comparison with prior year inventories, emissions from the extraordinary cruise ship visits in 2020 as described in Section 2.4.1 are not included in the OGV emission totals.

OGVs accounted for the largest fraction of DPM (57%) and NOx (76%) emissions in 2020 using the refined methodology. Berthing accounted for 29% (3.7 tons) of the OGV DPM emissions as shown in Figure 8.2 and for 17% of total Seaport DPM emissions in 2020. 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 cargo 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 2020 DPM emissions (29% with bunkering included). Harbor craft emissions are expected to decrease in the future as older engines continue to be replaced by newer models with lower emissions.

Table 8.1a. Summary of 2020 Seaport criteria pollutant emissions: Best Estimate methods (AIS-based speeds and revised load factors). (tons per year)

	ROG	CO	NOx	PM_{10}	$PM_{2.5}$	DPM	SOx
OGV[a]	63.47	119.28	1461.85	18.79	17.28	12.59	56.14
Harbor Craft: Dredge & OGV assist	20.85	101.52	156.01	5.35	5.15	5.35	0.17
Harbor Craft: Bunkering	2.47	7.42	22.52	1.15	1.11	1.15	0.02
CHE	39.66	116.16	195.87	2.76	2.54	2.54	0.41
Trucks	4.72	30.04	89.28	1.698	0.690	0.209	0.23
Locomotives	0.59	1.18	6.46	0.12	0.11	0.12	0.00
Other	1.290	39.714	2.519	0.072	0.067	0.025	0.006
Total[b]	**133.13**	**415.70**	**1,935.02**	**29.95**	**26.96**	**22.00**	**56.98**

[a]Excludes extraordinary cruise ship visits
[b]Sum of individual values may not equal indicated totals due to rounding

Table 8.1b. Summary of 2020 Seaport GHG emissions: Best Estimate methods (AIS-based speeds and revised load factors). (tons per year)

	CO_2	CH_4	N_2O	CO_2e[a]
OGV	90,957	1.04	4.69	94,781
Harbor Craft: Dredge & OGV assist	19,583	1.88	0.48	19,772
Harbor Craft: Bunkering	2,056	0.23	0.05	2,077
CHE	44,353	1.80	0.36	44,506
Trucks	24,621	0.22	3.87	25,782
Locomotives	483	0.03	0.01	488
Other	565	0.026	0.005	567
Total	**182,689**	**5.23**	**9.48**	**188,046**

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).
[c]Shore power CO_2e emissions of 2,401 tons from electricity generation and transmission in CO_2e are included in OGV totals based on recorded shore power electricity consumption and carbon intensity of shore power electricity provided at the Port.

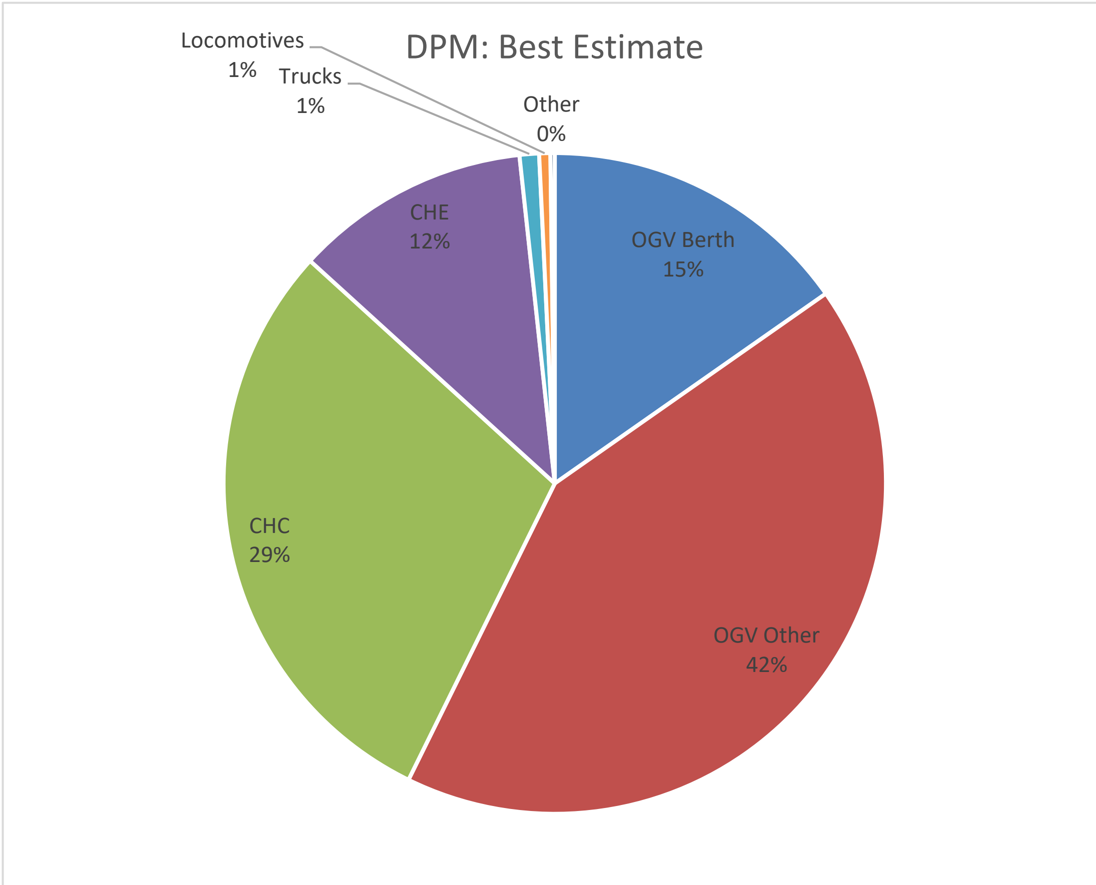


Figure 8-1a. 2020 DPM emissions: Best Estimate (AIS-based speeds and revised load factors).

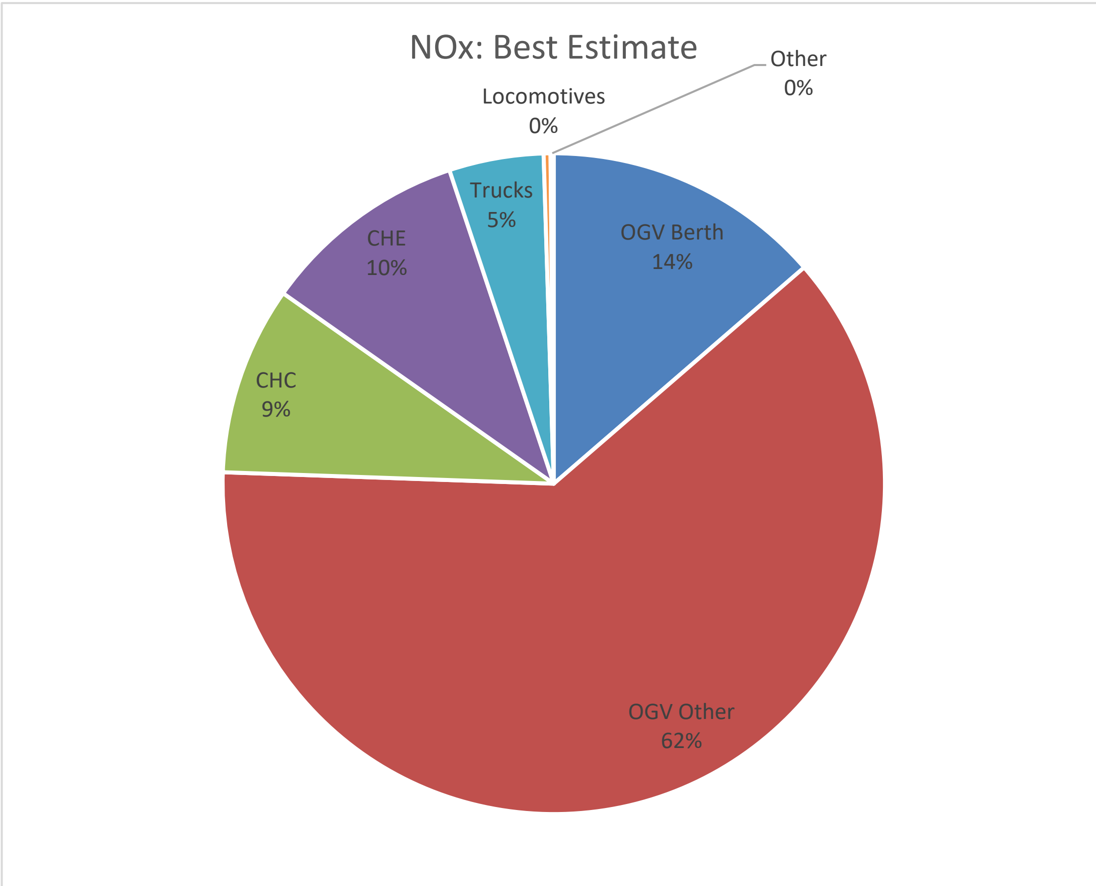


Figure 8-1b. 2020 NOx emissions: Best Estimate (AIS-based speeds and revised load factors).

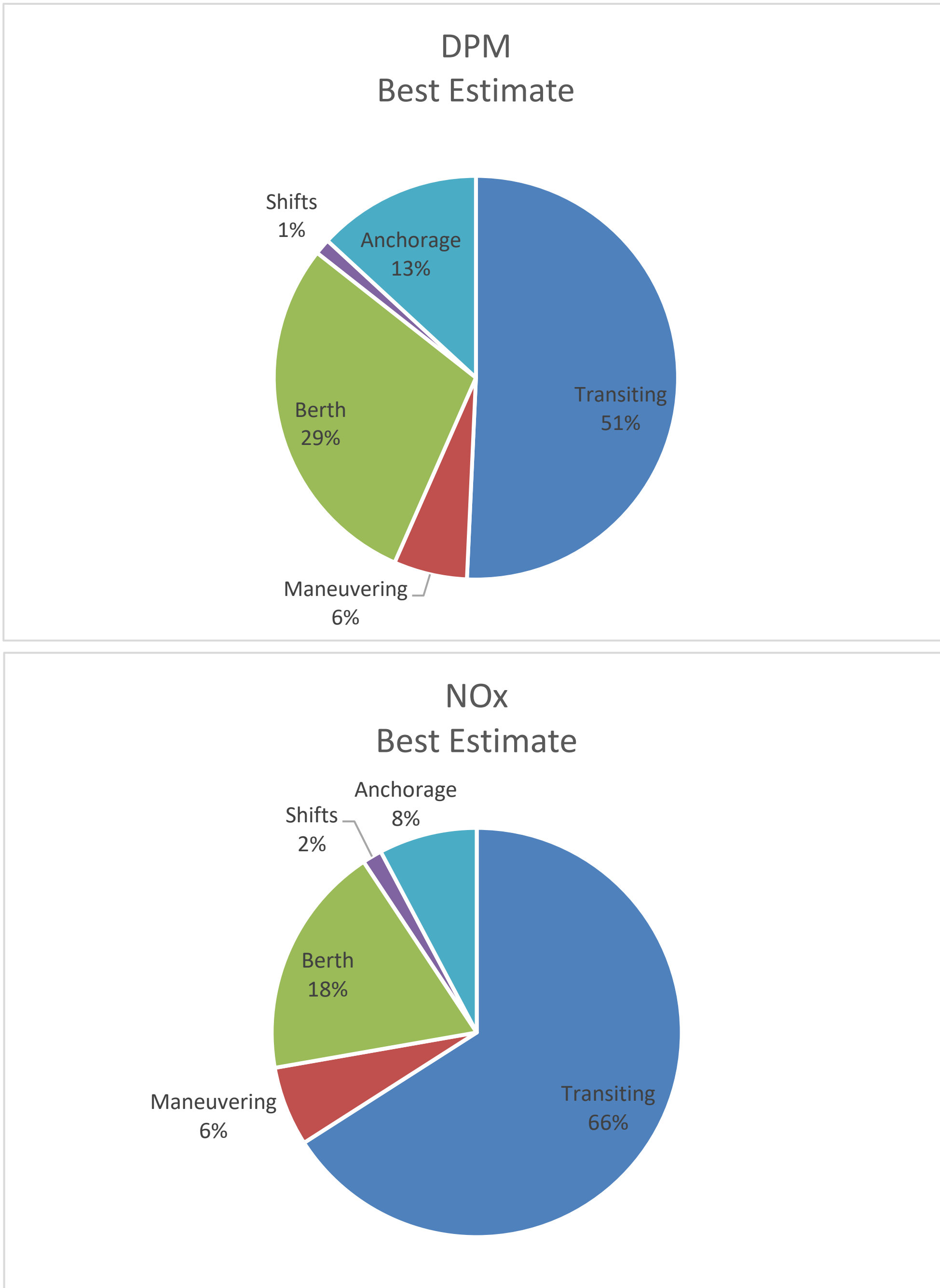


Figure 8-2. DPM and NOx emissions associated with OGV operating modes in 2020: Best Estimate (AIS-based speeds and revised load factors).

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. Comparing emission inventories completed for different years can be confounded by changes in inventory methodology, including changes in assumptions, data sources, emission factors, and other inputs. Overall, an attempt has been made to use consistent methods in developing the 2005, 2012, 2015, 2017, and 2020 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. On the other hand, applying 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 (Best Estimate) methods as well as the older methods (Historical Method) so as to provide a more consistent comparison with prior year results.

Key features of the 2020 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, revised low load adjustment factors as described in Section 2.3.2.1, and at-berth auxiliary engine loads based on shore power records as discussed in Section 2.3.3.3 results in a Best Estimate of emission that cannot be directly compared with prior year estimates which were based on the Historic Method (i.e., assumed average speeds as described in Section 2.2.3.1, historical low load adjustment factors as described in Section 2.3.2.1, and default 18% at-berth auxiliary engine loads). Comparisons with prior year inventories are based on the Historic Method for consistency.

Commercial Harbor Craft: Apart from updates to emission factors, methods used to calculate 2020 harbor craft emission are consistent with those used in prior year inventories. However, bunkering emissions were not included in inventories prior to 2017; comparisons of 2020 and 2017 emissions with previous inventories are therefore presented here with bunkering emissions excluded.

Cargo Handling Equipment: Apart from updates to emission factors, methods used for estimating 2020 CHE emissions are consistent with prior year inventories. However, inventories prior to 2017 did not include emissions at off-dock terminals, thus increasing the 2020 total CHE emissions relative to 2005. Emissions at the off-dock terminals accounted for 0.27 tons per year (17%) of total CHE DPM emissions in 2017 and for 0.08 tons per year (3%) of total CHE DPM emissions in 2020. Information about off-dock CHE activity in 2005 is not available.

On-Road Heavy-Duty Trucks: Methods used to estimate 2020 truck emissions are consistent with those used in prior year inventories. As in prior years, however, the latest CARB on-road emissions model was used to maintain consistency with other on-road inventories. One of the more significant differences in drayage truck emission factors between EMFAC2017 (which was used to prepare the 2017 inventory) and EMFAC2021 (used to prepare the 2020 inventory) was an increase in brake wear particulate matter emission factors in EMFAC2021 which partially contributed to the estimated increase in PM10 emissions between 2017 and 2020. Also, as noted in Section 5.6, a change in the source of data used to estimate the total volume of truck trips in 2020 resulted in an estimate 30% higher than the 2017 trip count despite only a slight increase in TEU throughput. Despite this apparent increase in activity, drayage truck DPM emissions (which are equivalent to exhaust PM10 emissions) still declined 20% in 2020 relative to 2017.

Rail Locomotives: Methods used to estimate 2020 rail locomotive emissions are consistent with those used in prior year inventories. As in 2017, locomotive activity in 2020 included activity at the new OHIT (OGRE) as well as the OIG (BNSF) railyard. 2020 and 2017 emissions 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: As in 2017, the 2020 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. Inventories prior to 2017 did not include other off-road equipment operated at off-dock terminals because activities at off-dock terminals may include transloading activity not related to Port imports and exports. However, in an effort to expand the Port of Oakland Seaport inventory to include activities at all Port maritime tenant facilities, emissions from other off-road equipment at off-dock terminals were included in Port inventories after 2005. 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) although they were included in a separate report (ENVIRON, 2008b): construction activities in 2005 were estimated to have contributed 34 tons of NOx and 1.2 tons of DPM. Given the significant amount of construction in 2005 and to avoid skewing the comparisons with results from more recent inventories, emissions from the 2005 construction activities are not included in the year-to-year comparisons presented 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 2020 and 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 86% below 2005 levels while NOx reductions have reached 40%. As shown in Table 8-4, most (80%) of the DPM reductions between 2005 and 2017 are attributable to reductions in OGV DPM emissions resulting from the introduction of low sulfur fuel and shore power while over two-thirds of the NOx reductions are a result of reductions roughly split evenly between CHE and OGV.

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, 3.5, 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 2020 as compared with previous inventories. NOx emission reductions resulted both from the increased 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. Reductions in both NOx and DPM also resulted from the trend towards fewer vessel calls.

Harbor craft emissions - excluding bunker barge activity - declined between 2005 and 2020 as vessel fleets turned over to incorporate lower emitting engines and the number of vessel assists decreased in line with the reduction in vessel calls. 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 88% and NOx emissions by 74% since 2005. Further emission reductions are expected in upcoming years, especially for DPM, as more equipment with Tier 4 engines and battery electric or hybrid technologies comes into use.

On-road heavy-duty truck NOx and DPM emissions in 2020 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 CARB'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 99% between 2005 and 2020. Similarly, NOx emissions decreased 72% between 2005 and 2012, 5% between 2012 and 2015, and 1% between 2015 and 2020 for an overall 2005 – 2020 NOx emission reduction of 73%.

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 NOx emissions at the Port have decreased by 92% and DPM emissions by 94% 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 Figure 8-5 and for NOx in Figure 8-6. As truck DPM emissions decreased from 6% to 0.5% of the inventory between 2005 and 2020, the relative contribution of OGV and harbor craft emissions increased from 85% in 2005 to 95% in 2020.

Table 8-2a. Comparisons of 2020 with prior year Port inventories: criteria pollutants (tons).

2020 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going Vessels[a]	145.4	217.1	1954.2	32.7	30.1	27.7	69.0
Harbor craft	20.9	101.5	156.0	5.3	5.1	5.3	0.2
CHE	39.7	116.2	195.9	2.8	2.5	2.5	0.4
Truck	4.7	30.0	89.3	1.7	0.7	0.2	0.2
Locomotive	0.6	1.2	6.5	0.1	0.1	0.1	0.0
Other	1.4	40.1	3.0	0.1	0.1	0.0	0.0
Total	**212.6**	**506.1**	**2404.9**	**42.7**	**38.7**	**35.9**	**69.8**
% Reduction from 2005	*14%*	*43%*	*40%*	*84%*	*85%*	*86%*	*95%*
2017 Inventory	**ROG**	**CO**	**NOx**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**SOx**
Ocean-going Vessels[a]	177.1	219.3	2344.6	49.5	45.9	42.2	128.9
Harbor craft	21.0	89.1	161.7	6.5	6.3	6.5	0.1
CHE	18.6	162.2	173.0	1.7	1.6	1.6	0.3
Truck	4.7	23.9	79.9	0.9	0.5	0.3	0.2
Locomotive	0.8	1.2	16.8	0.3	0.2	0.3	0.0
Other	0.8	40.2	10.5	0.3	0.3	0.3	0.0
Total	223.0	535.9	2786.6	59.2	54.9	51.1	129.6
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	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; excludes bunkering.
[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 2020 with prior year Port inventories: GHGs (tons)

2020 Inventory	CO_2	CH_4	N_2O	CO_2e[a]
Ocean-going vessels[b]	111,418	1.39	5.31	115,437[c]
Harbor craft	19,583	1.88	0.48	19,772
CHE	44,353	1.80	0.36	44,506
Truck	24,621	0.22	3.87	25,782
Locomotive	483	0.03	0.01	488
Other Offroad Equipment	635	0.03	0.01	637
Total	**201,094**	**5.35**	**10.05**	**206,625**
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	17,546	2.1	0.5	17,739
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	**196,111**	**17.3**	**8.6**	**209,675**
2015 Inventory	**CO_2**	**CH_4**	**N_2O**	**CO_2e[a]**
Ocean-going vessels	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	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	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]Emissions based on same methods as in prior year inventories; excludes bunkering.
[c]Shore power CO_2e emissions of 2,401 tons (for 2020) and 9,905 tons (for 2017) 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. 2020 percentage reductions from 2005.[a]

Source	DPM	NOx	CO_2e[b]
Ocean-going Vessels	87%	21%	20%
Harbor Craft	60%	55%	1%
Cargo Handling Equipment	88%	74%	-19%
Trucks	99%	73%	-19%
Locomotives	94%	92%	60%
Total	**86%**	**40%**	**8%**

[a]Negative values indicate emission increases; extraordinary cruise ship lay berthing in 2020 not included.
[b]2020 CO_2e emissions include shore power electricity generation and transmission.

Table 8-4. 2020 percentage contributions to total tons of emissions reduced since 2005.[a]

Source	DPM	NOx	CO_2e[b]
Ocean-going Vessels	80%	33%	160%
Harbor Craft	4%	12%	2%
Cargo Handling Equipment[c]	8%	35%	-43%
Trucks	7%	15%	-25%
Locomotives	1%	4%	4%

[a]Negative values result from emission increases.
[b]2020 CO_2e emissions include shore power electricity generation and transmission.
[c]Includes 2020 emissions from Other Offroad Equipment category.

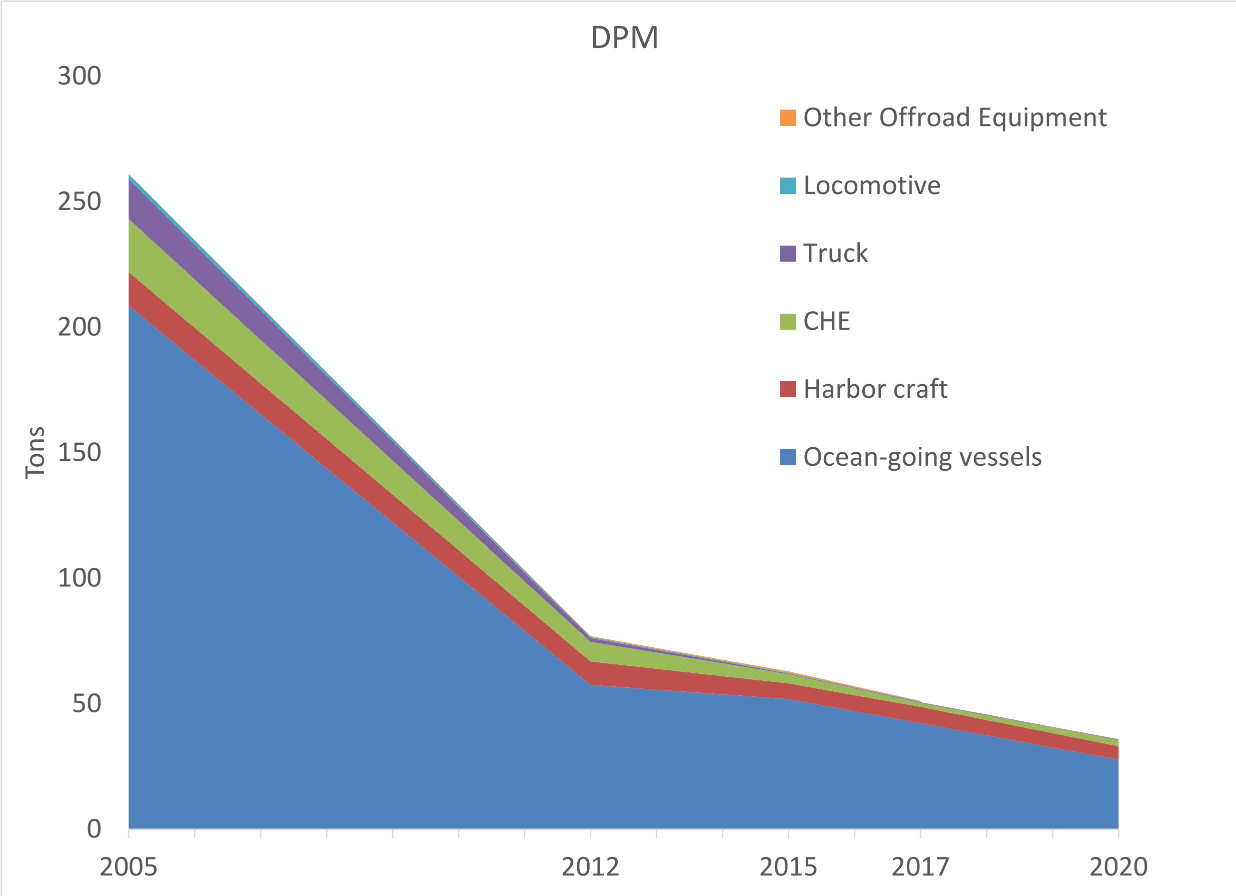


Figure 8-3. Seaport diesel particulate matter (DPM) emissions (tons).

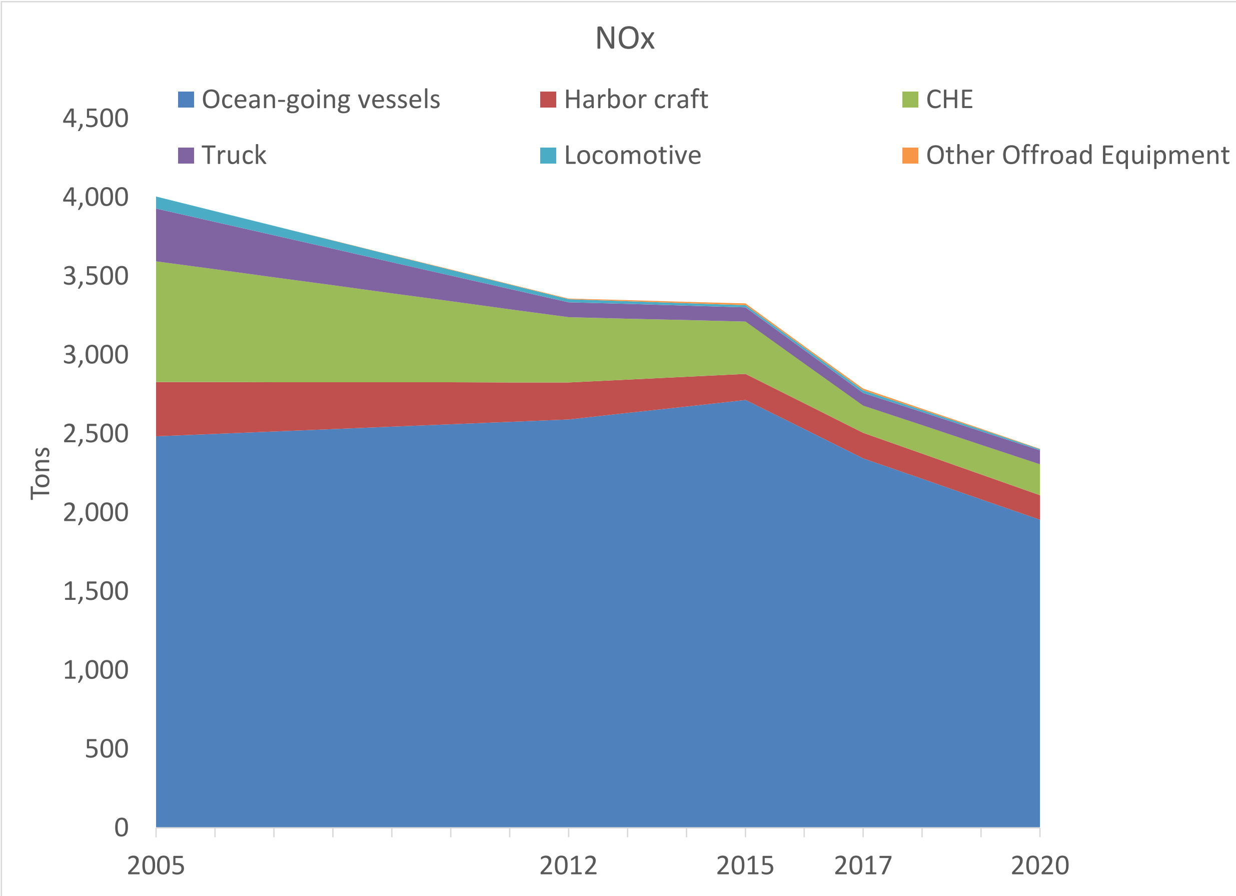


Figure 8-4. Seaport NOx emissions (tons).

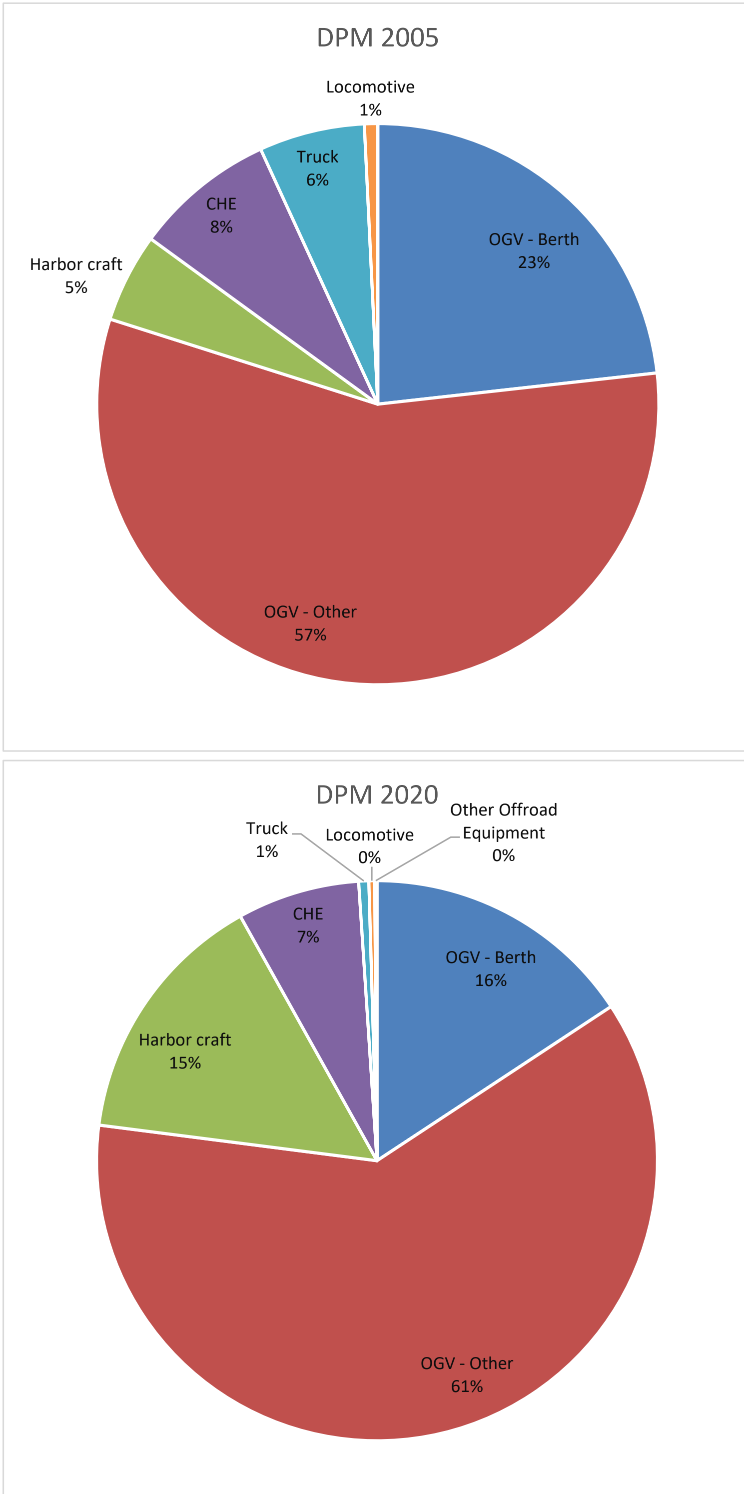
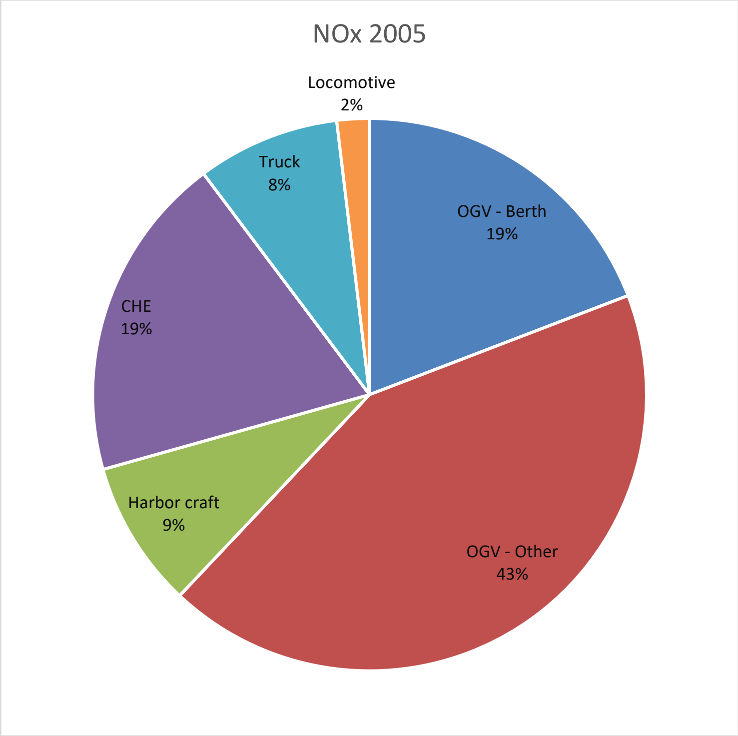


Figure 8-5. Contributions by source category to Seaport DPM emissions: 2005 (top) and 2020 (bottom).



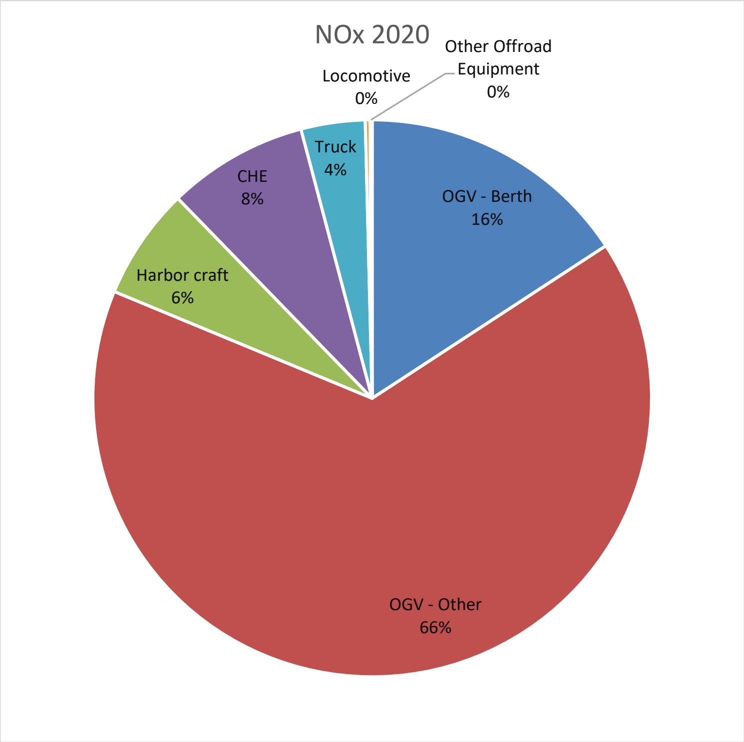


Figure 8-6. Contributions by source category to Seaport NOx emissions: 2005 (top) and 2020 (bottom).

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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

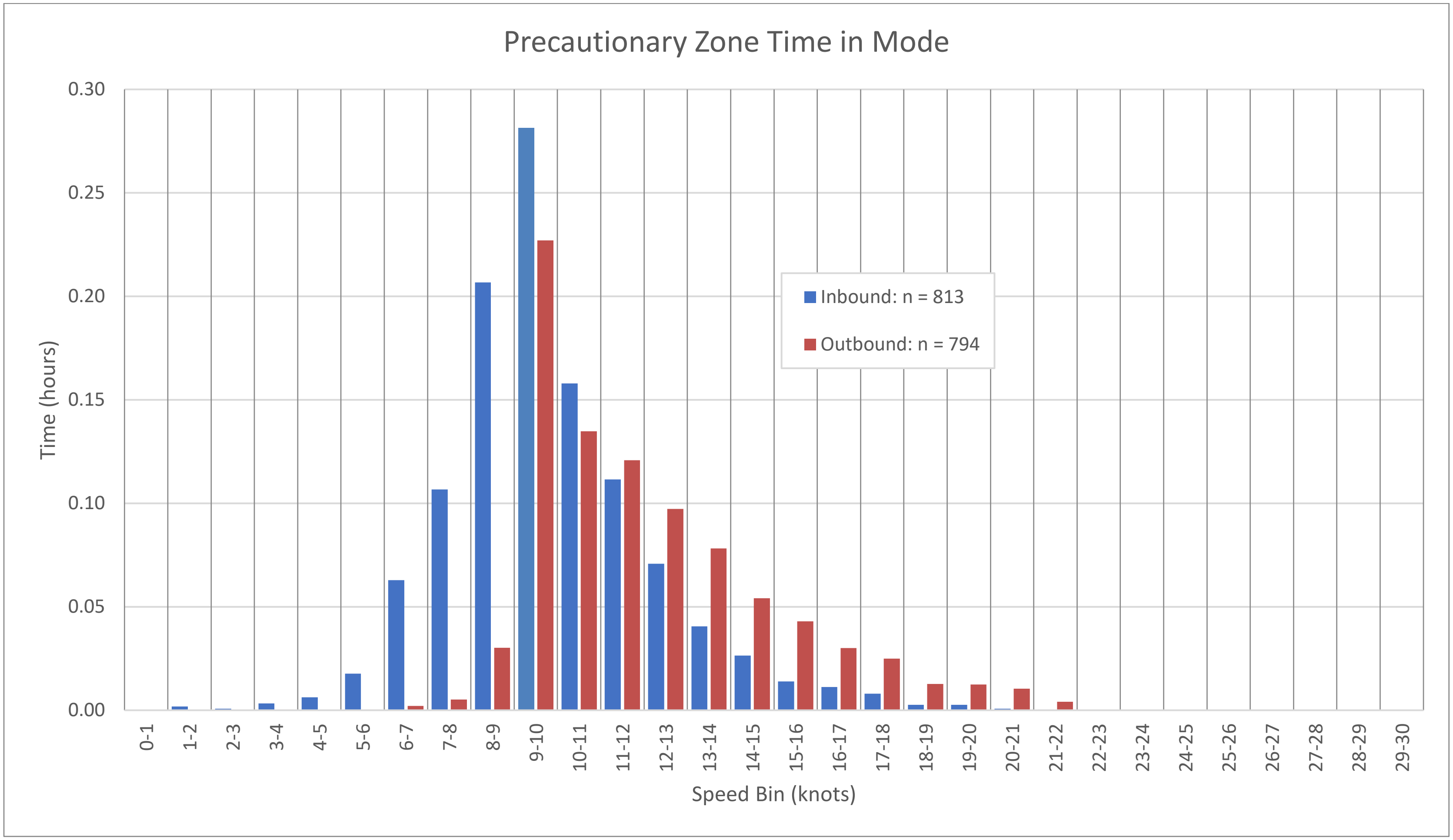

Figure A-1. Precautionary zone speed profile

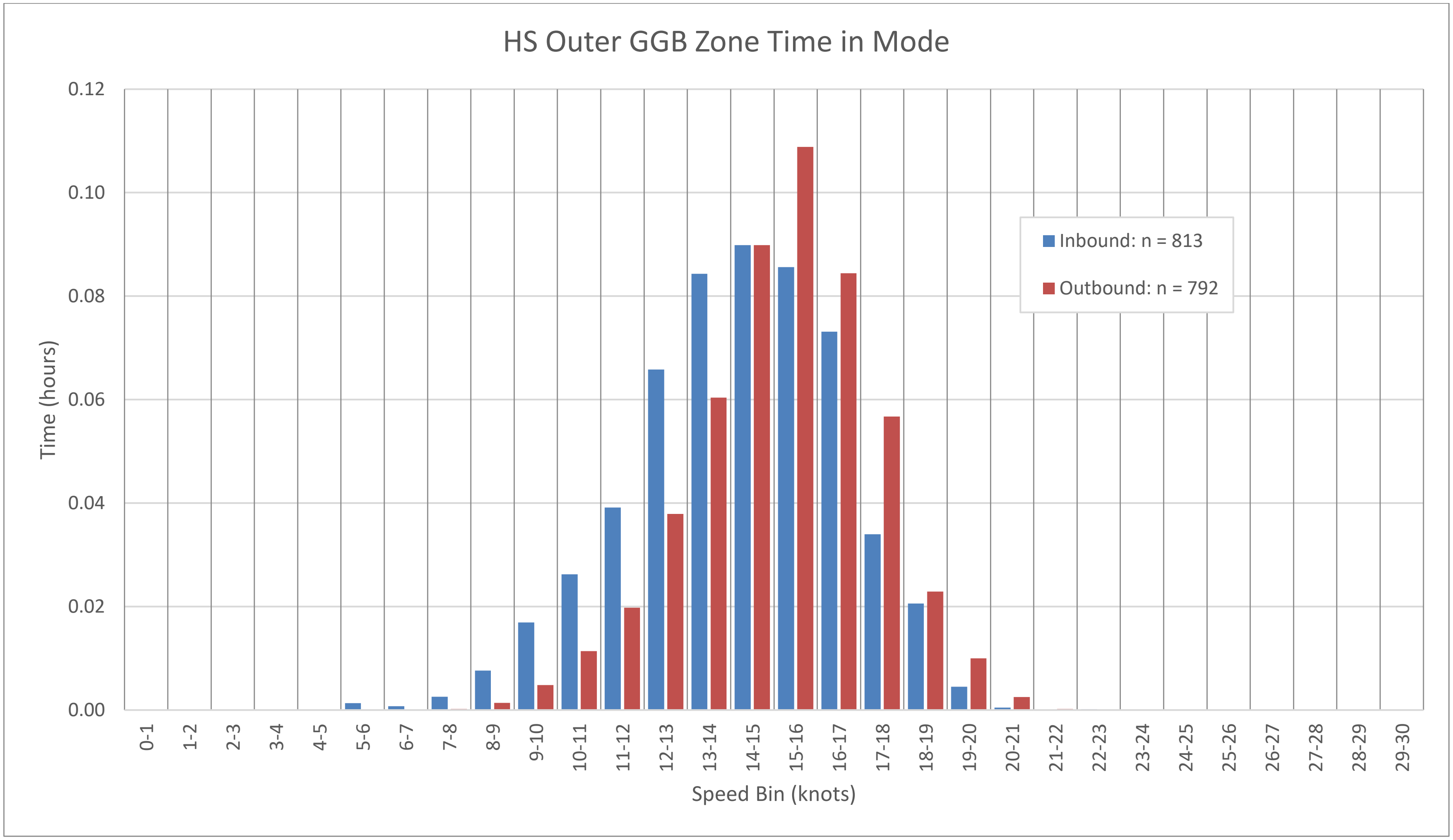

Figure A-2. HS Outer to GGB zone speed profile

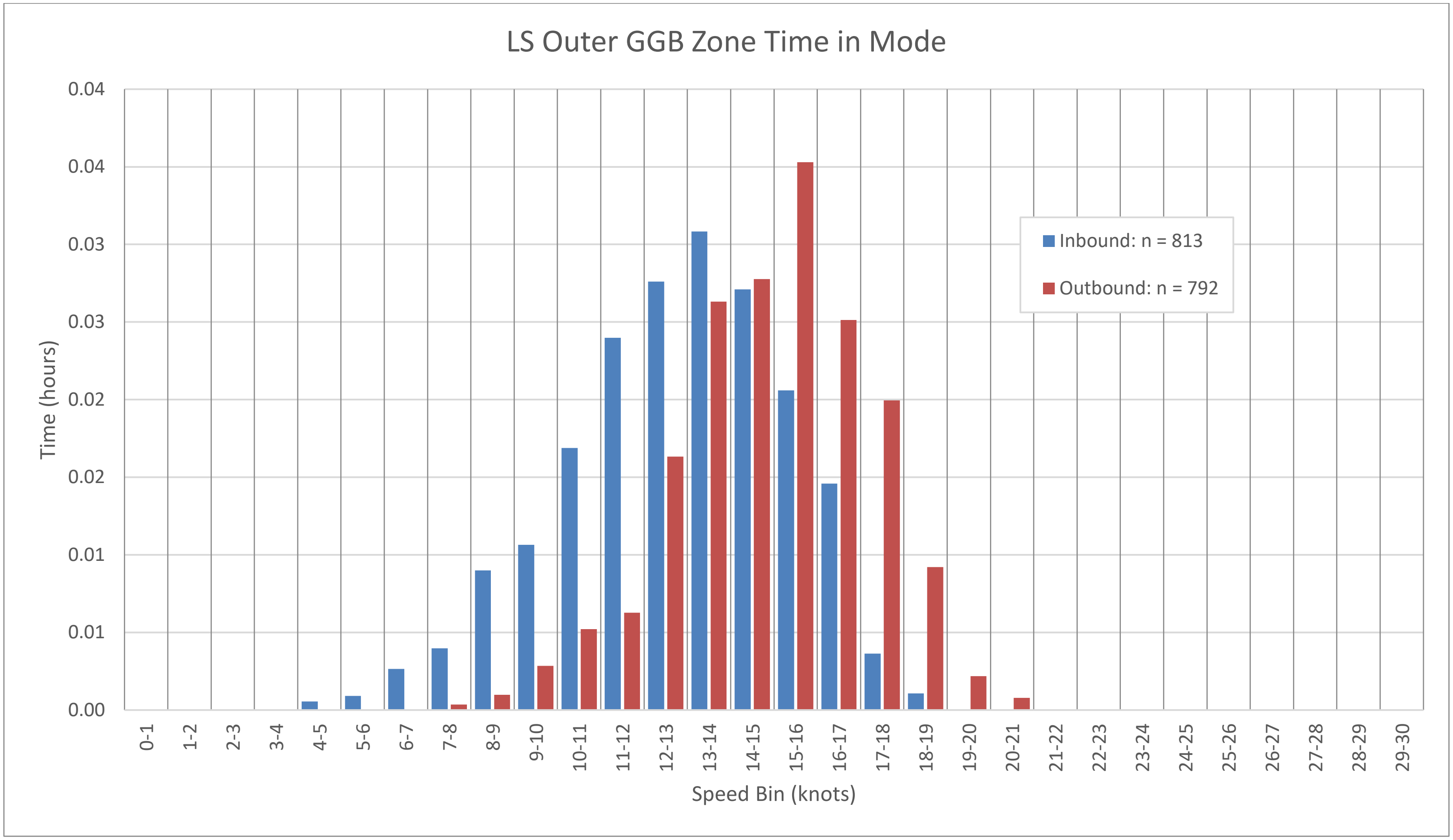

Figure A-3. LS Outer to GGB zone speed profile

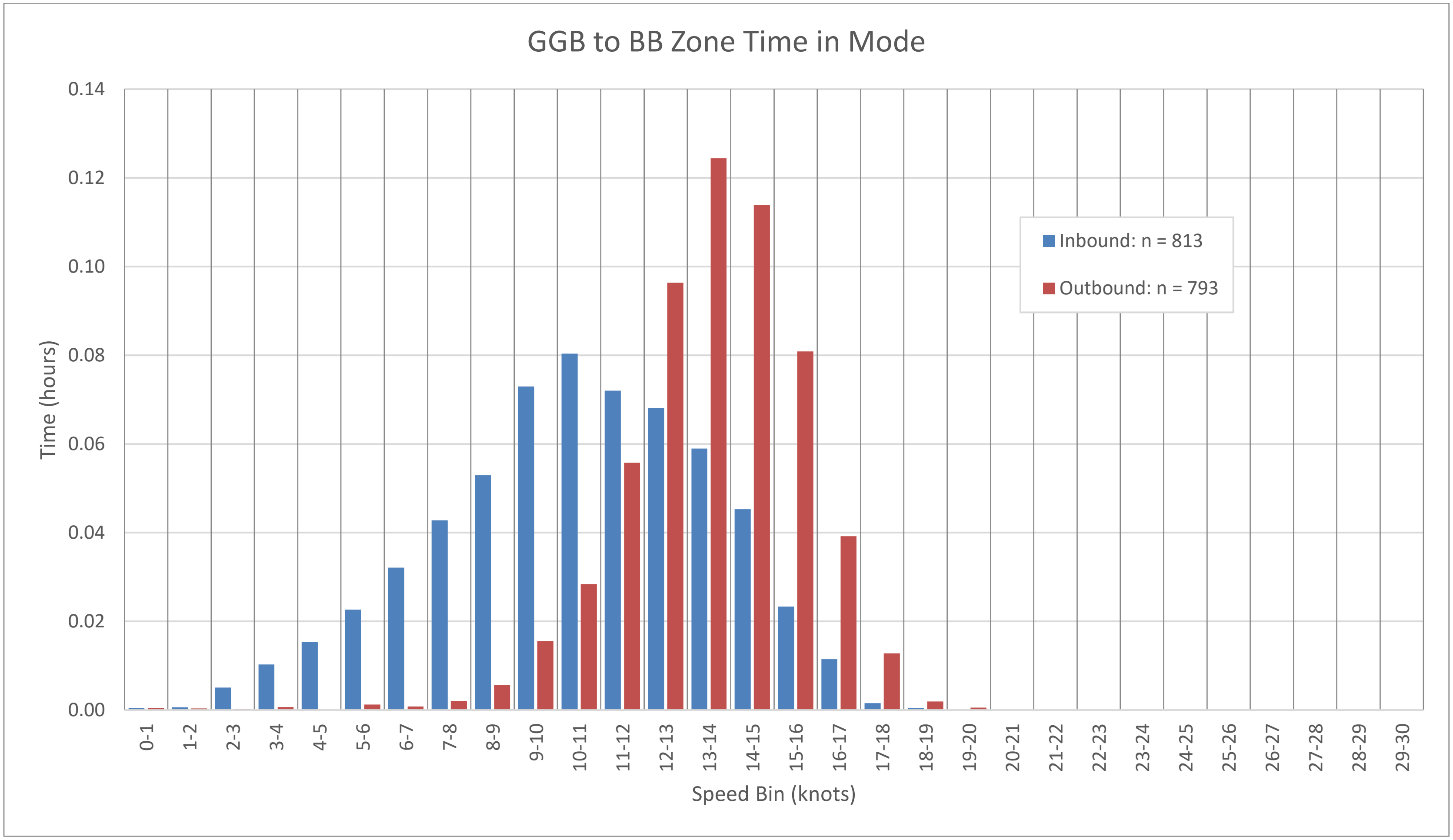

Figure A-4. GGB to BB zone speed profile

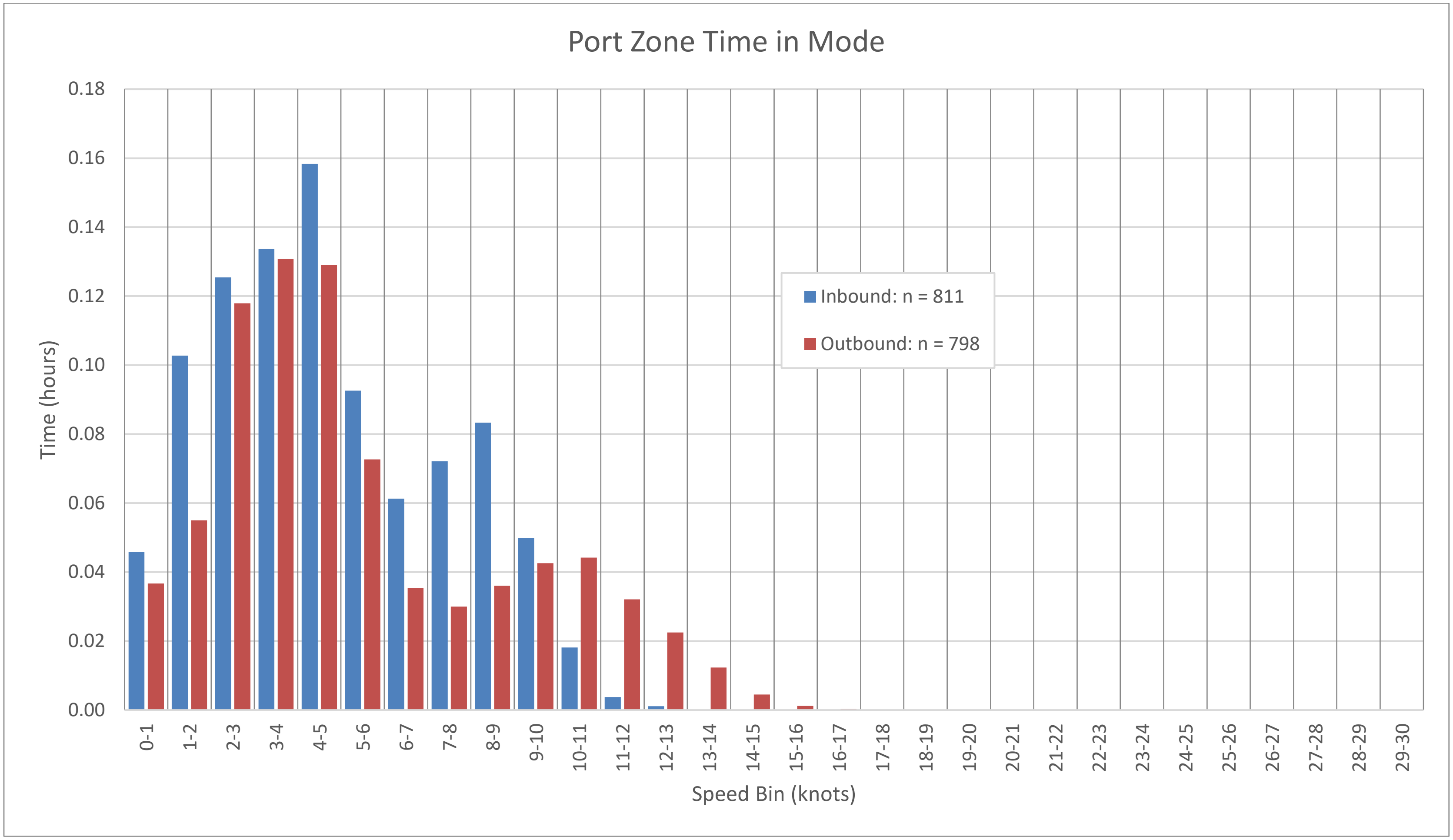

Figure A-5. Port zone speed profile

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