2025 California Ocean-Going Vessel Emissions Inventory

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CALIFORNIA
AIR RESOURCES BOARD

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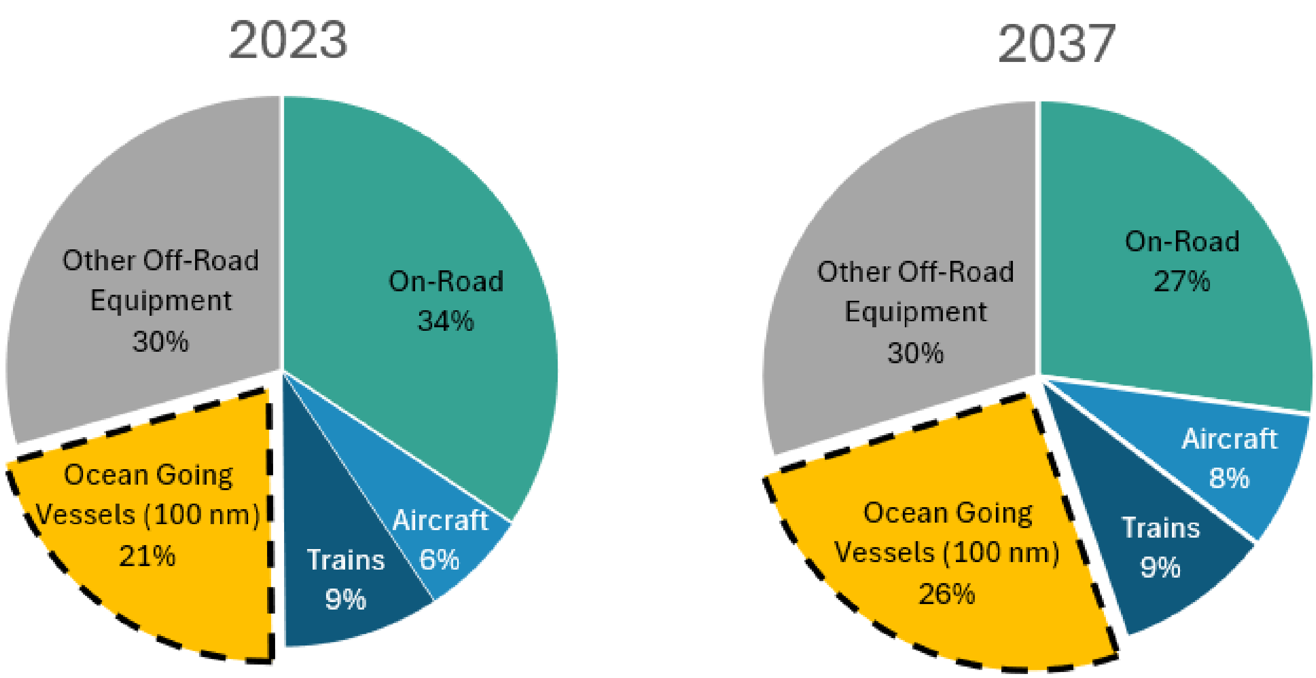
1 Executive Summary

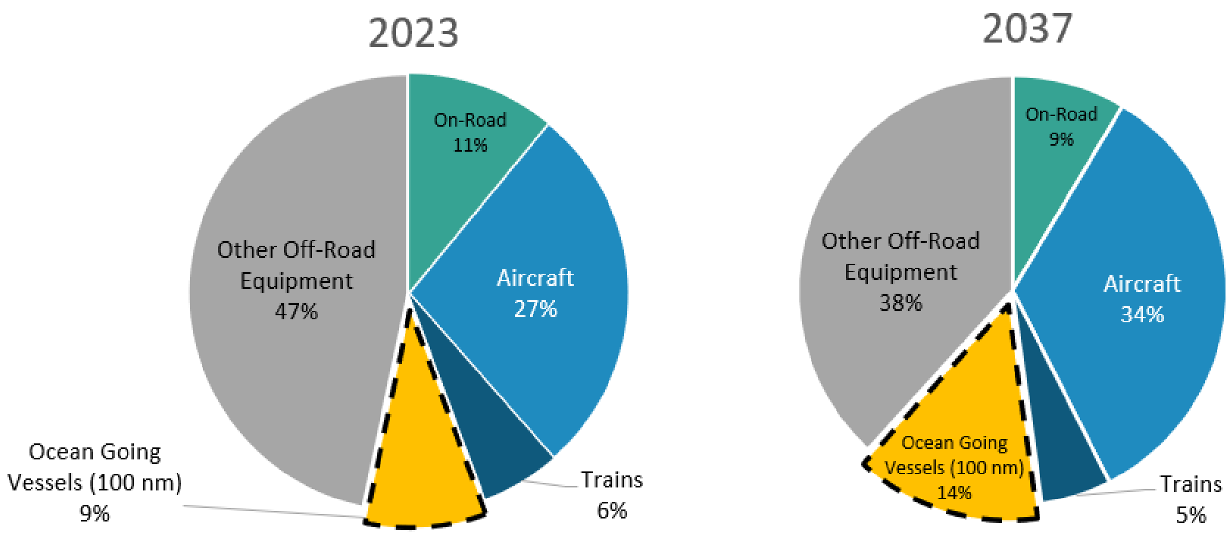
This inventory provides an update to the emissions from ocean-going vessels (OGV) that visit California's ports and waters. OGVs included in this inventory are defined as commercial vessels greater than 400 feet in length, with a carrying capacity of 10,000 gross tons or more and are propelled by a diesel marine compression ignition engine with a displacement of greater than or equal to 30 liters per cylinder. These vessels are an important part of the California and US economy but are also a significant source of pollution in areas near ports and marine terminal complexes (MTC). Specifically, OGV diesel engines and boilers continue to be one of the largest contributors of criteria pollutants in California, including oxides of nitrogen (NOx) and particulate matter (PM). The contribution from OGVs is expected to increase over time, as shown in Figure 1.

Figure 1: Statewide mobile source NOx emissions contributions by sector in 2023 and 2037[1].



[1] CEPAM 2019 v1.02 for non-OGV mobile sources, *https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php*

Figure 2: Statewide mobile source PM emissions contributions by sector in 2023 and 2037[1].



Major updates to the emission inventory methodology and data sources include:

- Basing total visits, activity, and vessel location on a five-year averaged base year from 2019 to 2023 instead of the 2020 single-year data in the previous inventory. Hours spent per activity mode was averaged for each vessel type and size across five years per county-air basin-district (CoAbDis) boundary. The five-year average is based on Automatic Information System (AIS) data, a system that tracks vessel movement via onboard transponders to terrestrial and satellite receivers. Additional parameters, such as time on shore power and engine loads, are based on the 2023 data, shown in greater detail in Table 1 in the following section.
- Updated activity-mode designation criteria based on latest U.S. Environmental Protection Agency (EPA) recommendations, such as when vessels are maneuvering or transiting.
- Updated growth forecast assumptions using the 2022 Freight Analysis Framework (FAF) modeling.
- Updated vessel characteristics using data reported to CARB enforcement, including updated vessel tiers and steam-powered pump capabilities.
- Updated emissions factors for main engines, auxiliary engines, boilers, and new low load adjustments for Tier III main engines.

Overall, these combined changes have slightly lowered statewide emissions compared to the previous model, the 2021 OGV Model, as shown in Figure 2, while increasing emissions previously forecasted in the South Coast region as shown in Figure 3.

Figure 3. Statewide NOx emissions from OGVs out to 100 nm using five-year average base year surrogate.

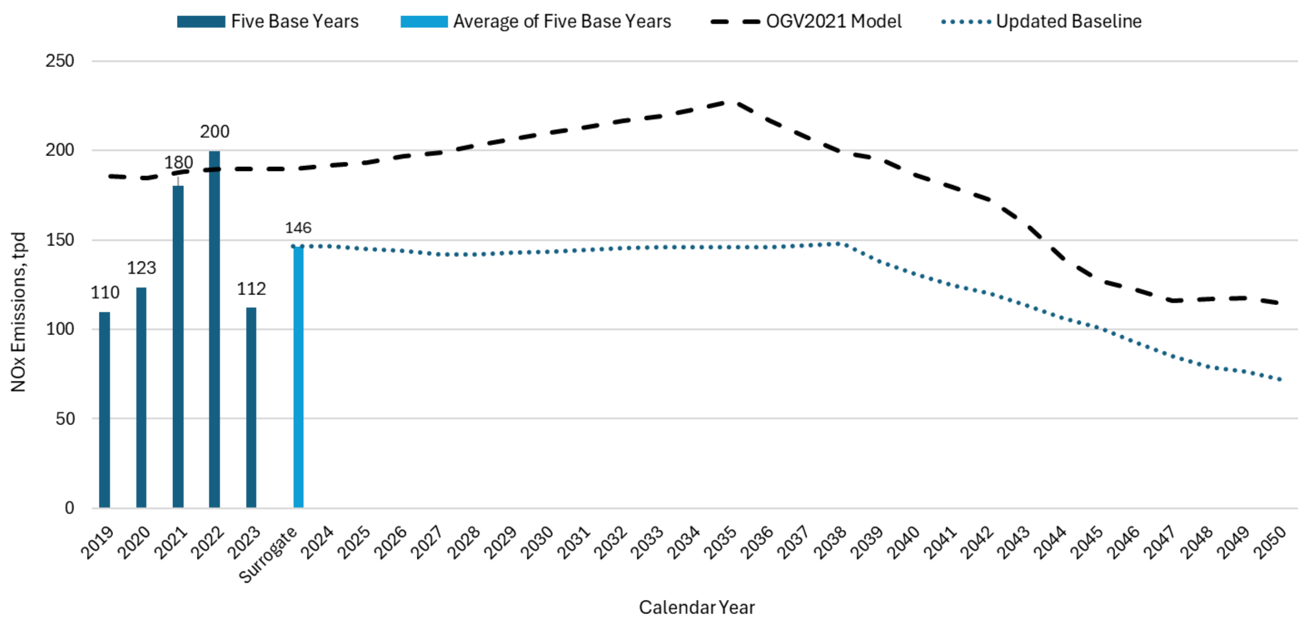


Figure 4. Statewide PM emissions from OGVs out to 100 nm using five-year average base year surrogate.

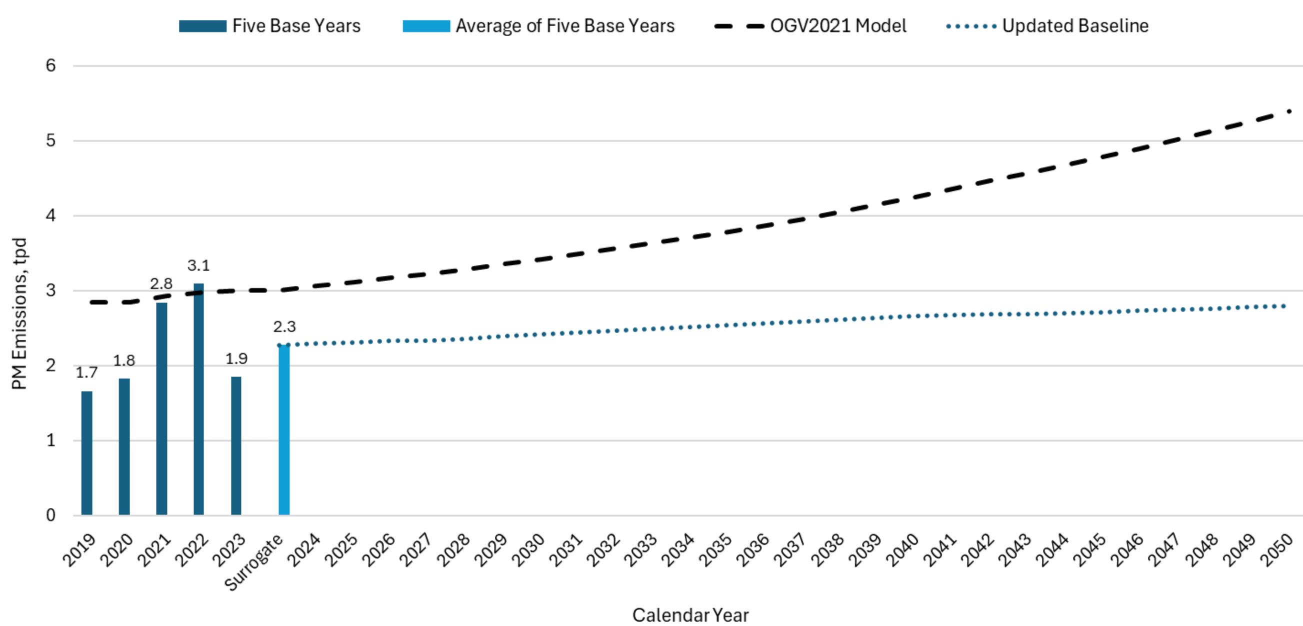


Figure 5. South Coast NOx emissions from OGVs out to 100 nm using five-year averaged base year surrogate.

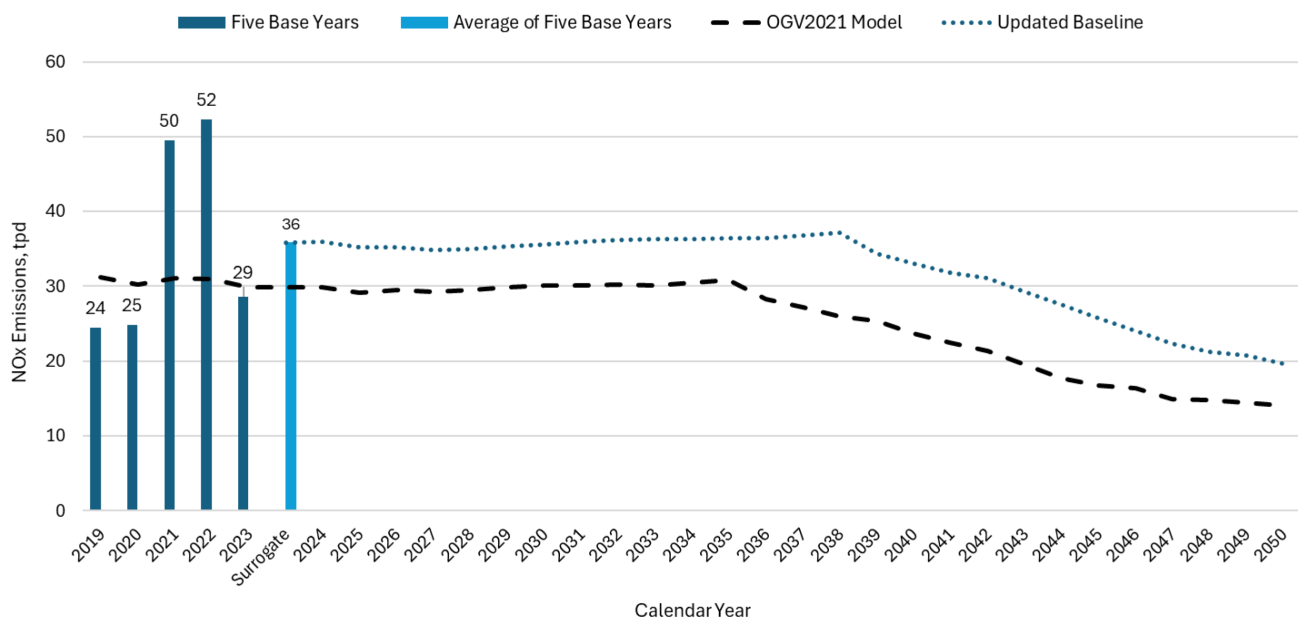
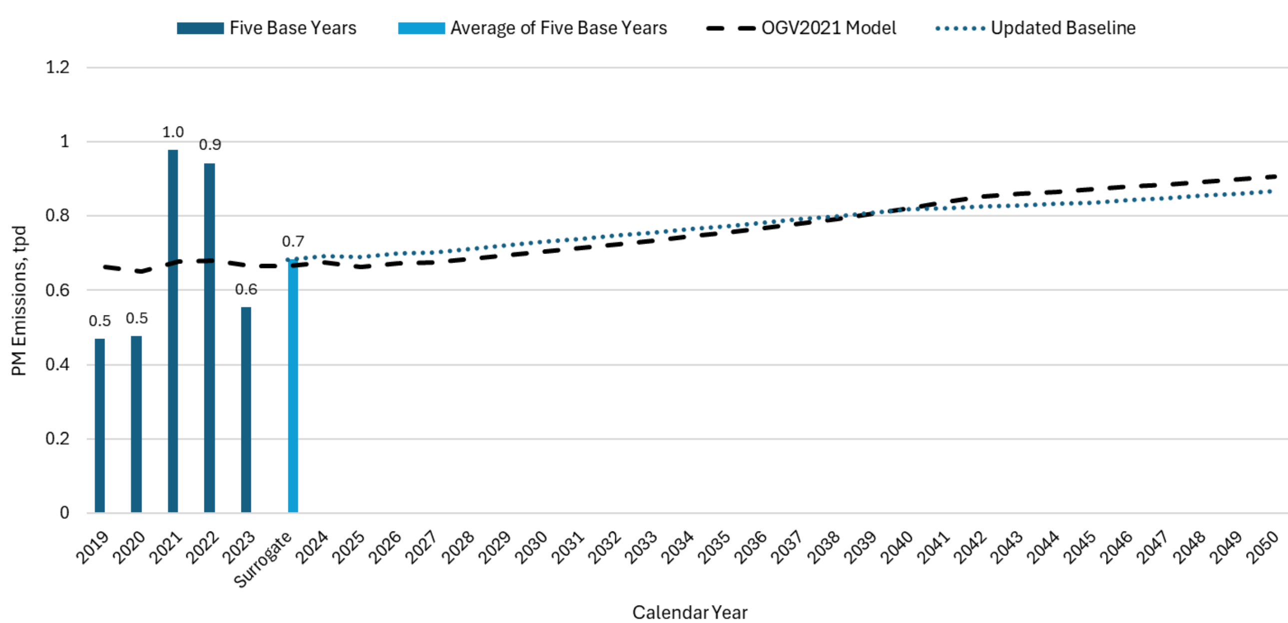


Figure 6. South Coast PM emissions from OGVs out to 100 nm using five-year averaged base year surrogate.



2 Data Sources and Methodology

2.1 Overview of Data Sources

The statewide OGV inventory leverages AIS-transmitted data and these other updated sources for a bottom-up approach to building the emission inventory, as further detailed in Table 1.

Table 1. Data flow and sources used in the base year update to the statewide ocean-going vessel model (OGV2025).

Input Type	Data Source	Description
Activity and Location Data	2019-2023 Automatic Identification System (AIS)[2] records from National Oceanic and Atmospheric Administration (NOAA)	Provides base year vessel movement
Vessel Data	2023 IHS Vessel Registry	Provides vessel and installed engine characteristics
Engine Operation Data	2023 Vessel Boarding Program (VBP) Average Engine Default Loads[3]	Provides engine characteristics specific to mode of operation.
Compliance Data	2023 CARB At Berth Compliance Reporting	Provides total time at berth and time on shore power, vessel tier, and whether tanker ships are equipped with steam-powered pumps.
Forecasting and Growth Data	Freight Analysis Framework (FAF5.1)[4], Historical port calls at PoLA[3] and PoLB[5], 2005 – 2023 2017 Mercator Report (Tier III Delay)[6] Historical monthly port TEUs, 2012 – 2023	Provides growth rates, port capacity, vessel tier forecast, and future vessel capacity distributions.
Emissions Factors	2022 U.S. EPA Emissions Factors[7], 2011 OGV Inventory Factors (ROG, TOG, NH3)	Provides emissions factors in grams per kilo-watt hour (g/kWh)
Model Output	2025 OGV Inventory Output	Output of emissions and energy use statewide and regionally for calendar years 2023 – 2050.

* Twenty-Foot Equivalent Unit (TEU), Reactive Organic Gases (ROG), Total Organic Gases (TOG), Ammonia (NH3)

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[2] 2023 AIS records, *https://coast.noaa.gov/htdata/CMSP/AISDataHandler/2023/index.html*
[3] Port of Los Angeles 2023 Emissions Inventory, *https://www.portoflosangeles.org/environment/air-quality/air-emissions-inventory*
[4] Freight Analysis Framework, *https://ops.fhwa.dot.gov/freight/freight_analysis/faf/*
[5] Port of Long Beach 2023 Emissions Inventory, *https://polb.com/environment/air/#emissions-inventory*
[6] Starcrest 2017 Tier Forecast Analysis, *http://www.cleanairactionplan.org/documents/vessel-forecast-draft.pdf/*
[7] 2022 US EPA Port Inventory Guidance, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf*

2.2 Geographic Domain

Geographic domain refers to the area of activities included within the emissions inventory. The statewide inventory includes all OGV activity within 100 nautical miles from a California shoreline, including vessels that travel through state waters but may not stop directly at a California port or marine terminal, otherwise known as transient vessels or innocent passage. Figure 4 shows the geographic domain of the inventory. Also notable are the near-shore areas that include 0 to 3 nautical miles (nm) from the shore, the 3 to 24 nm area, and the greater 24 to 100 nm boundary. The 3 to 24 nm boundary is extended by the Channel Islands and the San Clemente and San Nicholas Islands in Southern California, and islands in the Bay Area extend the boundary in Northern California.

Figure 7. Extent of marine areas covered in statewide inventory by nautical mile (nm) distance from California shoreline.

2.3 Activity Data: AIS

2.3.1 About AIS

Automatic Identification System (AIS) is an onboard navigation safety device, required on all OGVs per the International Convention for the Safety of Life at Sea[8], for improved navigation safety and collision avoidance. Every few seconds, reports are generated from AIS systems to provide vessel location and movement information within US waterways. Marine Cadastre is a large data archive of these historical records made publicly available through collaboration of the United States Coast Guard (USCG), National Oceanic and Atmosphere Administration (NOAA), and the Bureau of Ocean and Energy Management (BOEM).

CARB staff used AIS records from Marine Cadastre for calendar years 2019 through 2023, for the geographic domain shown in the previous chapter. These records provide the vessel identification numbers, otherwise known as the Maritime Mobile Service Identity (MMSI) or International Maritime Organization (IMO) number. Generally, AIS provides records that display location of each vessel every 60 seconds, and while highly location-specific, it does not reliably provide information on detailed vessel types, capacity, age, or other information necessary for emissions inventory.

The vessel instantaneous speed from AIS records, speed over ground (SOG), was used to estimate main engine loads during transit (covered further in Section 2.6.1) as well as assign operating mode when combined with location (latitude/longitude) as shown in Table 2. Duplicate date-timestamps by vessel identifiers were removed from the analysis, as well as records with incomplete date-timestamps in AIS records. CARB staff reviewed a variety of the records that were removed and found they were generally duplicated AIS signals or anomalous records, and therefore do not indicate any missing OGV activity from the emission inventory.

2.3.2 Activity Mode Designations

CARB assigned OGVs identified in AIS records an operation mode based on their location and speed for each time stamp, as detailed in Table 2. Total duration in hours for each vessel in each operating mode was calculated based on the timestamps provided by AIS minute-by minute records. Total daily hours for all vessels were adjusted not to exceed 24 hours to correct any errors. Subsequently, if a vessel only had one AIS record for that day, that record would be considered anomalous and would not be included in total activity hours for that vessel. This same approach was applied spatially at the county-air basin-district (CoAbDis) level, where a vessel would need at least two AIS records within the CoAbDis domain to have duration of activity calculated for that day.

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[8] International Convention for the Safety of Life at Sea, *https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx*

Table 2. OGV operation mode definitions applied in inventory.

Operating Mode	Description	Designation Method
Berth Hoteling (or At Berth)	Operations while moored or berthed to a dock	Within a 4 km grid of port, not in anchorage zone, and speed of 0 knots.
Anchorage Hoteling	Operations when the vessel drops anchor (generally within a few miles of a port, but not at a port or dock)	Within anchorage zones with speeds less than 1 knot.
Maneuvering	Slow speed vessel operations while in or near port areas	Within port areas or anchorage areas at speeds less than 1 knot.
Transit	Vessel operations at sea, between destinations	All speeds greater than 1 knot within the 3 nm boundary, or all operations outside anchorage areas past the port boundary.

Propulsion (main) engines are assumed to be off during the berth hoteling and anchorage hoteling operating modes. Appendix C identifies the locations of port and anchorage areas.

CARB staff validated berth hoteling time in the AIS data with 2023 CARB At Berth Compliance reporting for vessels subject to the regulation, to ensure the AIS data accurately captured times at berth and was comprehensive. Berth hoteling emissions occur when a vessel is at berth and is not using shore power, and reflect auxiliary engines running to power the vessel. When a vessel is on shore power, no auxiliary engine operations or emissions are modeled.

2.4 Vessel Characteristics Data: IHS Global Registry

Information Handling Services (IHS) maintains a global registry of technical specifications for marine vessels, including engine specifications and other vessel build parameters (such as vessel age, engine model year, capacity, length, and many others). Some of these specifications are necessary in the emission inventory but are not included in the AIS data. South Coast Air Quality Management District (AQMD) staff provided the 2023 IHS registry data, with the data provider's permission.

One limitation of the registry data source is the significant amount of missing data, impacting approximately 30 percent of ships, requiring the use of interpolation for maximum speeds or average default values for installed engine power, as detailed in Section 2.6.1. For example, if a container vessel between 5,000 and 6,000 TEU capacity was listed in the IHS data, but did not include maximum vessel speed, then the average maximum vessel speed for vessels in this category and size bin was used.

As an additional validation step, AIS records associated with OGVs via IHS registry were also cross referenced with discussions and comparisons to major California ports (Port of Oakland,

and Ports of Los Angeles and Long Beach) to ensure the AIS data was not missing any records and captured vessel visits observed by the ports.

2.4.1 Vessel Type and Size Bin Designations

OGVs can be broadly categorized by vessel type and size bins to understand operation characteristics, and to fill in data gaps using similar vessel characteristics. The vessel designations used in the 2024 statewide OGV inventory are defined in Table 3. Appendix B details how IHS reported vessel types were classified in CARB's inventory.

Table 3. OGV classifications used in inventory.

Vessel Type and Size Bin Designation	Capacity and Description
Auto Carrier*	Vessels designed for exclusive transport of automobiles and trucks.
Bulk Cargo	Vessels capable of transporting loose and dry bulk items such as mineral ore, fertilizer, wood chips, or grains.
Container	TEU capacity vessels transporting a wide variety of cargo in standard-sized containers. Each container vessel is assigned a size bin corresponding to the number of TEUs it can carry, with the bin name signifying the lower limit divided by one thousand. For example, 2,000 to 2,999 TEU capacity are assigned size bin 2.
Cruise	Vessels designed for passenger transport and pleasure voyages. These vessels are split into size bins based on the number of passengers they carry. Each size bin is based on how many thousand passengers the vessel is designed to carry.
General Cargo	Vessels designed to transport non-containerized cargo such as steel, palletized goods, and heavy machinery.
Reefer	Refrigerated cargo vessels designed to transport perishable commodities in either bulk holds or refrigerated containers.
RoRo*	Vessels equipped with a "roll on-roll off" (RoRo) facility enabling transport of wheeled cargo, in addition to other cargo.
Tanker, Aframax	Large capacity tankers not published on the Average Freight Rate assessment (AFRA) scale, these 80,001 – 120,000 DWT vessels are designed for bulk liquid transfer.
Tanker, Handysize	Smaller capacity vessels of 0 – 60,000 DWT and designed for bulk liquid transfer.
Tanker, Panamax	60,001 – 80,000 DWT vessels designed for bulk liquid transfer through the Panama Canal.

Vessel Type and Size Bin Designation	Capacity and Description
Tanker, Suezmax	120,001 – 200,000 DWT vessels designed for bulk liquid transfer through the Suez Canal.
Tanker, ULCC	Ultra-Large Crude Carriers are 315,001 – 520,000 DWT vessels designed for bulk liquid transfer.
Tanker, VLCC	Very Large Crude Carriers are 200,001 – 315,000 DWT vessels designed for bulk liquid transfer.
Vessels (Other)	Other miscellaneous OGVs such as hospital ships, drilling ships, and cable layers.

* Auto Carriers and RoRo vessels are referred to as separate categories for the purpose of emissions inventory but are considered the same category under "RoRo" for regulatory purposes (as seen in the Control Measures at Berth regulatory text and main Staff Report)[9].

** Twenty-Foot Equivalent Unit (TEU), Deadweight Tonnage (DWT)

2.4.2 Diesel Engine Speed Designations

Engine speed, measured in revolutions per minute (rpm), is typically used to determine engine type, such as slow- medium- or high-speed diesel engines. These designations are important because different engine types have different emission factors. For main engines, all vessels missing necessary fields to determine engine type are assigned as Slow Speed Diesel (SSD) by default, and auxiliary engines missing necessary fields are assigned as Medium-Speed Diesel (MSD) by default as recommended by U.S. EPA[10]. The speed designations used to determine engine type in this statewide inventory are as detailed in Table 4.

Table 4. OGV engine speed type designations.

Engine Type	Engine Speed Range	Engine Stroke Type
Slow-Speed Diesel, SSD	< 500 rpm	2
Medium-Speed Diesel, MSD	500 – 1400 rpm	4
High-Speed Diesel, HSD	> 1400 rpm	4

[9] 2019 Update to Inventory for Ocean-Going Vessels at Berth, *https://ww3.arb.ca.gov/msei/offroad/pubs/2019_ogv_inventory_writeup_ver_oct_18_2019.pdf*
[10] 2022 US EPA Port Inventory Guidance, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf*

2.4.3 Engine Tier Designations

OGV engine tiers refer to the emission standard that the engine was manufactured to meet. The tier standards are based on the keel laid date for the vessel (which can be different than the build year). The keel laid date is generally part of the IHS vessel characteristics data. In the inventory, 2023 data reported to enforcement, as required by the At Berth Regulation[11], was used to determine engine tiers wherever that data was available. Where reporting data were not available, the engine tier is assigned based on IHS reported year the keel of the vessel was laid, as detailed in Table 5 below.

Table 5. Engine tier designations used in OGV inventory.

Engine Tier	Keel Laid Year
Tier 0*	1999 and prior years
Tier I	2000 – 2010
Tier II	2011 – 2015
Tier III	2016 and later years

*IMO does not recognize an official Tier 0 standard; however, the OGV inventory uses this terminology to classify any engine prior to Tier I.

2.5 Emissions Factors

The factors assigned to estimate emissions can vary depending on:

- Engine: main (propulsion), auxiliary, or boiler
- Fuel type: CARB's OGV inventory consists of 90% distillate marine gas oil (MGO), 9% marine diesel oil (MDO), and alternative fuels with assigned factors for liquified natural gas (LNG) make up less than 1% of the inventory. No vessels are operating on traditional marine heavy fuel oil (HFO) in California regulated waters out to 24 nm from shore due to CARB's OGV Fuel Regulation.
- Engine tier based on keel-laid year
- Engine speed type: SSD, MSD, HSD

A small fraction of vessels, under 5 percent, have indicated they may perform fuel switching in the 24 to 100 nm range, and use heavy fuel oil (HFO), switching outside the 24 nm boundary. This inventory does not reflect this practice due to lack of information on exactly how much HFO may be used, and the small fraction of vessels engaging in this practice.

Emissions factors presented below reflect the latest information available from U.S. EPA[12]. The units for all emissions factors presented are grams per kWh. Per U.S. EPA guidance, all vessels with unknown fuel types were assumed to be using MGO to comply with fuel sulfur

[11] At Berth Regulation, *https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation*

[12] 2020 US EPA Port Inventory Guidance, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf*

regulations. Additionally, based on 2023 fuel oil data presented by IMO[13], there is limited global distribution of residual fuels at 0.1% sulfur content compared to distillate fuels with 0.1% sulfur content.

2.5.1 NOx Emissions Factors

Oxides of Nitrogen (NOx) have varying rates of emissions depending on engine, fuel type, engine type and engine tier, as shown in the tables below. Note that steam turbine (ST), gas turbine (GT), boilers, and LNG engines do not have different Tiers for emission rates.

Table 6. OGV NOx emissions rates in g/kW-hr.

Engine	Fuel	Type	No Tier/ Tier 0	Tier I	Tier II	Tier III
Main	Diesel (MGO/MDO)	SSD	17	16	14.4	3.4
Main	Diesel (MGO/MDO)	MSD	13.2	12.2	10.5	2.6
Auxiliary	Diesel (MGO/MDO)	MSD	13.8	12.2	10.5	2.6
Auxiliary	Diesel (MGO/MDO)	HSD	10.9	9.8	7.7	2
Main	Diesel (MGO/MDO)	ST	2	-	-	-
Main	Diesel (MGO/MDO)	GT	5.7	-	-	-
Main	LNG	LNG	1.3	1.3	1.3	1.3
Auxiliary	LNG	LNG	1.3	1.3	1.3	1.3
Boiler	Diesel (MGO/MDO)	Boiler	2	-	-	-

*Liquified natural gas (LNG), steam turbine (ST), gas turbine (GT)

2.5.2 Emissions Factors for Other Pollutants

Factors for other pollutants depend on engine, fuel type, and engine type, as shown in the table below. Note that rates for particulate matter, carbon monoxide, and sulfur dioxide are calculated based on the brake-specific fuel consumption rates.

The table includes values for brake-specific fuel consumption (BSFC), particulate matter less than 10 microns in diameter (PM10), hydrocarbons (HC), carbon monoxide (CO), nitrous oxide (N2O), volatile organic compounds (VOC), methane (CH4), carbon dioxide (CO2), and sulfur dioxide (SO2).

The emissions factors were adopted from U.S. EPA's latest 2022 guidance document[14] where available. LNG factors for CH4 and VOC were not reported in U.S. EPA's 2022 guidance and were adopted from U.S. DOT's Maritime Administration report[15]. ROG, TOG, and NH3 factors that remain unchanged from the prior updates to the OGV inventory.

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[13] IMO Marine Environmental Protection Committee 82nd Session Report, *https://hinsib.com/circulars_OMI/MEPC_82-INF.2.pdf*

[14] 2022 US EPA Port Inventory Guidance: *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf*

[15] US DOT Maritime Administration Emission Factors, *https://www.maritime.dot.gov/sites/marad.dot.gov/files/docs/innovation/meta/11986/marine-lcav2.docx*

The BSFC is the fuel consumption per unit engine power, while the other emissions factors here relate to air pollutants.

Table 7. OGV emissions rates for other pollutants in g/kW-hr.

Engine	Fuel	Type	BSFC	PM10	HC	CO	N2O	VOC	CH4	CO2	SO2
Main	Diesel	SSD	185	0.18	0.60	1.40	0.03	0.63	0.01	593	0.36
Main	Diesel	MSD	205	0.19	0.50	1.10	0.03	0.53	0.01	657	0.40
Main	Diesel	ST	300	0.16	0.10	0.20	0.08	-	-	-	-
Main	Diesel	GT	300	0.01	0.10	0.20	0.08	-	-	-	-
Main	Residual	SSD	195	0.61	0.60	1.40	0.03	0.63	0.01	607	0.38
Main	Residual	MSD	215	0.61	0.50	1.10	0.03	0.53	0.01	670	0.42
Main	Residual	ST	305	0.93	0.10	0.20	0.08	-	-	-	-
Main	Residual	GT	305	0.06	0.10	0.20	0.08	-	-	-	-
Main	LNG	LNG	166	0.03	0.00	1.30	0.03	0.50	5.05	457	0.32
Auxiliary	Diesel	MSD	217	0.19	0.40	1.10	0.03	0.42	0.01	696	0.42
Auxiliary	Diesel	HSD	217	0.19	0.40	1.10	0.03	0.42	0.01	696	0.42
Auxiliary	Residual	MSD	227	0.61	0.40	0.90	0.31	0.42	0.01	707	0.44
Auxiliary	Residual	HSD	227	0.61	0.40	0.90	0.31	0.42	0.01	707	0.44
Auxiliary	LNG	LNG	166	0.18	0.00	1.30	0.03	0.50	5.05	457	0.32
Boiler	Diesel	Boiler	300	0.20	0.10	0.20	0.08	0.11	0.00	962	0.59
Boiler	Residual	Boiler	305	0.62	0.10	0.20	0.08	0.11	0.00	950	0.60

2.5.3 Low Load Adjustments

Low load adjustment factors (LLAF) are adjustment factors that increase the emission factors when the engine is running at low loads, defined in this inventory at loads below 40 percent. These factors are applied based on engine testing that shows marine engines emit higher levels of pollution per unit work produced when the engine is running at low load. These factors are applied to all speeds main engines only and vary depending upon pollutant as shown in For emissions other than NOx, the LLAF are based on the U.S. EPA 2022 guidance document14.

CARB staff updated the NOx LLAF after corroborating the data from the Ports of Los Angeles and Long Beach against research on airborne plume capture, remote sensing, in-funnel measurements in field and measurements taken in a laboratory setting. This analysis was published in a paper by Grigoriadis et. al[15]. The Grigoriadis study was not used directly in the emission inventory, but only used to corroborate the NOx LLAF from the Port of Los Angeles and Port of Long Beach emissions testing. CARB staff will continue to work toward and monitor research on OGV engine testing for all pollutants to determine if using the LLAF adjustments is appropriate for pollutants other than NOx.

Table 8. OGV main engine low load adjustment factors per pollutant. The adjustment factors in the table apply to all main engine Tiers.

Low load adjustments are not currently applied to auxiliary generators or boilers, due to lack of testing data and available information supporting it. Auxiliary generators and boilers could be a key area for future emissions testing.

For the NOx LLAFs, the updated emission inventory now uses the low load factors developed by the Ports of Los Angeles, Long Beach, and Starcrest, based on in-field testing of OGV using MAN engines with slide valves during low-load operations[16] as shown in Figure 8.

For emissions other than NOx, the LLAF are based on the U.S. EPA 2022 guidance document[14].

CARB staff updated the NOx LLAF after corroborating the data from the Ports of Los Angeles and Long Beach against research on airborne plume capture, remote sensing, in-funnel measurements in field and measurements taken in a laboratory setting. This analysis was published in a paper by Grigoriadis et. al[15]. The Grigoriadis study was not used directly in the emission inventory, but only used to corroborate the NOx LLAF from the Port of Los Angeles and Port of Long Beach emissions testing. CARB staff will continue to work toward and monitor research on OGV engine testing for all pollutants to determine if using the LLAF adjustments is appropriate for pollutants other than NOx.

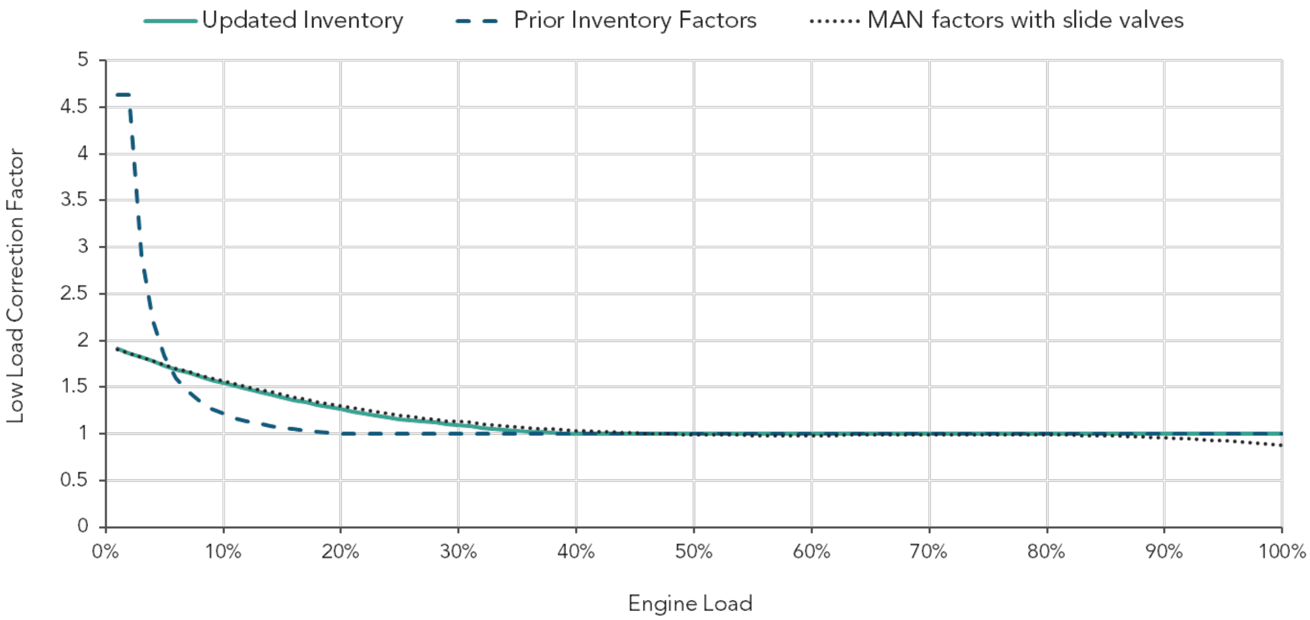
Table 8. OGV main engine low load adjustment factors per pollutant.

Main Engine Loads (%)	NOx	HC	CO	PM10	CO2	SO2 at 0.1% fuel sulfur content
≤ 1	1.91	21.18	9.68	7.29	3.28	9.54
2	1.86	21.18	9.68	7.29	3.28	9.54
3	1.82	11.68	6.46	4.33	2.44	6.38
4	1.78	7.71	4.86	3.09	2.01	4.79
5	1.73	5.61	3.89	2.44	1.76	3.85
6	1.69	4.35	3.25	2.04	1.59	3.21
7	1.66	3.52	2.79	1.79	1.47	2.76
8	1.62	2.95	2.45	1.61	1.38	2.42
9	1.58	2.52	2.18	1.48	1.31	2.16
10	1.55	2.20	1.96	1.38	1.25	1.95
11	1.51	1.96	1.79	1.30	1.21	1.78
12	1.48	1.76	1.64	1.24	1.17	1.63

[16] Port of Los Angeles Emission Inventory: *https://kentico.portoflosangeles.org/getmedia/8066ecf3-86a1-4fa8-b1c9-f9726b92be67/2014_Air_Emissions_Inventory_Full_Report*

Main Engine Loads (%)	NOx	HC	CO	PM10	CO2	SO2 at 0.1% fuel sulfur content
13	1.45	1.60	1.52	1.19	1.14	1.51
14	1.42	1.47	1.41	1.15	1.11	1.41
15	1.39	1.36	1.32	1.11	1.08	1.32
16	1.36	1.26	1.24	1.08	1.06	1.24
17	1.34	1.18	1.17	1.06	1.04	1.17
18	1.31	1.11	1.11	1.04	1.03	1.11
19	1.29	1.05	1.05	1.02	1.01	1.05
20	1.27	1.00	1.00	1.00	1.00	1.00
21	1.24	1.00	1.00	1.00	1.00	1.00
22	1.22	1.00	1.00	1.00	1.00	1.00
23	1.20	1.00	1.00	1.00	1.00	1.00
24	1.18	1.00	1.00	1.00	1.00	1.00
25	1.16	1.00	1.00	1.00	1.00	1.00
26	1.15	1.00	1.00	1.00	1.00	1.00
27	1.13	1.00	1.00	1.00	1.00	1.00
28	1.12	1.00	1.00	1.00	1.00	1.00
29	1.10	1.00	1.00	1.00	1.00	1.00
30	1.09	1.00	1.00	1.00	1.00	1.00
31	1.08	1.00	1.00	1.00	1.00	1.00
32	1.06	1.00	1.00	1.00	1.00	1.00
33	1.05	1.00	1.00	1.00	1.00	1.00
34	1.04	1.00	1.00	1.00	1.00	1.00
35	1.03	1.00	1.00	1.00	1.00	1.00
36	1.02	1.00	1.00	1.00	1.00	1.00
37	1.02	1.00	1.00	1.00	1.00	1.00
38	1.01	1.00	1.00	1.00	1.00	1.00
39	1.00	1.00	1.00	1.00	1.00	1.00
≥ 40	1.00	1.00	1.00	1.00	1.00	1.00

Figure 8. Comparison of changes to NOx low load adjustment factors



2.5.4 Tier III Main Engine Duty Cycle Adjustment

Tier III main engines primarily use selective catalytic reduction (SCR) and exhaust gas recirculation (EGR) for controlling NOx emissions to levels compliant by IMO standards. Recent studies[17] suggest that when these engines are at low loads, the emission controls are either not engaged or not operating efficiently.

As such, Tier III main engines operating below 25 percent capacity are modeled operating at Tier II emission factors and low-load adjustment factors for NOx emissions calculations. This is consistent with the U.S. EPA and the 2023 inventories for the Ports of Los Angeles and Long Beach. This is an area for future improvement and refinement in the inventories, with additional testing below 25 percent load needed.

In this inventory, the Tier III operation modeling has negligible impacts on emissions until 2030, due to the delayed arrival of Tier III vessels to California ports discussed later in the report.

2.6 Emissions Estimation

The 2019-2023 annual emissions for OGVs are calculated from the three main engine types: propulsion engines (main engines), auxiliary engines, and boilers. Specific parameters (emission factors, load, etc.) may vary depending on vessel and emission source, using the following equation:

[17] ICCT Feasibility Study, *https://theicct.org/sites/default/files/publications/ICCT_MarineSCR_Mar2014.pdf*

Emissions, g = (Engine Operating Power, kW) x (Hours of Operation) x (Emissions Factor, g per kWh) x (Low Load Adjustment Factor, unitless)

2.6.1 Engine and Boiler Operating Power

The operating power of an emissions source represents how much work per time an engine is producing. For main engines this is a variable that depends on the speed of the vessel. For auxiliary engines and boilers this is an averaged value depending on the mode of operation (i.e. one average for anchorage, another for berth, hoteling, etc.). In other inventories, power is generally calculated by multiplying a load factor by rated engine power. In this inventory, the operating power for auxiliary engines is the average output power, which is equivalent to average load multiplied by the maximum horsepower.

Propulsion Engine Operating Power

In the absence of vessel draft information for each vessel, main engine operating power was calculated using the propeller law[18], which varies engine load based on the cube of vessel speed over ground.

EPA lists the vessel draft as an adjustment that can impact vessel main engine power. Vessel draft information is not available in the current vessel registry data source used in this inventory but will be considered in future inventories if available.

Main Engine Percent Load = (AIS reported Speed Over Ground / IHS maximum speed)^3

Vessel total installed power was obtained for each vessel from the IHS registry. If engine maximum installed power was missing, the average from the 2023 registry data was applied by type and size bin.

Maximum speed is the corresponding ship speed when the propulsion engine is running at its maximum continuous rating (MCR), or at 100% engine load. The primary source of maximum vessel speed is the IHS registry data. However, wherever the IHS data did not list maximum speed for a vessel, the service speed (or average speed the vessel is designed to operate at under normal service conditions) was used to determine a reasonable maximum service speed. CARB staff developed a linear fit from vessels that included both vessel maximum speed and service speed for 4,823 OGVs of various types (see Figure 9). This linear fit was used to interpolate missing maximum speeds in the 2023 IHS registry data.

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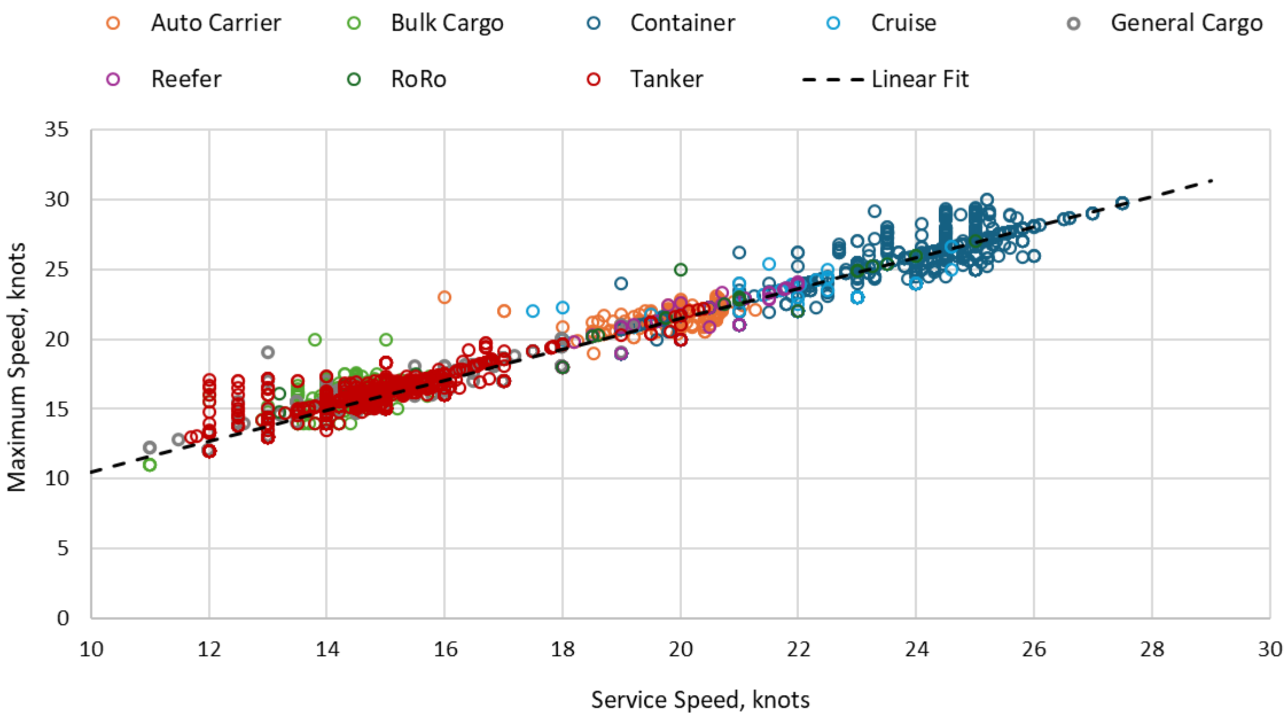
[18] *https://www.man-es.com/docs/default-source/marine/tools/basic-principles-of-ship-propulsion_web_links.pdf?sfvrsn=12d1b862_10*

Figure 9. Relationship between maximum and service speeds from IHS registry data for 4,000+ OGVs.



Maximum speeds by vessel according to registry data were also used as an upper bound for AIS-reported speeds over ground. For example, AIS records observed traveling at speeds above the vessel's maximum were corrected to be traveling at maximum speed. Similarly, AIS observed speeds under 0 knots were corrected to be traveling at 0 knots.

Auxiliary Engine Operating Power

Average auxiliary maximum installed power was taken from 2023 IHS by type and size bin and used along with Starcrest default operating power by activity mode. The average operating power was divided by maximum power to derive average percent load values by vessel type and size bin, as shown in the Appendix D. In rare cases, operating power values were corrected not to exceed maximum installed power.

Auxiliary engine operational power = (Maximum installed power) x (percent load by activity mode)

If engine maximum installed power was unavailable for operating power estimations, then the Starcrest default operating power was used directly for that vessel, as shown in Table 9. Operating power for chemical tankers and cruise ships were used directly from Starcrest's 2023 update using data from the Vessel Boarding Program and documented in the 2023 port emission inventories for the Ports of Los Angeles and Long Beach.

Table 9. 2023 Vessel Boarding Program auxiliary engine default operating power by mode, kW.

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier		570	1,193	962	561
Bulk		255	283	523	260
Bulk - Heavy Load		359	949	211	253
Bulk - Self Discharging		335	779	303	319
Container	1	1,317	1,314	767	1,000
Container	2	1,460	1,962	678	770
Container	3	1,473	1,608	1,026	636
Container	4	1,335	2,508	943	880
Container	5	1,404	2,317	998	941
Container	6	1,750	2,530	1,045	1,270
Container	7	1,580	2,530	1,024	826
Container	8	1,654	2,625	1,274	1,268
Container	9	1,615	2,829	1,089	1,144
Container	10	1,508	1,900	1,068	1,104
Container	11	1,931	2,538	1,071	1,330
Container	12	1,821	2,364	1,443	1,416
Container	13	1,616	2,287	1,250	1,242
Container	14	1,658	2,297	1,223	1,189
Container	15	1,962	2,313	878	1,115
Container	16	1,958	2,631	1,453	1,533
Container	17	1,617	1,953	1,225	1,220
Container	18	2,233	3,200	1,850	1,950
Container	19	2,000	2,800	1,200	1,100
Cruise	1500	2,768	3,833	2,965	3,038
Cruise	2000	6,883	8,100	5,624	-
Cruise	2500	8,033	9,000	7,680	-
Cruise	3000	8,052	8,577	6,410	7,820
Cruise	3500	7,867	9,511	7,069	8,036
Cruise	4000	8,615	9,230	7,201	8,736
Cruise	4500	8,552	9,086	7,851	8,100
Cruise	5000	8,980	9,359	8,479	8,181
General Cargo		448	1,036	714	180
Miscellaneous		284	379	230	233
Reefer		1,416	1,231	1,067	1,427
RoRo		132	396	229	132
Tanker	Chemical	467	573	1,300	376
Tanker	Handysize	661	682	1,052	560
Tanker	Panamax	487	550	860	401

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Tanker	Aframax	505	615	986	463
Tanker	Suezmax	667	568	689	509
Tanker	VLCC	640	749	1,061	599
Tanker	ULCC	771	912	1,229	625

Boiler Operating Power

Starcrest Consulting Group's updated boiler default operating power from the Vessel Boarding Program was used directly on all vessels in the inventory, as noted in Table 10.

Table 10. 2023 Vessel Boarding Program updates to boiler default operating power by mode, kW.

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier		84	173	296	287
Bulk		58	138	170	170
Bulk - Heavy Load		35	94	125	125
Bulk - Self Discharging		44	93	134	134
Container	1	119	239	599	303
Container	2	134	251	384	311
Container	3	196	294	720	439
Container	4	171	343	474	470
Container	5	245	471	545	539
Container	6	264	508	689	685
Container	7	345	549	596	594
Container	8	226	444	560	571
Container	9	367	543	646	618
Container	10	323	446	627	627
Container	11	192	320	463	465
Container	12	196	372	472	472
Container	13	249	332	570	576
Container	14	323	517	549	614
Container	15	247	380	402	402
Container	16	412	535	638	638
Container	17	184	335	592	592
Container	18	479	718	790	790
Container	19	38	144	848	848
Cruise	1500	692	766	850	594
Cruise	2000	1,070	1,145	1,951	976
Cruise	2500	1,382	1,773	3,005	1,506
Cruise	3000	671	736	1,363	616

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Cruise	3500	568	748	1,276	992
Cruise	4000	555	506	859	735
Cruise	4500	335	29	551	671
Cruise	5000	281	21	468	698
General Cargo		67	152	198	198
Miscellaneous		54	85	144	144
Reefer		89	171	234	234
RoRo		67	148	259	251
Tanker	Chemical	98	136	418	235
Tanker	Handysize	144	286	3,077	322
Tanker	Panamax	243	340	4,190	521
Tanker	Aframax	196	259	4,976	390
Tanker	Suezmax	144	99	8,170	516
Tanker	VLCC	240	137	8,390	490
Tanker	ULCC	235	322	10,718	366

Boiler Load Adjustment for Tankers with Steam-Driven Pumps

As noted in the documentation for the 2019 OGV emission inventory[19], the operational power of tanker boilers equipped with steam-driven pumps was adjusted based on the unique operational characteristics of vessels during berthing operations, specifically while loading and unloading product. Power provided to the pumps from electrical generators onboard two tanker vessels are coupled with steam turbines served by boilers, rather than auxiliary engines. Vessels equipped with steam-driven pumps were identified in the 2023 data as reported to CARB Enforcement. Auxiliary operational power from compression ignition diesel engines is assumed to be zero for these vessels during berth hoteling operations statewide.

Additionally, the operational power for boilers during this time is increased by an equivalent amount (based on the average operational power for tanker auxiliary engines by size as shown in Table 9), to reflect the increased load on the boilers providing electricity. This assumes equivalent efficiency for electricity generation between the auxiliary engines and the boiler generator system. While there may be some differences in efficiency, additional supporting data on power generation efficiencies of boiler-generator systems is needed for future inventory updates. Although the current adjustment maintains the same overall power consumption, it is important to note that auxiliary engines produce diesel particulate matter (DPM), and boilers do not have compression ignition engines and would instead emit PM.

[19] 2019 Update to Inventory for Ocean-Going Vessels At Berth, *https://ww3.arb.ca.gov/msei/offroad/pubs/2019_ogv_inventory_writeup_ver_oct_18_2019.pdf*

Cruise COVID-19 Pandemic Load Adjustment

The COVID-19 pandemic had a significant impact on cruise ship energy consumption due to suspended vessel operations. The suspension of vessel operations reduced the need to power onboard equipment and facilities in 2020. An analysis by Starcrest Consulting Group estimated the change in energy needs when cruise ships suspended major onboard operations. The Port of Los Angeles had a 27-percent reduction in cruise ship energy consumption on average[20], and the Port of Long Beach had a 31-percent reduction in cruise ship energy consumption on average[21]. Weighting these reductions based on the total calls of cruise vessels at each port, CARB staff applied a 28.78-percent reduction to energy consumption and emissions for auxiliary engines and boilers on cruise ships statewide in 2020. Because 2020 is included in the 5-year average used as the emission inventory baseline, this means the adjustment applies to emission inventory at one fifth of this value.

2.7 Forecasting Future Year Emissions

The OGV statewide inventory was forecasted to 2050 from the 2023 surrogate base year using a static age distribution model, which maintains the age distribution of vessels observed in the surrogate base year (a five-year average from 2019 to 2023) through all future years. Annual growth rates were applied to the base year inventory by calendar year, region, and vessel type. Containerships were adjusted further based on capacity over time, as detailed below.

2.7.1 Surrogate Base Year

Previous CARB updates to the OGV inventory have incorporated the best available information to forecast future emissions based on a single observed base year. However, over the past 15 years, various events, from labor disputes to freight congestion to the COVID pandemic, have created disruptions impacting the OGV sector and resulting emissions. A timeline of these events is shown in Figure 10. As a result, the inventory update proposes the use of a five-year averaged base year for forecasting future year OGV activities, including each calendar year from 2019 to 2023. This minimizes the extreme impacts that may stem from selecting a single base year, while also reasonably incorporating such events into the forecast.

Each year in the 5-year period has an equal weight on the base year of the inventory, or 20 percent influence on the emission inventory base year population, activity hours per vessel within each CoAbDis location, and emissions. Any vessel speed reduction (VSR) programs in place between 2019 and 2023 would be reflected in the base year and subsequently included in all forecasted years. CARB will continue to monitor the VSR programs to determine if adjustments are needed in future forecasts.

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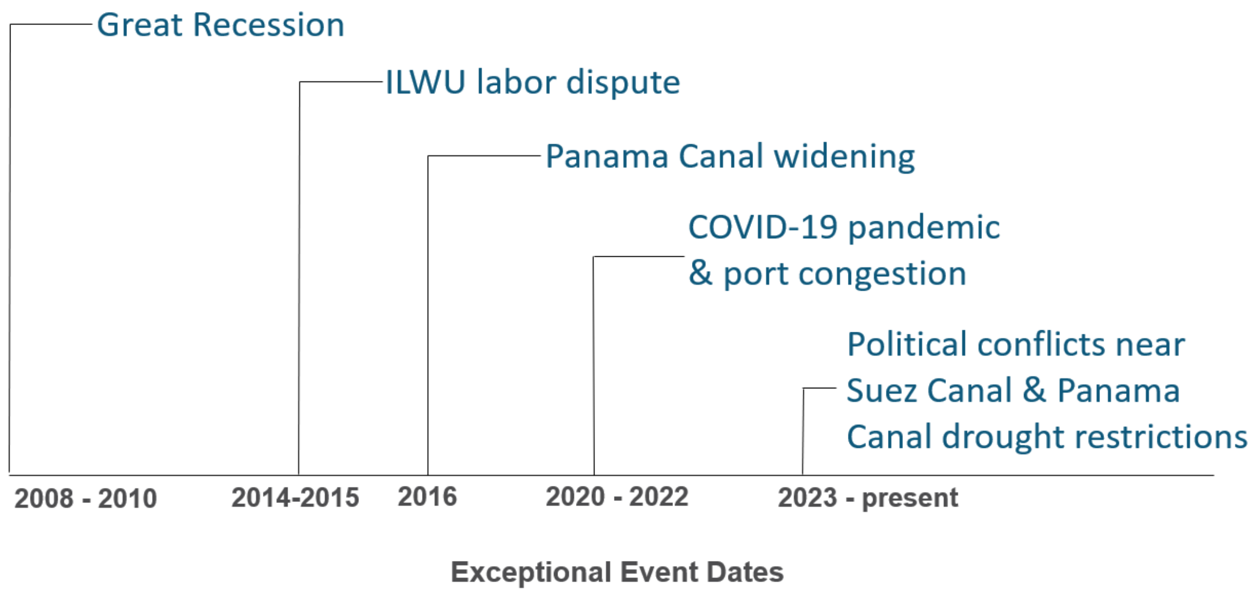
[20] Port of Los Angeles 2020 Emissions Inventory, *https://www.portoflosangeles.org/environment/air-quality/air-emissions-inventory*

[21] Port of Long Beach 2020 Emissions Inventory, *https://polb.com/environment/air/#emissions-inventory*

Figure 10. Historic events impacting water shipping operations over the last 15 years.



2.7.2 Base Year Age Distribution

The surrogate base year derived from 2019-2023 calendar years shows the majority of OGVs visiting California were Tier I vessels with very few Tier III visits. As shown in Figure 11 below, a large number of OGVs were built in 2015 before the Tier III engine standard came into effect. Additionally, the surrogate base year data revealed a small but still significant portion of fleet operators holding on to vessels greater than 25 years of age. Figure 12 shows the total OGV population across the 5 calendar years observed based on keel laid distribution in aggregate and by vessel type, which reveals a greater portion of newer, presumably Tier III vessels are tanker ships, whereas bulk cargo ships are predominantly Tier II.

Figure 11. Tier distribution of the combined 4,236 OGVs observed within 100 nm from California shoreline during calendar year 2019 through 2023.

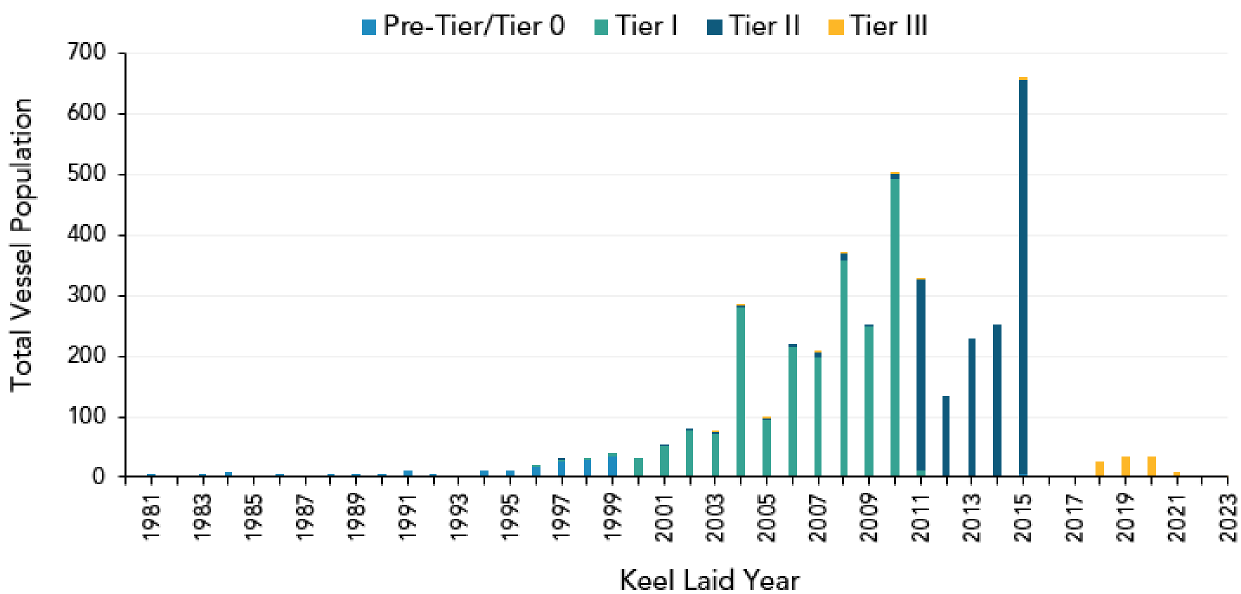
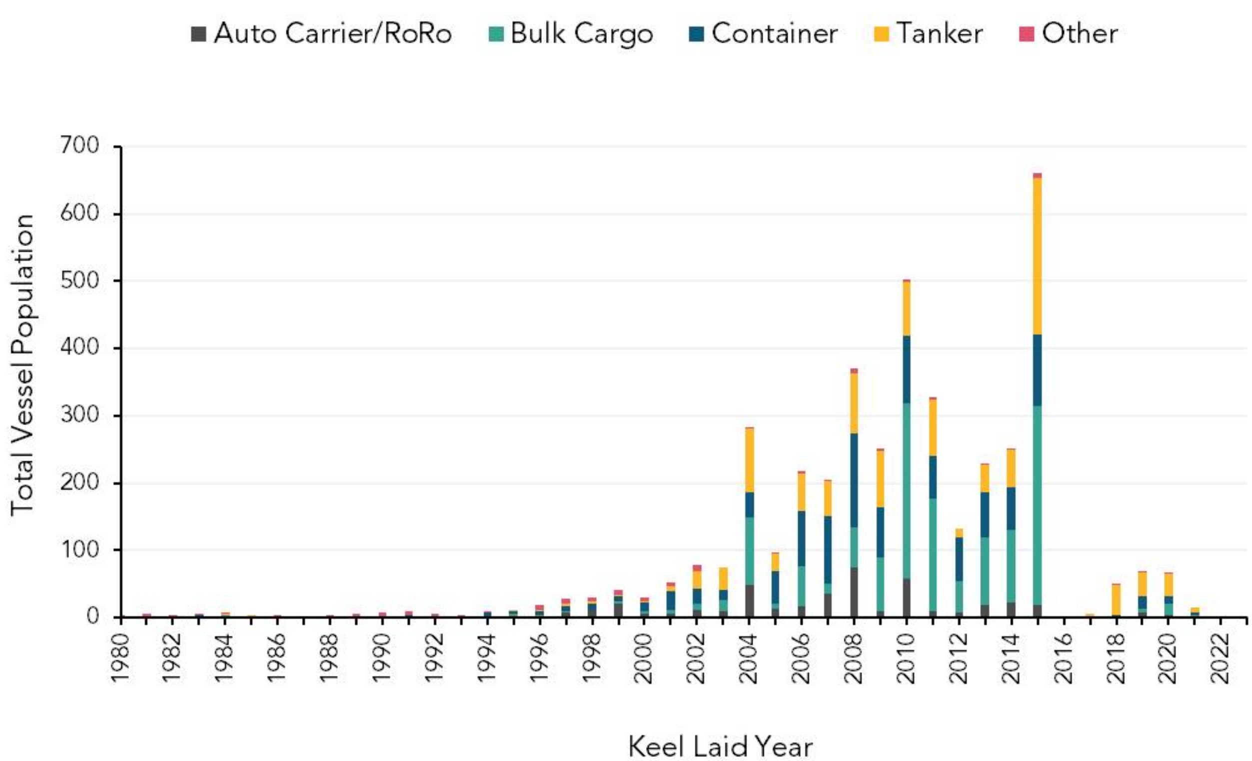


Figure 12. Keel laid distribution of the combined 4,236 OGVs observed within 100 nm from California shoreline during calendar year 2019 through 2023 by vessel type.



2.7.3 Growth Rates

Freight Analysis Framework v5.1

The Freight Analysis Framework (FAF) is a comprehensive national model of freight movements made available through the partnership of the Bureau of Transportation Statistics (BTS) and the Federal Highway Administration (FHWA). The model estimates commodity flows by region forecasted out to 2050 by freight mode, tonnage, and commodity type based on several data sources including the Commodity Flow Survey (CFS), international trade data from the Census Bureau, and sector specific data from agriculture, extraction, utility, and construction, among others.

Water-based transports were assigned to vessel types based on commodity as detailed in Table 11, and the annual growth rates for containerships is shown in Table 12.

Table 11. OGV type allocations to Freight Analysis Framework reported tons of commodity goods.

Vessel Type	FAF Commodity Type
Auto Carrier	Motorized vehicles
Bulk cargo	Animal feed
Bulk cargo	Building stone
Bulk cargo	Cereal grains
Bulk cargo	Coal
Bulk cargo	Coal-not elsewhere classified
Bulk cargo	Fertilizers
Bulk cargo	Gravel
Bulk cargo	Logs
Bulk cargo	Metallic ores
Bulk cargo	Milled grain products
Bulk cargo	Natural sands
Bulk cargo	Nonmetal min. products
Bulk cargo	Nonmetallic minerals
Container	Alcoholic beverages
Container	Articles-base metal
Container	Base metals
Container	Electronics
Container	Furniture
Container	Misc. manufactured products
Container	Mixed freight
Container	Newsprint/paper
Container	Paper articles
Container	Pharmaceuticals
Container	Plastics/rubber
Container	Precision instruments

Vessel Type	FAF Commodity Type
Container	Printed products
Container	Textiles/leather
Container	Tobacco products
Container	Waste/scrap
Container	Wood products
General cargo	Chemical products
General cargo	Live animals/fish
General cargo	Machinery
Reefer	Meat/seafood
Reefer	Other agricultural products
Reefer	Other foodstuffs
RoRo	Transport equipment
Tanker	Basic chemicals
Tanker	Crude petroleum
Tanker	Fuel oils
Tanker	Gasoline

Table 12. Annual growth rates applied to containerized cargo based on Freight Analysis Framework (FAF5.1).

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2023	Container	3.52%	3.32%	3.35%	3.55%	2.33%
2024	Container	3.14%	0%	0%	3.34%	2.66%
2025	Container	3.14%	0%	0%	3.34%	2.66%
2026	Container	3.51%	0%	0%	2.83%	2.58%
2027	Container	3.51%	0%	0%	2.83%	2.58%
2028	Container	3.51%	0%	0%	2.83%	2.58%
2029	Container	3.51%	0%	0%	2.83%	2.58%
2030	Container	3.51%	0%	0%	2.83%	2.58%
2031	Container	3.10%	0%	0%	2.58%	2.45%
2032	Container	3.10%	0%	0%	2.58%	2.45%
2033	Container	3.10%	0%	0%	2.58%	2.45%
2034	Container	3.10%	0%	0%	2.58%	2.45%
2035	Container	3.10%	0%	0%	2.58%	2.45%
2036	Container	3.19%	0%	0%	2.62%	2.50%
2037	Container	3.19%	0%	0%	2.62%	2.50%
2038	Container	3.19%	0%	0%	2.62%	2.50%
2039	Container	3.19%	0%	0%	2.62%	2.50%
2040	Container	3.19%	0%	0%	2.62%	2.50%
2041	Container	3.29%	0%	0%	2.65%	2.54%

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2042	Container	3.29%	0%	0%	2.65%	2.54%
2043	Container	3.29%	0%	0%	2.65%	2.54%
2044	Container	3.29%	0%	0%	2.65%	2.54%
2045	Container	3.29%	0%	0%	2.65%	2.54%
2046	Container	3.38%	0%	0%	2.64%	2.53%
2047	Container	3.38%	0%	0%	2.64%	2.53%
2048	Container	3.38%	0%	0%	2.64%	2.53%
2049	Container	3.38%	0%	0%	2.64%	2.53%
2050	Container	3.38%	0%	0%	2.64%	2.53%

2.7.4 Containership Capacity Trends

Historical San Pedro Bay Ports (SPBP) Vessel Calls, 2005 – 2023

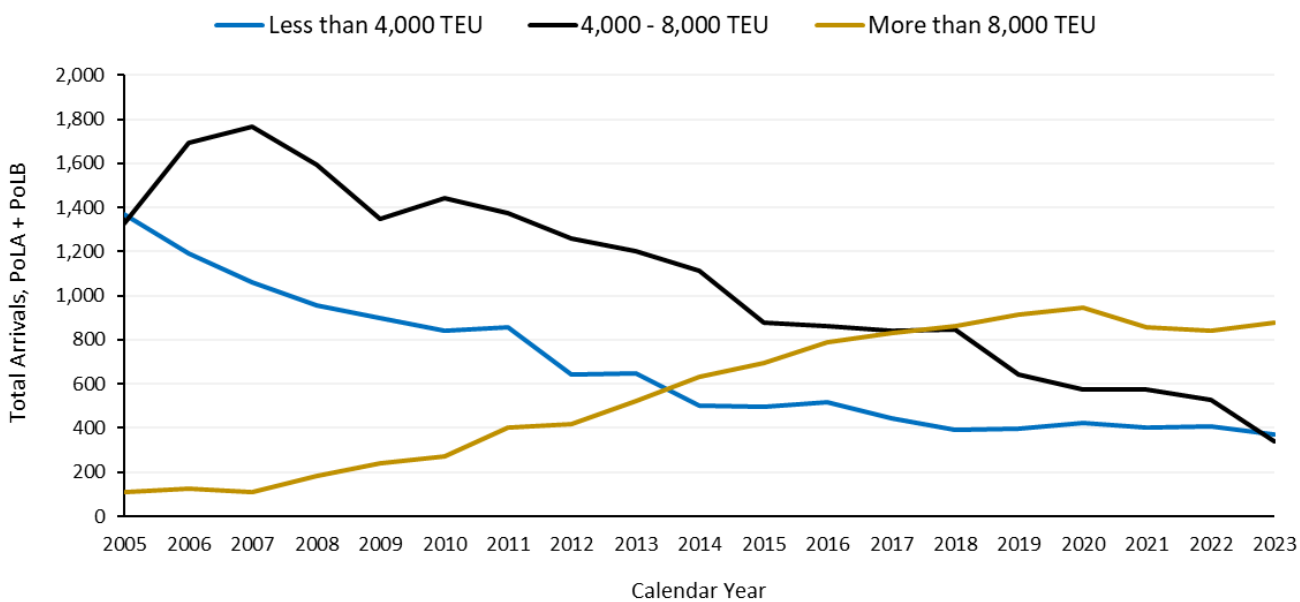
Based on 2005 to 2023 data on container vessels that visit the Port of Los Angeles[22] and the Port of Long Beach[23], containerships with less than 8,000 TEU capacity have been calling less frequently to the Ports of Los Angeles and Ports of Long Beach while containerships with more than 8,000 TEU capacity have been calling more frequently. Containerships with larger capacities are more efficient in terms of containers transported per trip, as well as more efficient in terms of energy consumption per TEU delivered[24]. The work required to transport an individual container is less for larger vessels, particularly for main engines. Figure 13 below depicts these trends over time.

[22] Port of Los Angeles Emissions Inventories, *https://www.portoflosangeles.org/environment/air-quality/air-emissions-inventory*

[23] Port of Long Beach Emissions Inventories, *https://polb.com/environment/air/#emissions-inventory*

[24] 2019 Update to Inventory for Ocean-Going Vessels At Berth, *https://ww3.arb.ca.gov/msei/offroad/pubs/2019_ogv_inventory_writeup_ver_oct_18_2019.pdf*

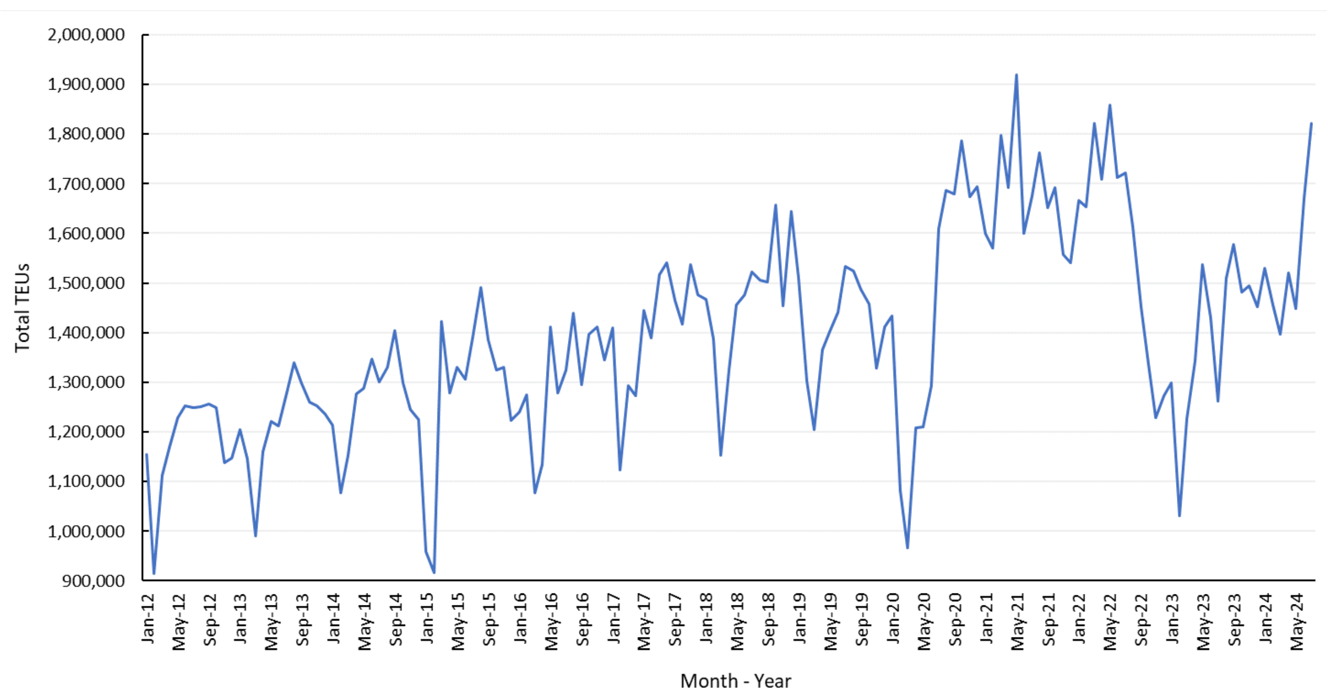
Figure 13. 2005 through 2023 container vessel visit trends at SPBPs by TEU capacity



Historical Monthly TEUs at Major Ports, 2012 – 2023

The freight growth at major ports since 2012 have largely been met by increases in calls from these larger capacity containerships.

Figure 14. SPBPs combined monthly total TEUs from January 2012 through July 2024.



Containership Growth Capacity Adjustment

Annual growth rates were applied to containerships based on TEU capacity necessary to meet TEU growth according to FAF. Based on historical trends, containerships with capacities less than 8,000 TEU are not projected to grow into the future, and instead maintain their current vessel visit levels.

The growth rate of vessels over 8,000 TEU capacity was adjusted to meet the overall freight goods demand predicted in the FAF TEU forecast. In each future year, activity from containerships over 8,000 TEU capacity was increased until they met the freight demand for that forecasted year, as detailed in Table 13.

For example, if FAF predicted a 2 percent growth in overall water-transported containerized freight, only the activity for containerships over 8,000 TEU capacity is increased until total TEUs delivered from *all* containerships increased by 2 percent. In this case, this means that if vessels with capacities over 8,000 TEUs transported half of all TEUs in that year, the growth rate would be set at 4 percent for those vessels, such that total TEUs delivered increased by 2 percent across all visiting container vessels.

This method incorporates the increasing efficiency of using larger containerships into the growth forecast.

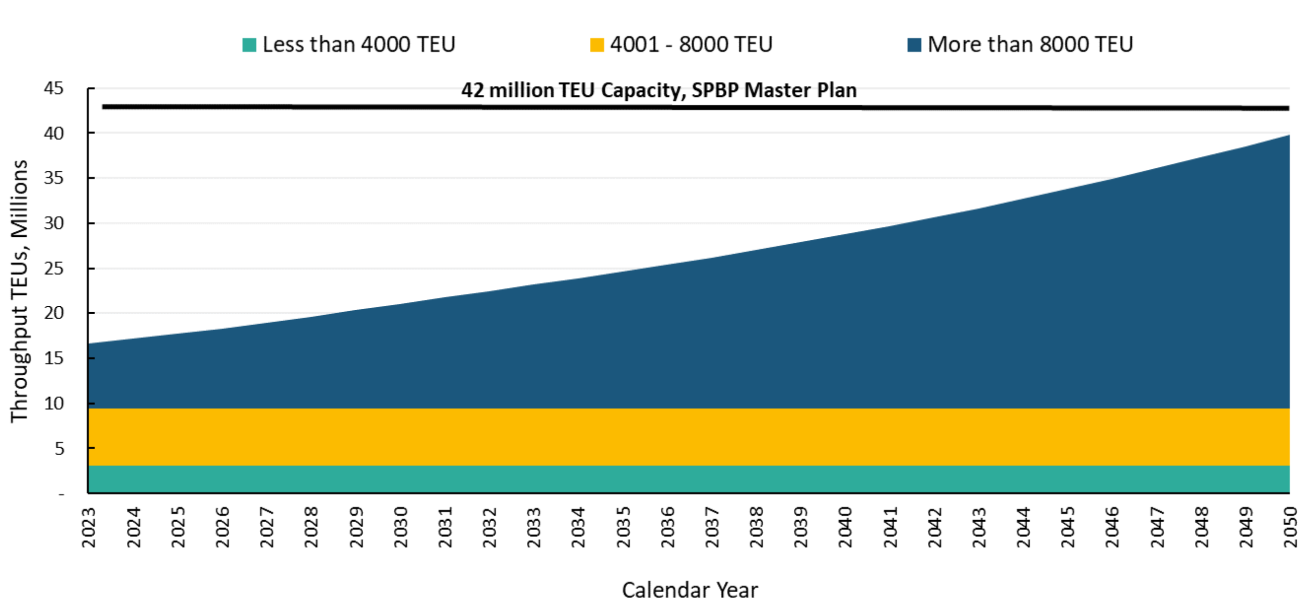
Table 13. Growth Rate for Container Vessels over 8,000 TEU Capacity

Year	Percent Annual Growth
2023	5.0%
2024	4.4%
2025	4.3%
2026	4.8%
2027	4.8%
2028	4.7%
2029	4.7%
2030	4.6%
2031	4.0%
2032	4.0%
2033	4.0%
2034	3.9%
2035	3.9%
2036	4.0%
2037	4.0%
2038	3.9%
2039	3.9%
2040	3.9%
2041	4.0%
2042	3.9%

Year	Percent Annual Growth
2043	3.9%
2044	3.9%
2045	3.9%
2046	3.9%
2047	3.9%
2048	3.9%
2049	3.9%
2050	3.9%

After applying the containership growth capacity adjustment based on FAF-grown TEU delivery demand, the total forecasted TEUs delivered by containership capacity size groupings were cross-referenced with the SPBP Master Plan. As shown in the figure below, the combined TEU throughput for the Ports of Los Angeles and Long Beach with the forecasting method described above are not expected to exceed the 42 million TEU capacity limit as stated in the 2018 Master Plan[25] prior to 2050 (the last year of the inventory forecast).

Figure 15. SPBPs forecasted containership throughput and maximum capacity (million TEUs).



[25] Port Master Plan, *https://kentico.portoflosangeles.org/getmedia/adf788d8-74e3-4fc3-b774-c6090264f8b9/port-master-plan-update-with-no-29_9-20-2018*

2.7.5 Tier Assumptions

Mercator Report, Tier III Delay

IMO engine standards[26] require installation of Tier III engines in all new marine vessels with keels laid after January 1, 2016. However, according to an analysis conducted by Starcrest Consulting Group[27] for SPBPs based on the Mercator report, the widespread introduction of new Tier III vessels at California ports will likely be delayed until 2030. The adoption of Tier III vessel delay was based on California ports rarely receiving visits from the newest container vessels that typically service Asian and European freight routes, as well as the large number of vessel builds ordered immediately prior to the Tier III marine standard introduction, as observed in the age distribution. Vessel builds that began prior to the Tier III marine engine standards initial date may have Tier II marine engines installed, even if the vessel is put into service later.

2.7.6 Modeled 2020 At Berth Regulation

The 2020 At Berth Regulation[28] achieves emission reductions from OGVs docked at berth at California ports. Vessels arriving at a regulated California port or marine terminal must use a CARB Approved Emission Control Strategy (CAECS), which includes shore power and alternative control strategies that capture and treat exhaust. 2023 data as reported to CARB Enforcement identified that vessels subject to the At Berth Regulation used shore power or alternative control strategies at varying rates while berthed depending on port location and vessel type, as shown in Table 15. CARB staff assumed compliance rates in 2023 for regulated California ports and terminals were maintained through all forecasted years leading up to the regulatory compliance dates as shown in Table 14. After the 2025 and 2027 forecasted compliance years, all regulated vessel types are modeled with compliance rates of containerships observed in 2023, shown in Table 16. For example, Tankers in Long Beach are modeled as having a 79% compliance rate in 2025 and later.

Table 14. 2020 At Berth Regulation compliance dates by vessel type as modeled for regulated California ports or terminals.

Compliance Year	Vessel Type and Location
2023	All container, reefer, and cruise ships statewide
2025	All RoRo statewide, and all southern California tankers
2027	All remaining tankers statewide

Table 15. Percent time using CARB Approved Emission Control Strategy (CAECS) at regulated California ports based on 2023 reporting to CARB enforcement.

Port	Container	Cruise	Reefer	RoRo*	Tanker

[26] IMO Annex VI NOx Standards, *https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx*

[27] Starcrest 2017 Tier Forecast Analysis, *http://www.cleanairactionplan.org/documents/vessel-forecast-draft.pdf/*

[28] At Berth Regulation, *https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation*

Hueneme	85 %	N/A	N/A	0 %	0 %
Long Beach	79 %	73 %	N/A	5 %	1 %
Los Angeles	91 %	74 %	10 %	0 %	0 %
Oakland	67 %	N/A	N/A	68 %	0 %
San Diego	97 %	59 %	94 %	0 %	0 %
San Francisco	N/A	54 %	N/A	0 %	0 %

*RoRo vessels observed utilizing emissions controls in 2023 reporting were "ConRo" ships, or containerships with onboard RoRo facilities.

Table 16. Projected percent time using CAECS at regulated California ports in 2027 and later

Port	Container	Cruise	Reefer	RoRo	Tanker*
Hueneme	85 %	N/A	N/A	85 %	85 %
Long Beach	79 %	73 %	N/A	79 %	79 %
Los Angeles	91 %	74 %	10 %	91 %	91 %
Oakland	67 %	N/A	N/A	68 %	67 %
San Diego	97 %	59 %	94 %	97 %	97 %
San Francisco	N/A	54 %	N/A	80 %	80 %

* Tanker vessels in future years may utilize remediation funding to comply with At Berth Regulation requirements. The future emissions reductions are modeled in the inventory for tanker vessels without further adjustments.

3 Emissions Results

Summary

As described previously, the base year activity data taken from AIS provided the vessel locations and speed, IHS data provided vessel characteristics, and Starcrest's VBP data provided engine operation characteristics. The five-year averaged surrogate base year data was combined with growth forecasts, and the assumption that future year vessel visits would mostly likely resemble the current age of the fleet. These steps were all combined into the emissions forecast.

Results

Statewide emissions forecasted out to calendar year 2050 are generally lower than previously estimated in the 2021 updates to statewide OGV emissions, as shown in Figure 16. Figure 19 shows statewide emissions by activity mode, where additional detail on emissions by engine category is available in Appendix E.

Figure 16. Statewide NOx emissions from OGVs out to 100 nautical miles by vessel type.

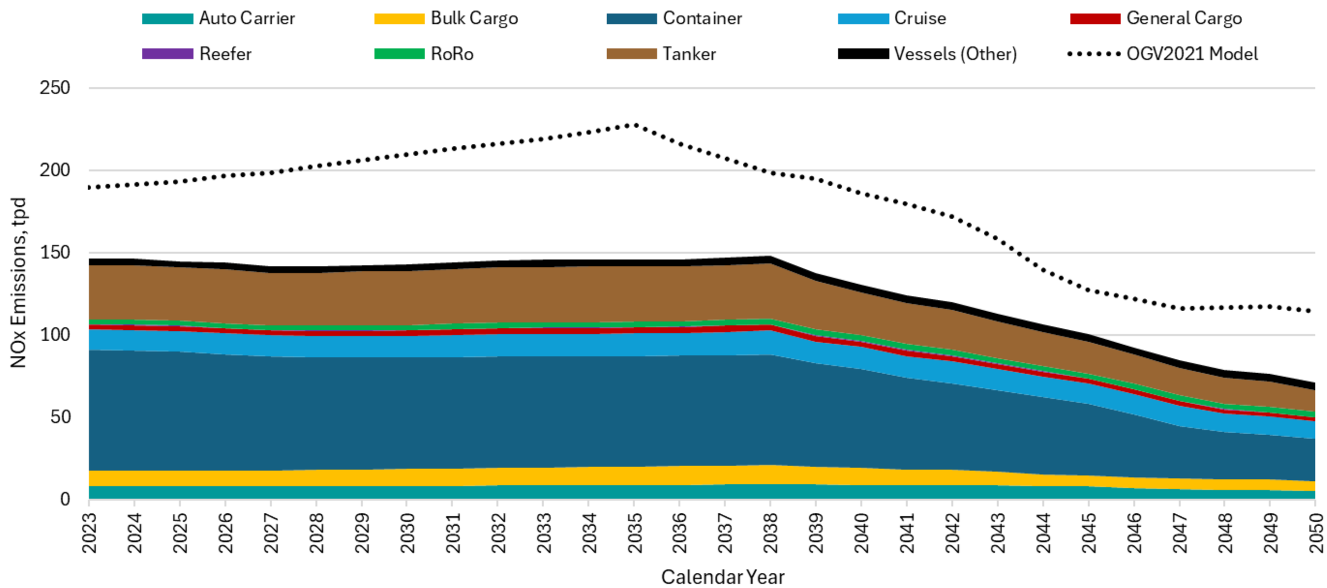


Figure 17. Statewide PM emissions from OGVs out to 100 nautical miles by vessel type.

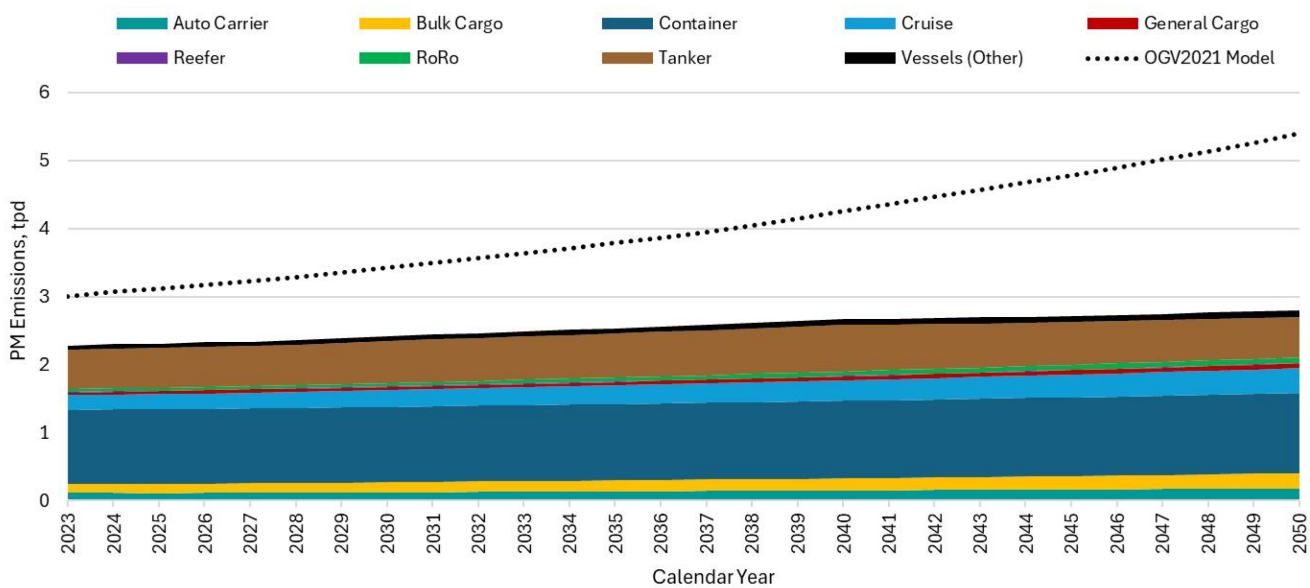


Figure 18. Statewide GHG emissions from OGVs out to 100 nautical miles by vessel type.

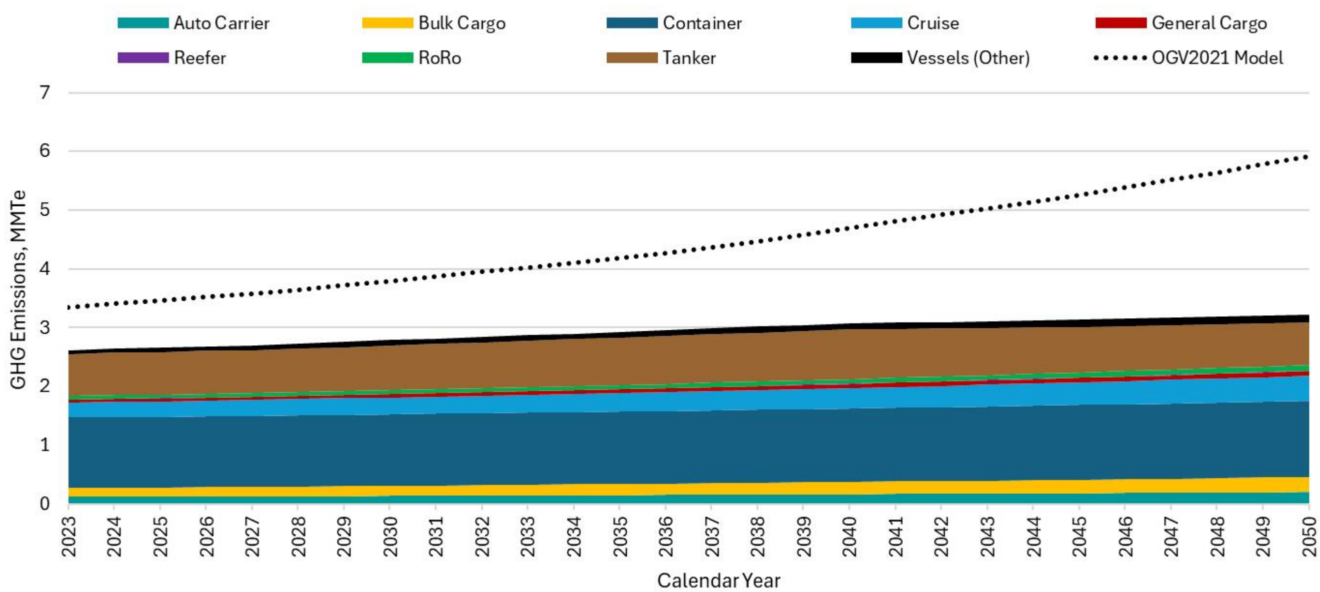


Figure 19. Statewide NOx emissions from OGVs out to 100 nautical miles by mode

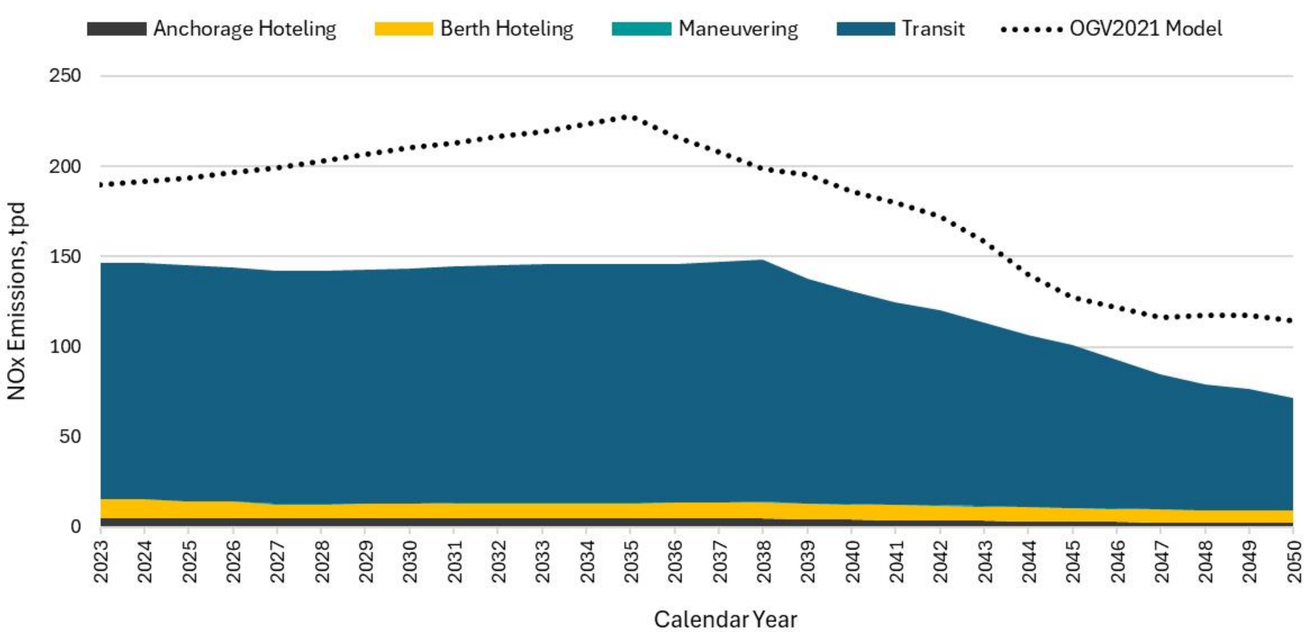


Figure 20. Statewide PM emissions from OGVs out to 100 nautical miles by mode

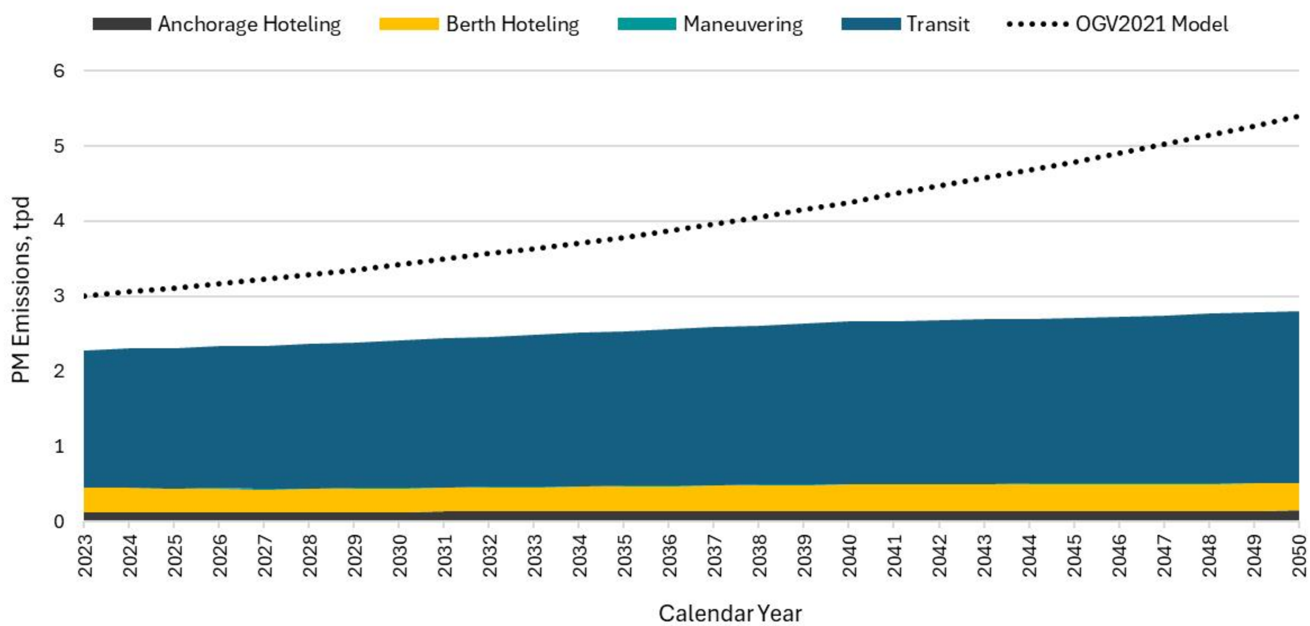


Figure 21. Statewide GHG emissions from OGVs out to 100 nautical miles by mode

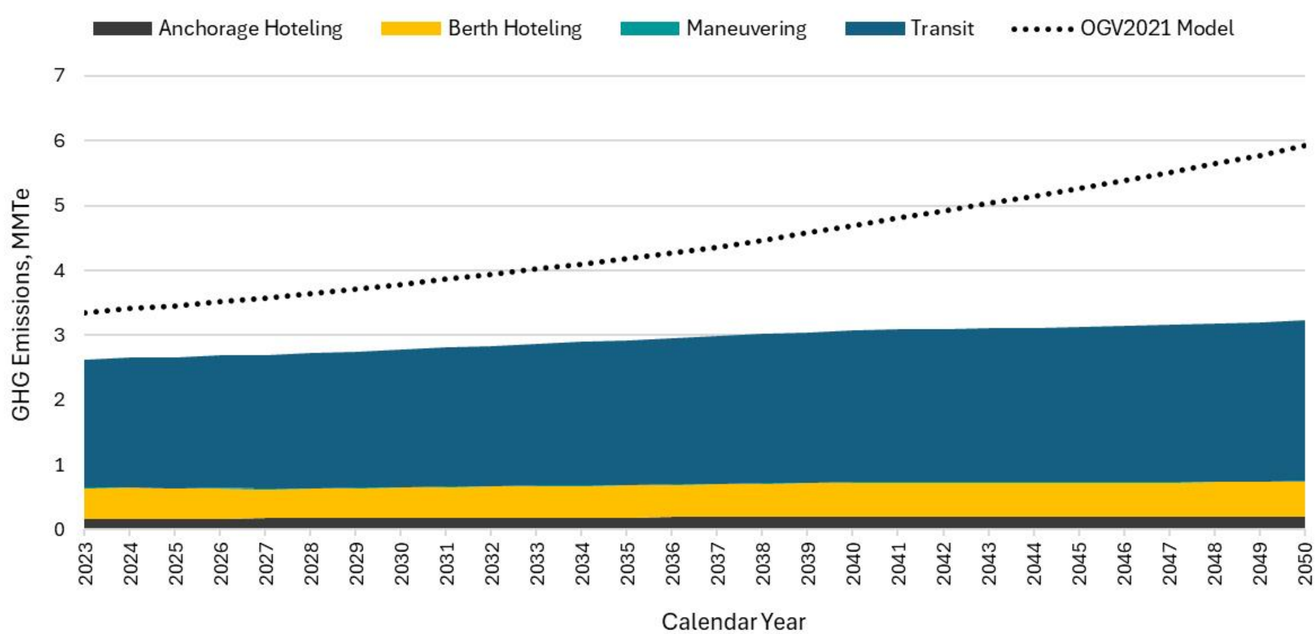


Table 17. Statewide OGV base year surrogate 2023 emissions in tons per day (tpd) by air district (100 nautical miles).

Air District, Out to 100 nm	NOx	PM_{10}	CO	N_2O	VOC	CH_4	CO_2
Bay Area AQMD	21.9	0.4	2.2	0.1	0.8	0.0	1,391

Air District, Out to 100 nm	NOx	PM_{10}	CO	N_2O	VOC	CH_4	CO_2
Mendocino County APCD	5.2	0.1	0.5	0.0	0.2	0.0	214.5
Monterey Bay Unified APCD	12.3	0.2	1.3	0.0	0.5	0.0	534.7
North Coast Unified AQMD	6.0	0.1	0.5	0.0	0.2	0.0	247.0
Northern Sonoma County APCD	2.6	0.0	0.3	0.0	0.1	0.0	110.8
Sacramento Metropolitan AQMD	0.1	0.0	0.0	0.0	0.0	0.0	3.3
San Diego County APCD	13.1	0.2	1.4	0.0	0.5	0.0	719.0
San Joaquin Valley APCD	0.5	0.0	0.0	0.0	0.0	0.0	38.2
San Luis Obispo County APCD	9.8	0.1	1.0	0.0	0.4	0.0	406.8
Santa Barbara County APCD	24.3	0.3	2.6	0.0	0.9	0.0	1,010
South Coast AQMD	35.9	0.7	4.1	0.1	1.3	0.0	2,452
Ventura County APCD	14.5	0.2	1.6	0.0	0.5	0.0	649.9
Yolo/Solano AQMD	0.2	0.0	0.0	0.0	0.0	0.0	11.6
Statewide Total	146.3	2.3	15.4	0.4	5.4	0.1	7,777

However, emissions in some air districts, specifically South Coast, are higher than previously estimated, as shown in Figure 22. Other districts have lower emission totals, including the Bay Area, shown in Figure 25. Changes in number of visits, length of visits, and the resulting shifts in engine activity are the primary driving force of changes in emissions.

Figure 22. South Coast NOx emissions from OGVs out to 100 nautical miles by vessel type.

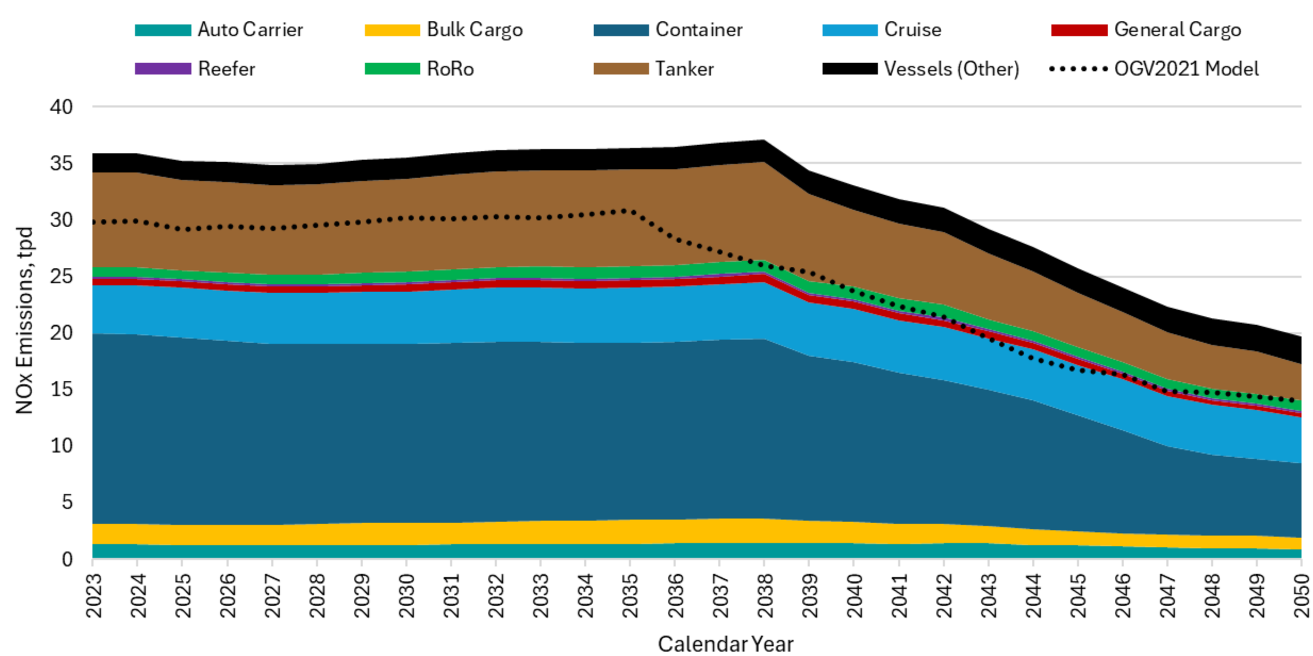


Figure 23. South Coast PM emissions from OGVs out to 100 nautical miles by vessel type.

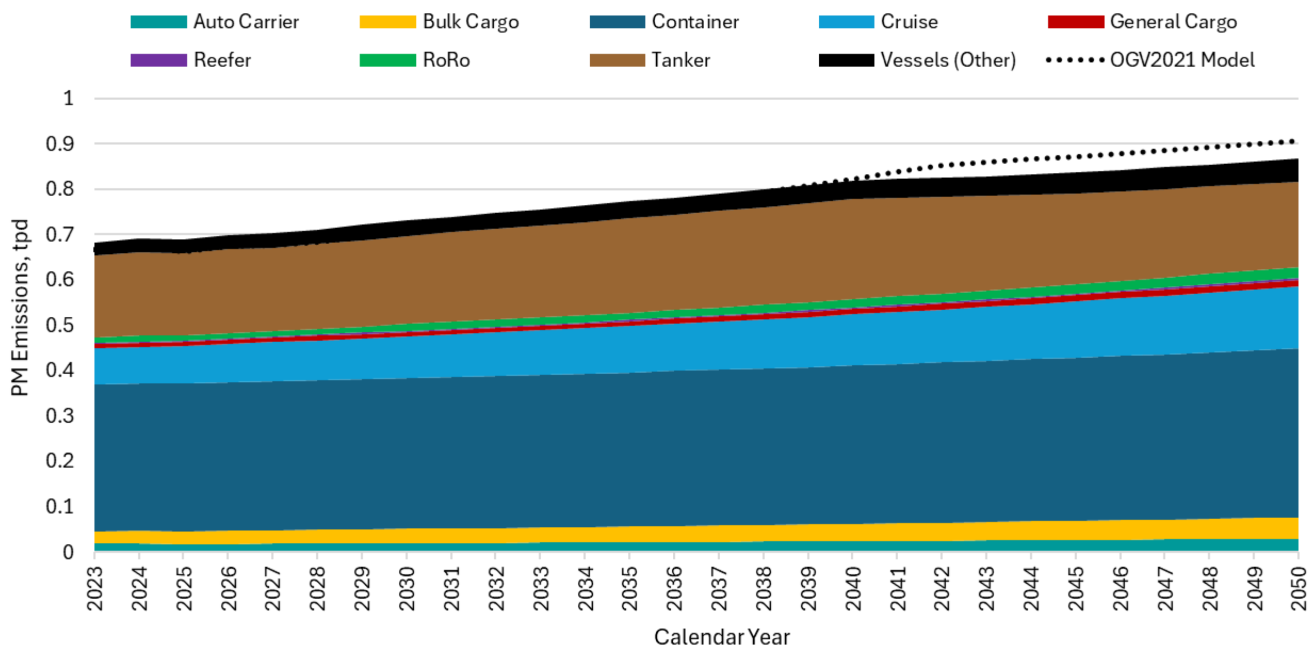


Figure 24. South Coast GHG emissions from OGVs out to 100 nautical miles by vessel type.

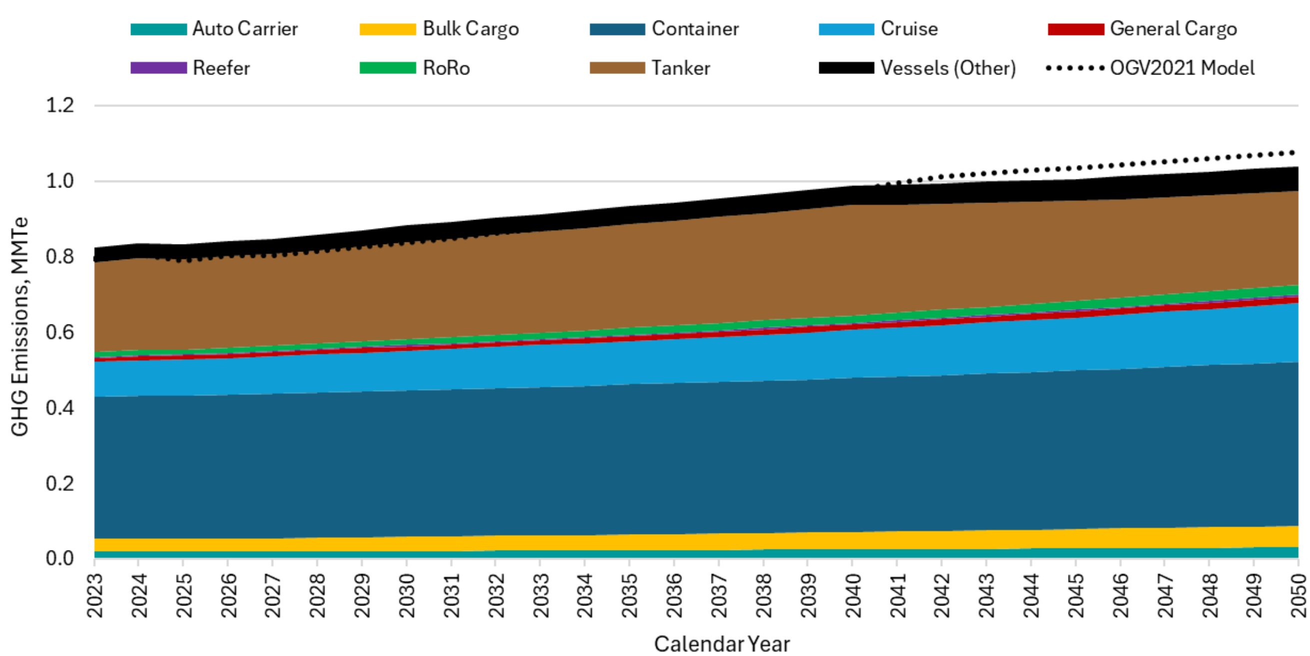


Figure 25. Bay Area NOx emissions from OGVs out to 100 nautical miles by vessel type.

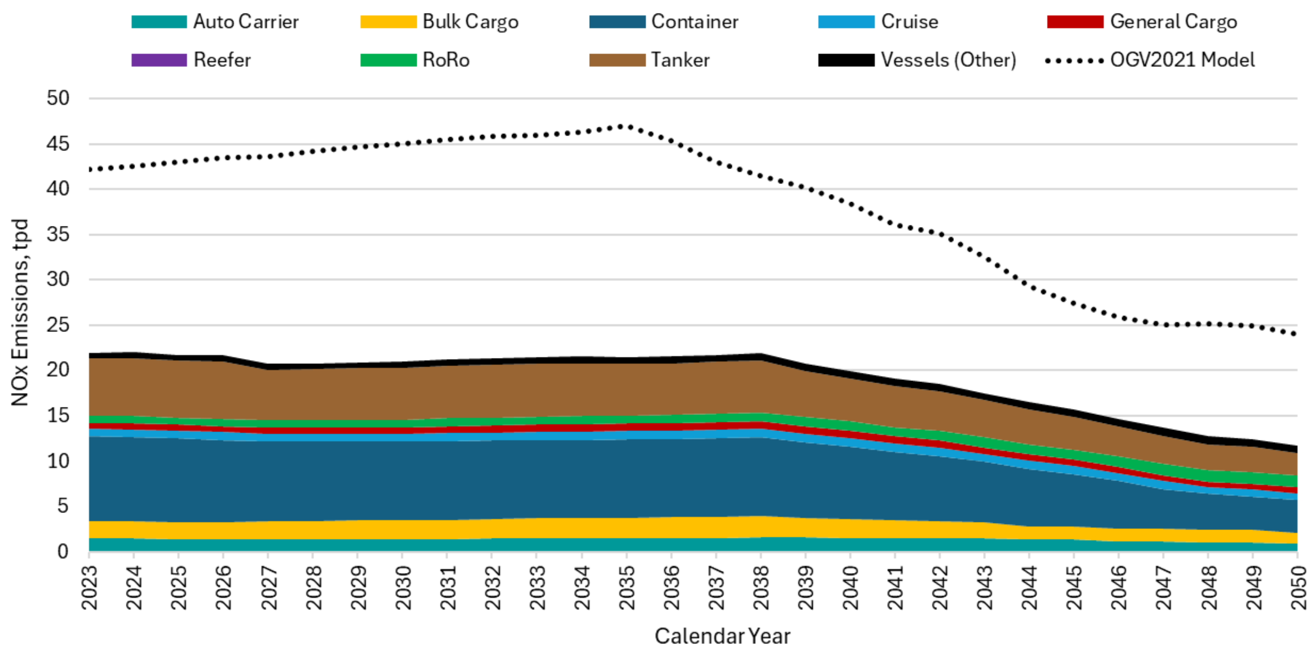


Figure 26. Bay Area PM emissions from OGVs out to 100 nautical miles by vessel type.

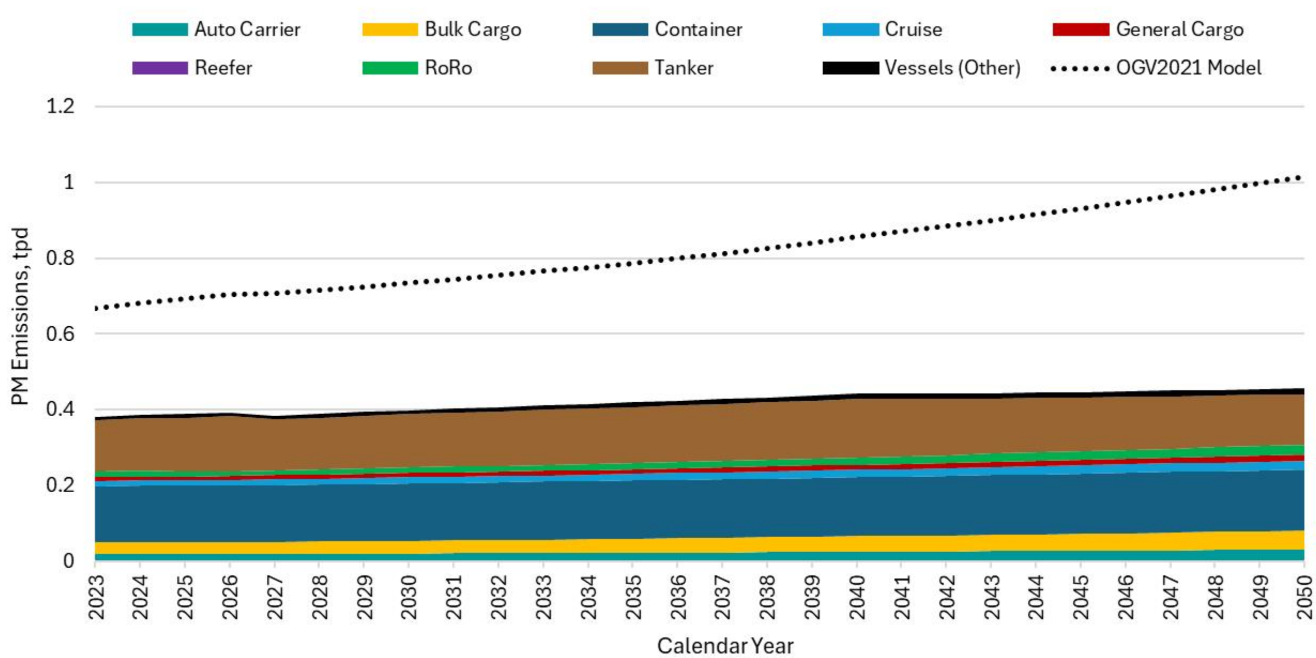
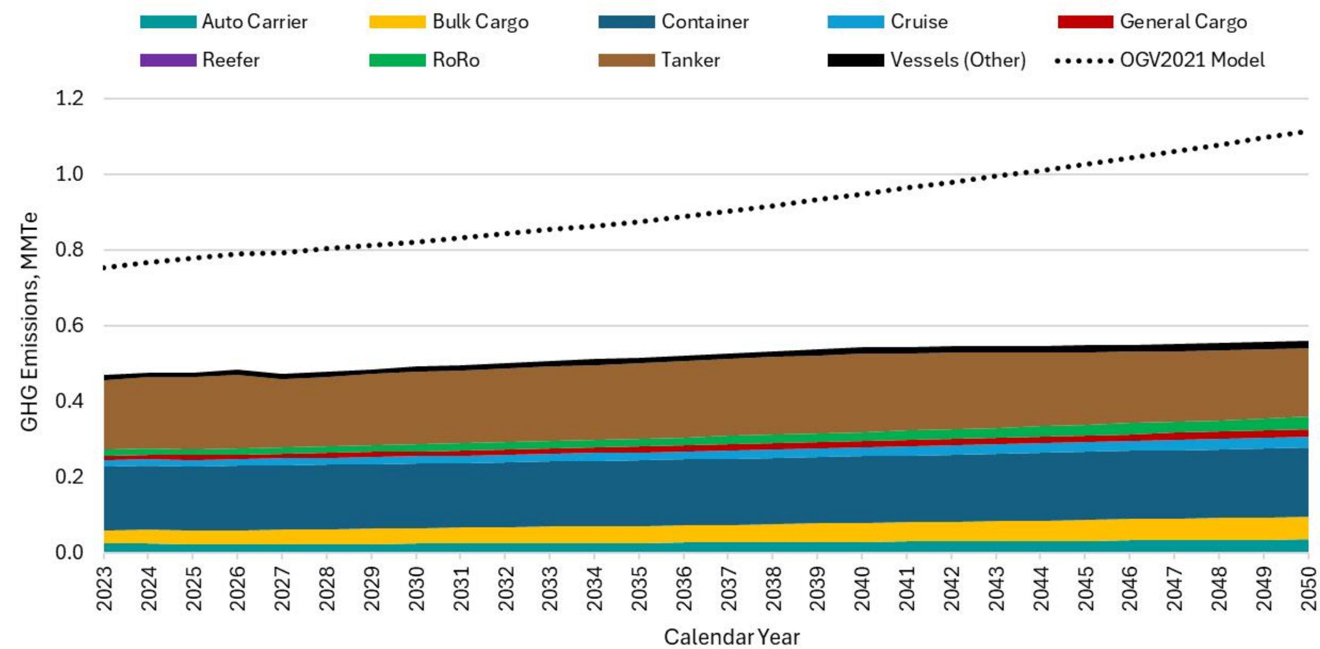


Figure 27. Bay Area GHG emissions from OGVs out to 100 nautical miles by vessel type.



4 Appendices

Appendix A. Applied annual growth rates by vessel type and FAF region using FAF v5.1.

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2023	Bulk Cargo	0.68%	1.37%	0.28%	0.44%	0.60%
2024	Bulk Cargo	0.28%	0%	0%	2.23%	3.56%
2025	Bulk Cargo	0.28%	0%	0%	2.23%	3.56%
2026	Bulk Cargo	-0.32%	0%	0%	2.02%	3.29%
2027	Bulk Cargo	-0.32%	0%	0%	2.02%	3.29%
2028	Bulk Cargo	-0.32%	0%	0%	2.02%	3.29%
2029	Bulk Cargo	-0.32%	0%	0%	2.02%	3.29%
2030	Bulk Cargo	-0.32%	0%	0%	2.02%	3.29%
2031	Bulk Cargo	-0.20%	0%	0%	2.21%	2.82%
2032	Bulk Cargo	-0.20%	0%	0%	2.21%	2.82%
2033	Bulk Cargo	-0.20%	0%	0%	2.21%	2.82%
2034	Bulk Cargo	-0.20%	0%	0%	2.21%	2.82%
2035	Bulk Cargo	-0.20%	0%	0%	2.21%	2.82%
2036	Bulk Cargo	-0.03%	0%	0%	2.39%	2.96%

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2037	Bulk Cargo	-0.03%	0%	0%	2.39%	2.96%
2038	Bulk Cargo	-0.03%	0%	0%	2.39%	2.96%
2039	Bulk Cargo	-0.03%	0%	0%	2.39%	2.96%
2040	Bulk Cargo	-0.03%	0%	0%	2.39%	2.96%
2041	Bulk Cargo	0.16%	0%	0%	2.64%	3.06%
2042	Bulk Cargo	0.16%	0%	0%	2.64%	3.06%
2043	Bulk Cargo	0.16%	0%	0%	2.64%	3.06%
2044	Bulk Cargo	0.16%	0%	0%	2.64%	3.06%
2045	Bulk Cargo	0.16%	0%	0%	2.64%	3.06%
2046	Bulk Cargo	0.36%	0%	0%	2.62%	3.03%
2047	Bulk Cargo	0.36%	0%	0%	2.62%	3.03%
2048	Bulk Cargo	0.36%	0%	0%	2.62%	3.03%
2049	Bulk Cargo	0.36%	0%	0%	2.62%	3.03%
2050	Bulk Cargo	0.36%	0%	0%	2.62%	3.03%
2023	RoRo	1.59%	2.05%	1.67%	-0.09%	1.07%
2024	RoRo	3.39%	0%	0%	3.37%	3.78%
2025	RoRo	3.39%	0%	0%	3.37%	3.78%
2026	RoRo	2.94%	0%	0%	2.87%	3.13%
2027	RoRo	2.94%	0%	0%	2.87%	3.13%
2028	RoRo	2.94%	0%	0%	2.87%	3.13%
2029	RoRo	2.94%	0%	0%	2.87%	3.13%
2030	RoRo	2.94%	0%	0%	2.87%	3.13%
2031	RoRo	2.52%	0%	0%	2.41%	2.66%
2032	RoRo	2.52%	0%	0%	2.41%	2.66%
2033	RoRo	2.52%	0%	0%	2.41%	2.66%
2034	RoRo	2.52%	0%	0%	2.41%	2.66%
2035	RoRo	2.52%	0%	0%	2.41%	2.66%
2036	RoRo	2.56%	0%	0%	2.44%	2.70%
2037	RoRo	2.56%	0%	0%	2.44%	2.70%
2038	RoRo	2.56%	0%	0%	2.44%	2.70%
2039	RoRo	2.56%	0%	0%	2.44%	2.70%
2040	RoRo	2.56%	0%	0%	2.44%	2.70%
2041	RoRo	2.59%	0%	0%	2.46%	2.73%
2042	RoRo	2.59%	0%	0%	2.46%	2.73%
2043	RoRo	2.59%	0%	0%	2.46%	2.73%
2044	RoRo	2.59%	0%	0%	2.46%	2.73%
2045	RoRo	2.59%	0%	0%	2.46%	2.73%
2046	RoRo	2.58%	0%	0%	2.48%	2.75%
2047	RoRo	2.58%	0%	0%	2.48%	2.75%
2048	RoRo	2.58%	0%	0%	2.48%	2.75%

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2049	RoRo	2.58%	0%	0%	2.48%	2.75%
2050	RoRo	2.58%	0%	0%	2.48%	2.75%
2023	General Cargo	3.92%	4.18%	3.90%	3.66%	4.01%
2024	General Cargo	3.19%	0%	0%	3.11%	3.22%
2025	General Cargo	3.19%	0%	0%	3.11%	3.22%
2026	General Cargo	3.01%	0%	0%	2.95%	2.84%
2027	General Cargo	3.01%	0%	0%	2.95%	2.84%
2028	General Cargo	3.01%	0%	0%	2.95%	2.84%
2029	General Cargo	3.01%	0%	0%	2.95%	2.84%
2030	General Cargo	3.01%	0%	0%	2.95%	2.84%
2031	General Cargo	2.71%	0%	0%	2.66%	2.53%
2032	General Cargo	2.71%	0%	0%	2.66%	2.53%
2033	General Cargo	2.71%	0%	0%	2.66%	2.53%
2034	General Cargo	2.71%	0%	0%	2.66%	2.53%
2035	General Cargo	2.71%	0%	0%	2.66%	2.53%
2036	General Cargo	2.76%	0%	0%	2.74%	2.57%
2037	General Cargo	2.76%	0%	0%	2.74%	2.57%
2038	General Cargo	2.76%	0%	0%	2.74%	2.57%
2039	General Cargo	2.76%	0%	0%	2.74%	2.57%
2040	General Cargo	2.76%	0%	0%	2.74%	2.57%
2041	General Cargo	2.81%	0%	0%	2.82%	2.62%
2042	General Cargo	2.81%	0%	0%	2.82%	2.62%
2043	General Cargo	2.81%	0%	0%	2.82%	2.62%
2044	General Cargo	2.81%	0%	0%	2.82%	2.62%
2045	General Cargo	2.81%	0%	0%	2.82%	2.62%
2046	General Cargo	2.87%	0%	0%	2.83%	2.65%
2047	General Cargo	2.87%	0%	0%	2.83%	2.65%
2048	General Cargo	2.87%	0%	0%	2.83%	2.65%
2049	General Cargo	2.87%	0%	0%	2.83%	2.65%
2050	General Cargo	2.87%	0%	0%	2.83%	2.65%
2023	Tanker	0.99%	0.70%	2.89%	2.98%	0.70%
2024	Tanker	2.27%	2.38%	1.43%	-0.19%	1.74%
2025	Tanker	2.27%	2.38%	1.43%	-0.19%	1.74%
2026	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2027	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2028	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2029	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2030	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2031	Tanker	1.22%	1.13%	1.33%	0.20%	0.91%
2032	Tanker	1.22%	1.13%	1.33%	0.20%	0.91%

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2033	Tanker	1.22%	1.13%	1.33%	0.20%	0.91%
2034	Tanker	1.22%	1.13%	1.33%	0.20%	0.91%
2035	Tanker	1.22%	1.13%	1.33%	0.20%	0.91%
2036	Tanker	-1.89%	-2.69%	1.43%	0.38%	-1.70%
2037	Tanker	-1.89%	-2.69%	1.43%	0.38%	-1.70%
2038	Tanker	-1.89%	-2.69%	1.43%	0.38%	-1.70%
2039	Tanker	-1.89%	-2.69%	1.43%	0.38%	-1.70%
2040	Tanker	-1.89%	-2.69%	1.43%	0.38%	-1.70%
2041	Tanker	-1.26%	-2.01%	1.54%	0.53%	-1.20%
2042	Tanker	-1.26%	-2.01%	1.54%	0.53%	-1.20%
2043	Tanker	-1.26%	-2.01%	1.54%	0.53%	-1.20%
2044	Tanker	-1.26%	-2.01%	1.54%	0.53%	-1.20%
2045	Tanker	-1.26%	-2.01%	1.54%	0.53%	-1.20%
2046	Tanker	0.99%	0.70%	2.89%	2.98%	0.70%
2047	Tanker	2.27%	2.38%	1.43%	-0.19%	1.74%
2048	Tanker	2.27%	2.38%	1.43%	-0.19%	1.74%
2049	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2050	Tanker	1.27%	1.19%	1.23%	0.07%	0.90%
2023	Reefer	3.91%	3.80%	3.91%	3.91%	3.68%
2024	Reefer	2.35%	0%	0%	2.65%	2.10%
2025	Reefer	2.35%	0%	0%	2.65%	2.10%
2026	Reefer	2.34%	0%	0%	2.62%	2.34%
2027	Reefer	2.34%	0%	0%	2.62%	2.34%
2028	Reefer	2.34%	0%	0%	2.62%	2.34%
2029	Reefer	2.34%	0%	0%	2.62%	2.34%
2030	Reefer	2.34%	0%	0%	2.62%	2.34%
2031	Reefer	2.12%	0%	0%	2.42%	2.24%
2032	Reefer	2.12%	0%	0%	2.42%	2.24%
2033	Reefer	2.12%	0%	0%	2.42%	2.24%
2034	Reefer	2.12%	0%	0%	2.42%	2.24%
2035	Reefer	2.12%	0%	0%	2.42%	2.24%
2036	Reefer	2.24%	0%	0%	2.55%	2.31%
2037	Reefer	2.24%	0%	0%	2.55%	2.31%
2038	Reefer	2.24%	0%	0%	2.55%	2.31%
2039	Reefer	2.24%	0%	0%	2.55%	2.31%
2040	Reefer	2.24%	0%	0%	2.55%	2.31%
2041	Reefer	2.35%	0%	0%	2.66%	2.38%
2042	Reefer	2.35%	0%	0%	2.66%	2.38%
2043	Reefer	2.35%	0%	0%	2.66%	2.38%
2044	Reefer	2.35%	0%	0%	2.66%	2.38%

Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2045	Reefer	2.35%	0%	0%	2.66%	2.38%
2046	Reefer	2.29%	0%	0%	2.56%	2.36%
2047	Reefer	2.29%	0%	0%	2.56%	2.36%
2048	Reefer	2.29%	0%	0%	2.56%	2.36%
2049	Reefer	2.29%	0%	0%	2.56%	2.36%
2050	Reefer	2.29%	0%	0%	2.56%	2.36%
2023	Container	3.52%	3.32%	3.35%	3.55%	2.33%
2024	Container	3.14%	0.00%	0.00%	3.34%	2.66%
2025	Container	3.14%	0%	0%	3.34%	2.66%
2026	Container	3.51%	0%	0%	2.83%	2.58%
2027	Container	3.51%	0%	0%	2.83%	2.58%
2028	Container	3.51%	0%	0%	2.83%	2.58%
2029	Container	3.51%	0%	0%	2.83%	2.58%
2030	Container	3.51%	0%	0%	2.83%	2.58%
2031	Container	3.10%	0%	0%	2.58%	2.45%
2032	Container	3.10%	0%	0%	2.58%	2.45%
2033	Container	3.10%	0%	0%	2.58%	2.45%
2034	Container	3.10%	0%	0%	2.58%	2.45%
2035	Container	3.10%	0%	0%	2.58%	2.45%
2036	Container	3.19%	0%	0%	2.62%	2.50%
2037	Container	3.19%	0%	0%	2.62%	2.50%
2038	Container	3.19%	0%	0%	2.62%	2.50%
2039	Container	3.19%	0%	0%	2.62%	2.50%
2040	Container	3.19%	0%	0%	2.62%	2.50%
2041	Container	3.29%	0%	0%	2.65%	2.54%
2042	Container	3.29%	0%	0%	2.65%	2.54%
2043	Container	3.29%	0%	0%	2.65%	2.54%
2044	Container	3.29%	0%	0%	2.65%	2.54%
2045	Container	3.29%	0%	0%	2.65%	2.54%
2046	Container	3.38%	0%	0%	2.64%	2.53%
2047	Container	3.38%	0%	0%	2.64%	2.53%
2048	Container	3.38%	0%	0%	2.64%	2.53%
2049	Container	3.38%	0%	0%	2.64%	2.53%
2050	Container	3.38%	0%	0%	2.64%	2.53%

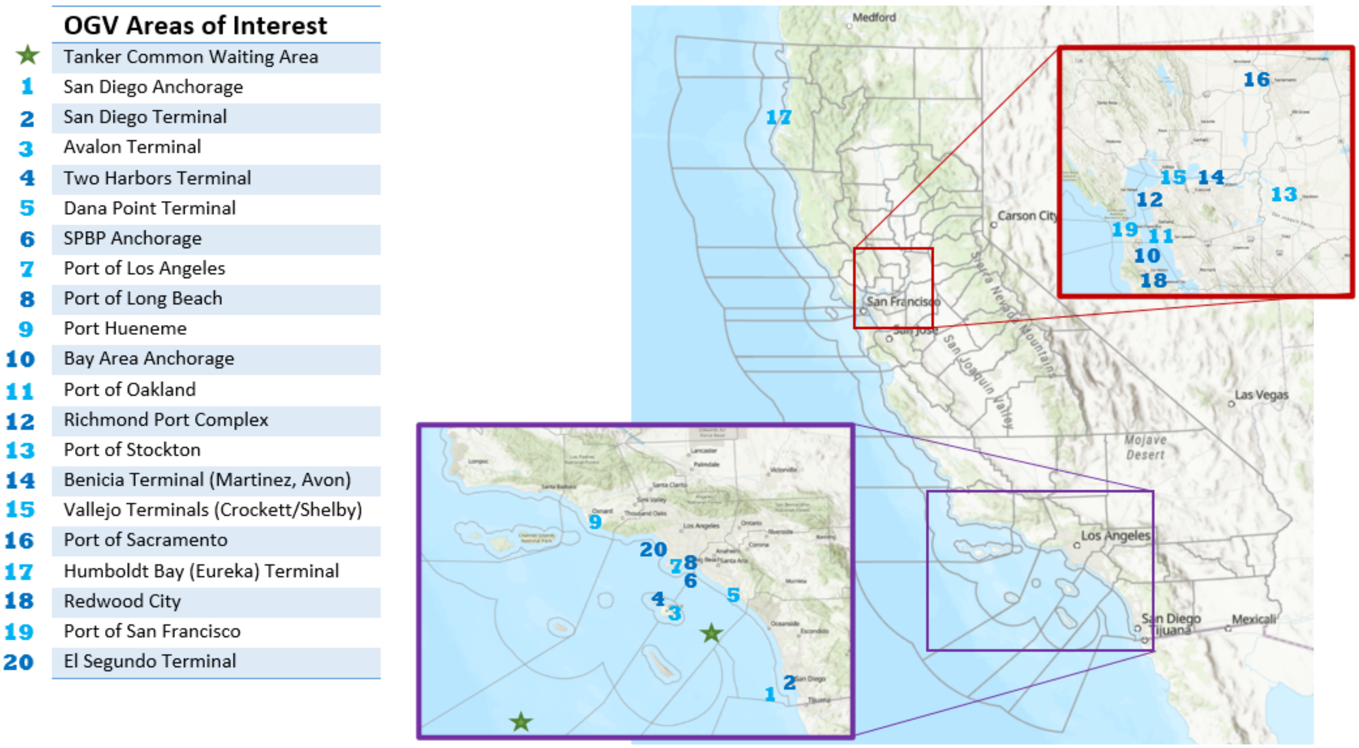
Appendix B. 2023 IHS global registry ship types with statewide inventory vessel classification

Vessel Type	Registry Type
Auto Carrier	Vehicles Carrier

Vessel Type	Registry Type
Bulk Cargo	Bulk Carrier
Bulk Cargo	Bulk Carrier, Self-discharging
Bulk Cargo	Replenishment Dry Cargo Vessel
Bulk Cargo	Wood Chips Carrier
Bulk Cargo	Heavy Load Carrier
Bulk Cargo	Barge Carrier
Bulk Cargo	Heavy Load Carrier, semi submersible
Bulk Cargo	Cement Carrier
Bulk Cargo	Ore Carrier
Container	Container Ship (Fully Cellular)
Container	Container
General Cargo	Open Hatch Cargo Ship
General Cargo	General Cargo Ship
General Cargo	Fish Factory Ship
General Cargo	Crane Vessel LoLo (Lift On-Lift Off)
General Cargo	General Cargo
Cruise	Passenger/Cruise
Reefer	Refrigerated Cargo Ship
Reefer	Reefer
RoRo	RoRo Cargo Ship
RoRo	Container Ship (Fully Cellular/RoRo Facility)
RoRo	Yacht Carrier, semi submersible
RoRo	General Cargo Ship (with RoRo facility)
RoRo	Passenger RoRo
RoRo	RoRo/Container
Tanker	Chemical/Products Tanker
Tanker	Products Tanker
Tanker	Crude Oil Tanker
Tanker	Crude/Oil Products Tanker
Tanker	Replenishment Tanker
Tanker	Products Tanker
Tanker	LPG Tanker
Tanker	LNG Tanker
Tanker	Oil Products Tanker
Tanker	Oil/Chemical Tanker
Tanker	Tanker
Vessels (Other)	Cable Layer
Vessels (Other)	Hospital Vessel
Vessels (Other)	Drilling Ship
Vessels (Other)	Hopper Dredger
Vessels (Other)	Pipe Layer Crane Vessel

Vessel Type	Registry Type
Vessels (Other)	Unknown

Appendix C. Map of marine vessel regional areas of interest



Appendix D. 2023 IHS registry data vessel averages by type and size bin for vessels within 100 NM of California

Vessel Type	Size Bin	Average Engine RPM while Operating	Average of Main Engine Total Installed kW	Average of Auxiliary Engine Total Installed kW
Auto Carrier		105.082	14,342.206	1,472.738
Bulk Cargo		112.567	9,113.541	644.873
Container	1	166.714	9,984.000	1,026.000
Container	2	142.800	20,156.961	2,334.063
Container	3	100.889	25,204.702	1,778.850
Container	4	101.898	36,229.159	1,975.097
Container	5	100.947	43,999.362	2,246.820
Container	6	97.986	58,108.972	2,297.902
Container	7	99.788	56,742.047	2,934.086
Container	8	98.080	65,703.653	3,179.365

Vessel Type	Size Bin	Average Engine RPM while Operating	Average of Main Engine Total Installed kW	Average of Auxiliary Engine Total Installed kW
Container	9	92.034	59,108.551	3,647.170
Container	10	90.732	58,868.463	3,379.844
Container	11	96.971	60,811.441	3,645.161
Container	12	88.000	55,485.500	4,160.000
Container	13	97.518	68,283.571	3,575.964
Container	14	85.948	55,859.190	3,676.840
Container	15	78.000	46,288.333	3,571.333
Container	16	100.000	75,275.000	3,571.333
Container	17	83.667	60,530.000	4,500.000
Container	18	102.000	80,080.000	4,320.000
Container	19	80.857	61,892.857	4,485.714
Container	23	80.000	75,570.000	4,466.667
Cruise		1,049.011	30,972.567	2,043.955
General Cargo		238.035	7,969.003	757.185
Reefer		130.378	12,062.632	1,115.963
RoRo		297.320	23,789.771	1,709.750
Tanker	Aframax	218.080	17,964.442	1,244.843
Tanker	Handysize	125.455	9,006.791	971.287
Tanker	Panamax	151.530	11,817.653	904.948
Tanker	Suezmax	100.505	17,860.284	1,105.341
Tanker	ULCC	71.900	27,816.520	1,555.560
Tanker	VLCC	71.387	25,495.403	1,295.763
Vessels (Other)		1,445.477	5,102.604	321.716

Appendix E. OGV2025 Model forecasted NOx emissions (tpd) through 2050 by mode and engine category out to 100 NM

Year	Activity Mode	Auxiliary	Boiler	Main Engine
2023	Anchorage Hoteling	4.250	0.490	0.000
2024	Anchorage Hoteling	4.218	0.496	0.000
2025	Anchorage Hoteling	4.205	0.503	0.000
2026	Anchorage Hoteling	4.144	0.509	0.000
2027	Anchorage Hoteling	4.119	0.516	0.000
2028	Anchorage Hoteling	4.121	0.523	0.000
2029	Anchorage Hoteling	4.147	0.531	0.000
2030	Anchorage Hoteling	4.157	0.538	0.000
2031	Anchorage Hoteling	4.186	0.544	0.000
2032	Anchorage Hoteling	4.211	0.549	0.000
2033	Anchorage Hoteling	4.226	0.555	0.000

2034	Anchorage Hoteling	4.216	0.561	0.000
2035	Anchorage Hoteling	4.148	0.567	0.000
2036	Anchorage Hoteling	4.142	0.573	0.000
2037	Anchorage Hoteling	4.169	0.579	0.000
2038	Anchorage Hoteling	4.207	0.586	0.000
2039	Anchorage Hoteling	3.806	0.592	0.000
2040	Anchorage Hoteling	3.545	0.599	0.000
2041	Anchorage Hoteling	3.396	0.598	0.000
2042	Anchorage Hoteling	3.270	0.597	0.000
2043	Anchorage Hoteling	2.983	0.597	0.000
2044	Anchorage Hoteling	2.743	0.597	0.000
2045	Anchorage Hoteling	2.547	0.597	0.000
2046	Anchorage Hoteling	2.243	0.599	0.000
2047	Anchorage Hoteling	2.009	0.600	0.000
2048	Anchorage Hoteling	1.837	0.602	0.000
2049	Anchorage Hoteling	1.747	0.604	0.000
2050	Anchorage Hoteling	1.559	0.606	0.000
2023	Berth Hoteling	8.753	1.859	0.000
2024	Berth Hoteling	8.800	1.889	0.000
2025	Berth Hoteling	7.428	1.919	0.000
2026	Berth Hoteling	7.413	1.949	0.000
2027	Berth Hoteling	5.995	1.980	0.000
2028	Berth Hoteling	6.033	2.012	0.000
2029	Berth Hoteling	6.083	2.043	0.000
2030	Berth Hoteling	6.145	2.074	0.000
2031	Berth Hoteling	6.217	2.094	0.000
2032	Berth Hoteling	6.254	2.115	0.000
2033	Berth Hoteling	6.306	2.136	0.000
2034	Berth Hoteling	6.359	2.158	0.000
2035	Berth Hoteling	6.389	2.180	0.000
2036	Berth Hoteling	6.464	2.202	0.000
2037	Berth Hoteling	6.537	2.225	0.000
2038	Berth Hoteling	6.592	2.248	0.000
2039	Berth Hoteling	6.266	2.272	0.000
2040	Berth Hoteling	6.169	2.296	0.000
2041	Berth Hoteling	6.047	2.282	0.000
2042	Berth Hoteling	5.944	2.270	0.000
2043	Berth Hoteling	5.595	2.258	0.000
2044	Berth Hoteling	5.391	2.247	0.000
2045	Berth Hoteling	5.229	2.237	0.000
2046	Berth Hoteling	5.009	2.234	0.000
2047	Berth Hoteling	4.830	2.232	0.000
2048	Berth Hoteling	4.715	2.230	0.000

2049	Berth Hoteling	4.695	2.229	0.000
2050	Berth Hoteling	4.641	2.229	0.000
2023	Maneuvering	0.332	0.016	0.000
2024	Maneuvering	0.331	0.017	0.000
2025	Maneuvering	0.330	0.017	0.000
2026	Maneuvering	0.329	0.017	0.000
2027	Maneuvering	0.327	0.017	0.000
2028	Maneuvering	0.328	0.018	0.000
2029	Maneuvering	0.332	0.018	0.000
2030	Maneuvering	0.333	0.018	0.000
2031	Maneuvering	0.336	0.019	0.000
2032	Maneuvering	0.339	0.019	0.000
2033	Maneuvering	0.341	0.019	0.000
2034	Maneuvering	0.344	0.019	0.000
2035	Maneuvering	0.347	0.020	0.000
2036	Maneuvering	0.341	0.020	0.000
2037	Maneuvering	0.344	0.020	0.000
2038	Maneuvering	0.348	0.020	0.000
2039	Maneuvering	0.314	0.021	0.000
2040	Maneuvering	0.300	0.021	0.000
2041	Maneuvering	0.290	0.021	0.000
2042	Maneuvering	0.282	0.021	0.000
2043	Maneuvering	0.265	0.021	0.000
2044	Maneuvering	0.241	0.021	0.000
2045	Maneuvering	0.222	0.021	0.000
2046	Maneuvering	0.203	0.021	0.000
2047	Maneuvering	0.181	0.021	0.000
2048	Maneuvering	0.170	0.021	0.000
2049	Maneuvering	0.164	0.021	0.000
2050	Maneuvering	0.141	0.021	0.000
2023	Transit	18.468	0.740	111.514
2024	Transit	18.386	0.749	111.536
2025	Transit	18.371	0.758	111.555
2026	Transit	18.135	0.766	110.861
2027	Transit	17.950	0.776	110.108
2028	Transit	17.931	0.785	110.225
2029	Transit	17.982	0.794	110.802
2030	Transit	18.030	0.803	111.215
2031	Transit	18.136	0.812	112.035
2032	Transit	18.209	0.820	112.741
2033	Transit	18.225	0.828	113.180
2034	Transit	18.095	0.837	113.372
2035	Transit	18.063	0.845	113.446

2036	Transit	18.056	0.854	113.359
2037	Transit	18.137	0.864	114.170
2038	Transit	18.247	0.873	115.051
2039	Transit	16.951	0.882	106.693
2040	Transit	15.727	0.892	101.293
2041	Transit	15.080	0.897	95.913
2042	Transit	14.507	0.902	92.460
2043	Transit	13.618	0.907	86.973
2044	Transit	12.830	0.913	81.400
2045	Transit	12.252	0.919	76.777
2046	Transit	11.164	0.926	70.384
2047	Transit	10.143	0.933	63.904
2048	Transit	9.522	0.940	58.794
2049	Transit	9.239	0.948	56.981
2050	Transit	8.771	0.956	52.693