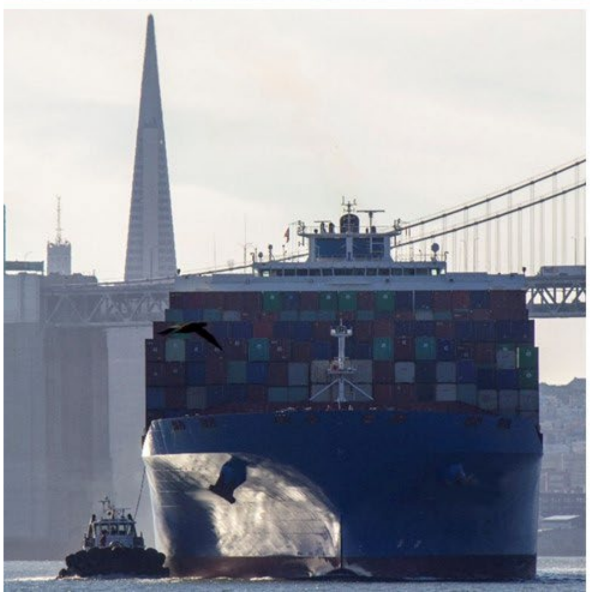
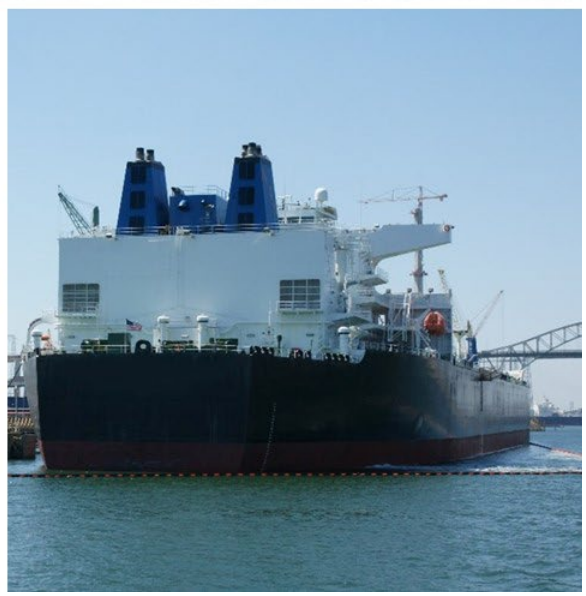
2021 California Ocean-Going Vessels Emissions Inventory





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CALIFORNIA
AIR RESOURCES BOARD

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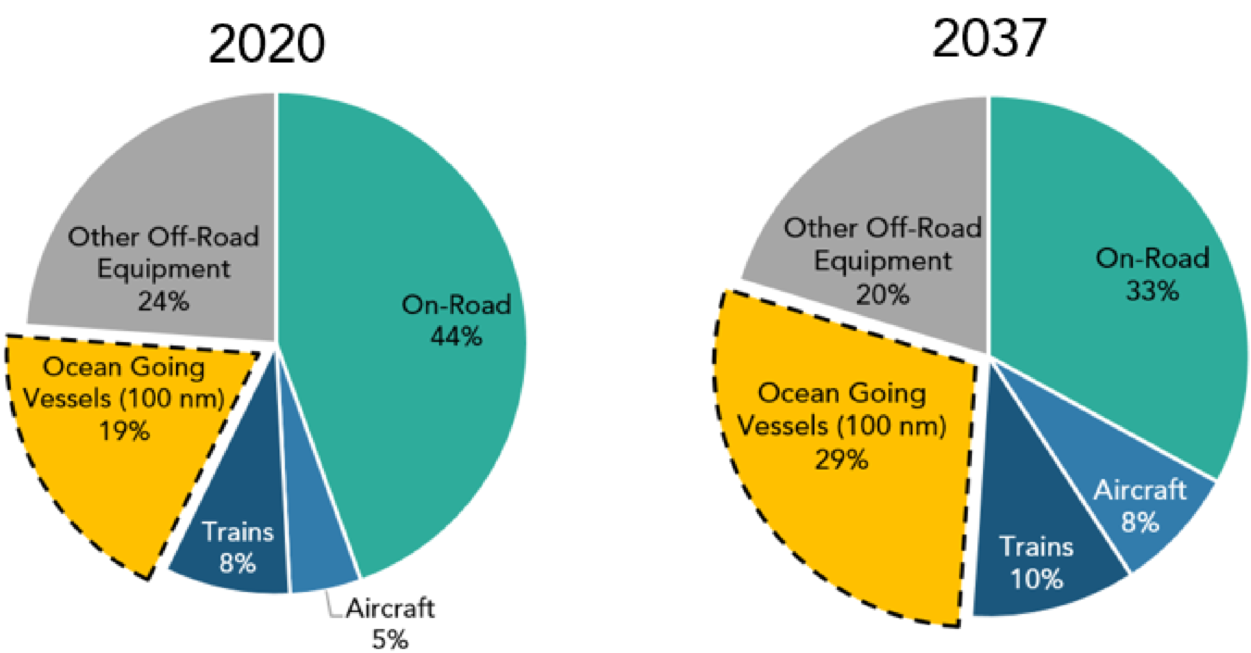
1 Executive Summary

This inventory provides an update to the emissions from ocean-going vessels (OGVs) that visit California's ports and waters. The 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 the US economy but are also a significant source of pollution in areas near ports and marine terminal complexes (MTCs). Specifically, the vessels' diesel engines and boilers continue to be one of the largest contributors of criteria pollutants in the state, including oxides of nitrogen (NOx) and particulate matter (PM). OGV are one of the few categories that are expected to continue to increase emissions contributions even as other sources are reduced by strict engine standards and in-use requirements, see Figure 1.

Figure 1. Statewide mobile source NOx emissions contributions by sector in 2020 and 2037[1].



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

- Improved location specificity and base year accuracy by using Automated Information System (AIS) data, a system that tracks vessel movement via onboard transponders to terrestrial and satellite receivers.

[1] CEPAM 2019 v1.02, *https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php*

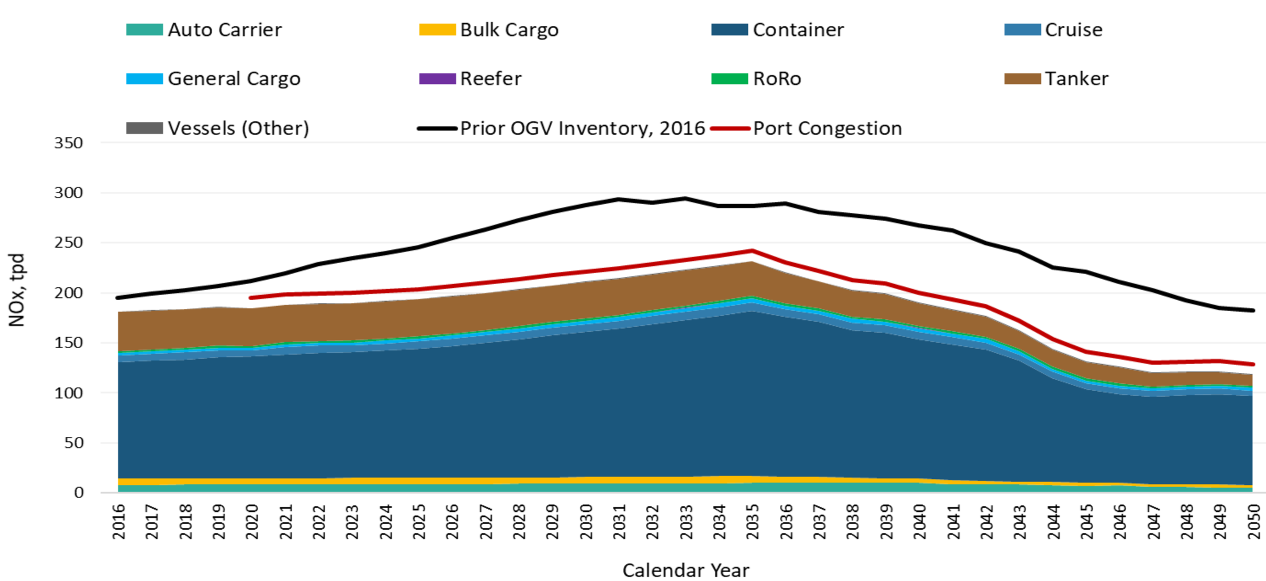
- Updated growth forecast and future engine tier assumptions, including the delay of Tier 3 marine engines until 2030 (previously only reflected in update to emissions at-berth)
- Updated emissions factors for main and auxiliary engines and boilers

Overall, these combined changes have slightly lowered statewide emissions, emissions in the South Coast region and the Bay Area, as shown in Figure 2 below.

In late 2020 and throughout 2021, there was a significant increase in freight throughput and congestion near the Ports of Los Angeles, Long Beach, and Oakland. This led to increased vessel visits and a vast increase in anchorage emissions from vessel parked just off the coast of impacted ports. The impacts from this event are not yet reflected in this inventory. The AIS data to complete that assessment will be available in mid-2022. CARB has released an initial estimate for the Ports of Los Angeles and Long Beach[2], based on vessel counts, of the impact from the increased anchorage, showing an increase of between 10 to 25 tpd of NOx in the past year. With the implementation of mitigation measures by the Ports, notably queuing of ships much further off-shore, near shore emissions impacts have been reduced.

In Figure 2 below, the black line at the top represents the previous inventory. The shaded area at the bottom represents the official updated inventory (which does not include increased anchorage emissions). The red line above that represents a scenario for the new inventory with an additional 10 tons per day of NOx due to increased anchorage emissions.

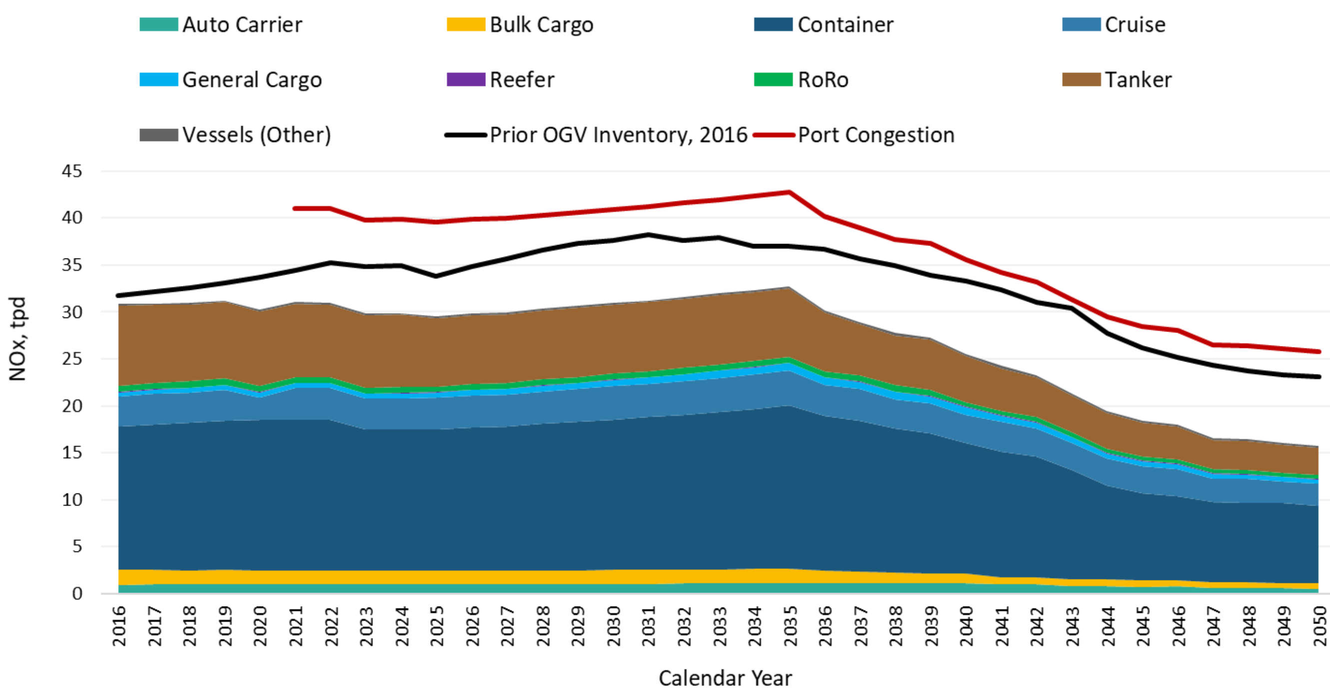
Figure 2. Statewide NOx emissions from OGVs out to 100nm by vessel type



[2] *https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/msei-documentation-port-congestion-impacts*

a large impact on port communities, particularly in South Coast. The figure below shows the impact on the South Coast Air basin.

Figure 3. South Coast NOx emissions from OGVs out to 100nm by vessel type



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.

- 2020 Automatic Identification System (AIS)[3] records from National Oceanic and Atmospheric Administration (NOAA).
- 2020 vessel technical specifications data from the Information Handling Services (IHS).
- 2020 US EPA emissions factors[4]
- 2020 engine load defaults from Vessel Boarding Program (VBP) conducted by Starcrest Consulting Group at the Port of Los Angeles (PoLA)[5] and the Port of Long Beach (PoLB)[6].
- 2019 CARB At-Berth Compliance Reporting from CARB's Enforcement Division
- 2019 Data from Chevron[7] for tanker engine load during operations
- Growth forecasts from Freight Analysis Framework (FAF) version 4.4[8]
- Historical port calls at PoLA[3] and PoLB[4], 2005 – 2019
- Historical monthly TEUs at major ports, 2012 – 2020
- Tier III arrival at CA ports forecasted from the Mercator Report, completed by the Ports of Los Angeles and Long Beach (POLA/POLB)[9]

Table 1. Data flow and sources used in 2020 base year update to the statewide ocean-going vessels model (OGV2021).

Input Type	Data Source	Description
Activity and Location Data	2020 Automatic Identification System (AIS)	Provides base year vessel movement
Vessel Data	2020 IHS Vessel Registry	Provides vessel and installed engine characteristics
Engine Operation Data	2020 Vessel Boarding Program (VBP) Average Engine Default Loads, 2019 Tanker Loads from Industry	Provides engine characteristics specific to mode of operation.
Compliance Data	2019 CARB At-Berth Compliance Reporting	Provides total time at berth and time on shorepower.

[3] 2020 AIS records, *https://coast.noaa.gov/htdata/CMSP/AISDataHandler/2020/index.html*

[4] 2020 US EPA Port Inventory Guidance, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf*

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

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

[7] 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*

[8] Freight Analysis Framework, *https://ops.fhwa.dot.gov/freight/freight_analysis/faf/*

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

Input Type	Data Source	Description
Forecasting and Growth Data	Freight Analysis Framework (FAF4.4), Historical port calls (2005 – 2019), 2019 Tioga Report (Oakland), 2016 Mercator Report (Tier III Delay)	Provides growth rates, port capacity, vessel tier forecast, and future vessel capacity distributions.
Emissions Factors	2020 US EPA Updates to Emissions Factors, 2011 OGV Inventory Factors (ROG, TOG, NH3)	Provides emissions rates in grams per kilo-watt hour (g/kWh)
Model Output	2021 OGV Inventory Output	Output of emissions and energy use statewide and regionally for calendar years 2016 – 2050.

2.2 Geographic Domain

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

Figure 4. 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[10], 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 massive data archive of these historical records made publicly available through collaboration of the United States Coast Guard (USCG), National Oceanic (NOAA), and the Bureau of Ocean and Energy Management (BOEM).

AIS records were downloaded from Marine Cadastre for the calendar year 2020, for the geographic domain shown in the previous section. 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 2Table 1 below. Duplicate date-timestamps by vessel identifiers were removed from analysis, as well as records with incomplete date-timestamps in AIS records.

2.3.2 Activity Mode Designations

OGVs identified in AIS records were assigned 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 difference in the timestamps provided by AIS minute-by minute records. Total daily hours for all vessels were adjusted not to exceed 24 hours to correct for 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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[10] 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 Hotelling (or At-Berth)	Operations while moored or berthed to a dock	Within 4 km grid of port, not in anchorage zone, and speed of 0 knots.
Anchorage Hotelling	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 3 nm of shore or anchorage areas at speeds less than 3 knots.
Transit	Vessel operations at sea, between destinations	All speeds greater than 3 knots within the 3 nm boundary, or all operations outside anchorage areas past the 3 nm boundary.

Propulsion (main) engines are assumed to be off during the berth hoteling and anchorage hoteling operating modes.

Berth hoteling time based on AIS was validated with 2019 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 hotelling emissions account for time using shore power and reflect no engine operations during reported time plugged into shore power.

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, etc). This IHS data was used to fill in vessel characteristics needed in the inventory, but not provided in the AIS data. The 2020 IHS registry data was provided by South Coast AQMD staff with the data provider's permission. The vessel characteristics data was then matched to the 2020 AIS activity records based on vessel identifiers IMO and MMSI.

A limitation of using registry data sources is the significant amount of missing data, 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

OGV 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 2021 statewide OGV inventory are as defined in Table 3.

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 lower limit in thousands used. 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.
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 80001 – 120000 DWT vessels are designed for bulk liquid transfer.
Tanker, Handysize	Smaller capacity vessels of 0 – 60000 DWT and designed for bulk liquid transfer.
Tanker, Panamax	60001 – 80000 DWT vessels designed for bulk liquid transfer through the Panama Canal.
Tanker, Suezmax	120001 – 200000 DWT vessels designed for bulk liquid transfer through the Suez Canal.

Vessel Type and Size Bin Designation	Capacity and Description
Tanker, ULCC	Ultra-Large Crude Carriers are 315001 – 520000 DWT vessels designed for bulk liquid transfer.
Tanker, VLCC	Very Large Crude Carriers are 200001 – 315000 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)[11].

** Twenty-Foot Unit Equivalent (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 SSD by default, and auxiliary engines missing necessary fields are assigned as MSD by default as recommended by the US EPA[12]. 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

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

[11] 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*

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

the build year). The keel laid date is generally part of the IHS vessel characteristics data. In the inventory, the engine tier is assigned based on the 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

2.5 Emissions Factors

The factors assigned to estimate emissions can vary depending on:

- Engine: main (propulsion), auxiliary, or boiler
- Fuel type: diesel fuels are distillate marine gas oil (MGO) or marine diesel oil (MDO), residual fuels are residual marine (RM) or heavy fuel oil (HFO), and alternative fuels with assigned factors are liquified natural gas (LNG)
- Engine tier based on keel-laid year
- Engine speed type: SSD, MSD, HSD

Emissions factors presented below reflect the latest information available from US EPA[13]. The units for all emissions factors presented are grams per kWh. Per EPA recommendation, all vessels with unknown fuel types were assumed to be using diesel fuels to comply with fuel sulfur regulations. Note that electric drive engines have not been assigned distinct emissions factors by the US EPA due to insufficient available data, as such MSD-ED engines are assigned the same emissions factors as MSD engines. This is an area for future study and refinement.

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	SSD	17	16	14.4	3.4
Main	Diesel	MSD	13.2	12.2	10.5	2.6
Main	Residual	SSD	18.1	17	15.3	3.4

[13] 2020 US EPA Port Inventory Guidance, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf*

Engine	Fuel	Type	No Tier/ Tier 0	Tier I	Tier II	Tier III
Main	Residual	MSD	14	13	11.2	2.6
Auxiliary	Diesel	MSD	10.9	9.8	7.7	2
Auxiliary	Diesel	HSD	13.8	12.2	10.5	2.6
Auxiliary	Residual	MSD	14.7	13	11.2	2
Auxiliary	Residual	HSD	11.6	10.4	8.2	2.6
Main	Diesel	ST	2	-	-	-
Main	Diesel	GT	5.7	-	-	-
Main	Residual	ST	2.1	-	-	-
Main	Residual	GT	6.1	-	-	-
Main	LNG	LNG	1.3	-	-	-
Auxiliary	LNG	LNG	1.3	-	-	-
Boiler	Diesel	Boiler	2	-	-	-
Boiler	Residual	Boiler	2.1	-	-	-

*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.

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	0.1836	0.6	1.4	0.029	0.6318	0.012	593.110	0.3617
Main	Diesel	MSD	205	0.1867	0.5	1.1	0.029	0.5265	0.010	657.230	0.4008
Main	Diesel	ST	300	0.1600	0.1	0.2	0.075	-	-	-	-
Main	Diesel	GT	300	0.0100	0.1	0.2	0.075	-	-	-	-
Main	Residual	SSD	195	0.6067	0.6	1.4	0.031	0.6318	0.012	607.230	0.3812
Main	Residual	MSD	215	0.6099	0.5	1.1	0.031	0.5265	0.010	669.510	0.4203
Main	Residual	ST	305	0.9300	0.1	0.2	0.080	-	-	-	-
Main	Residual	GT	305	0.0600	0.1	0.2	0.080	-	-	-	-
Main	LNG	LNG	166	0.0300	0.0	1.3	0.029	0.0000	0.000	456.500	0.3245
Auxiliary	Diesel	MSD	217	0.1886	0.4	1.1	0.029	0.4212	0..008	695.702	0.4242
Auxiliary	Diesel	HSD	217	0.1886	0.4	1.1	0.029	0.4212	0.008	695.702	0.4242
Auxiliary	Residual	MSD	227	0.6118	0.4	0.9	0.310	0.4212	0.008	706.878	0.4438
Auxiliary	Residual	HSD	227	0.6118	0.4	0.9	0.310	0.4212	0.008	706.878	0.4438
Auxiliary	LNG	LNG	166	0.1806	0.0	1.3	0.029	0.0000	0.000	456.500	0.3245
Boiler	Diesel	Boiler	300	0.2016	0.1	0.2	0.075	0.1053	0.002	961.800	0.5865

Engine	Fuel	Type	BSFC	PM10	HC	CO	N2O	VOC	CH4	CO2	SO2
Boiler	Residual	Boiler	305	0.6240	0.1	0.2	0.080	0.1053	0.002	949.770	0.5963

*Brake-specific fuel consumption (BSFC), particulate matter greater than 10-microns in diameter (PM10), hydrocarbon (HC), carbon monoxide (CO), nitrous oxide (N2O), volatile organic compounds (VOC), methane (CH4), carbon dioxide (CO2), sulfur dioxide (SO2).

2.5.3 Low Load Adjustments

Low load adjustment factors (LLAF)[14] are applied to main engines when operating below 20-percent capacity, otherwise LLAF is equal to 1 in emissions calculations, as shown in Table 8. OGV main engine low load adjustment factors per pollutant. These adjustments vary depending on pollutant and account for the main engines becoming less efficient at low loads, leading to increased fuel consumption. Low load adjustments are not needed for auxiliary generators or boilers which are not subject to the same operating inefficiencies.

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

Main Engine Loads (%)	NOx	HC	CO	PM	CO2	SO2 at 0.1% fuel sulfur content
≤ 2	4.63	21.18	9.68	7.29	3.28	9.54
3	2.92	11.68	6.46	4.33	2.44	6.38
4	2.21	7.71	4.86	3.09	2.01	4.79
5	1.83	5.61	3.89	2.44	1.76	3.85
6	1.60	4.35	3.25	2.04	1.59	3.21
7	1.45	3.52	2.79	1.79	1.47	2.76
8	1.35	2.95	2.45	1.61	1.38	2.42
9	1.27	2.52	2.18	1.48	1.31	2.16
10	1.22	2.20	1.96	1.38	1.25	1.95
11	1.17	1.96	1.79	1.30	1.21	1.78
12	1.14	1.76	1.64	1.24	1.17	1.63
13	1.11	1.60	1.52	1.19	1.14	1.51
14	1.08	1.47	1.41	1.15	1.11	1.41
15	1.06	1.36	1.32	1.11	1.08	1.32
16	1.05	1.26	1.24	1.08	1.06	1.24
17	1.03	1.18	1.17	1.06	1.04	1.17
18	1.02	1.11	1.11	1.04	1.03	1.11
19	1.01	1.05	1.05	1.02	1.01	1.05
≥ 20	1.00	1.00	1.00	1.00	1.00	1.00

[14] 2020 US EPA Port Inventory Guidance, *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf*

2.5.4 Tier III Main Engine Duty Cycle Adjustment

Tier III main engines are primarily selective catalytic reduction (SCR) and exhaust gas recirculation (EGR). Recent evidence[15] suggests that when these engines are at low loads, the engine temperatures may not heat enough for the SCR or EGR systems to operate efficiently. As such, Tier III main engines operating below 25 percent capacity are modeled operating at Tier II levels for NOx emissions calculations. This is consistent with the planned inventory 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 capacity 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 in Section 2.7.4.

2.6 Emissions Estimation

The 2020 base year 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:

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 power 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 hotelling, etc.). In other inventories, power is generally calculated by multiplying a load factor by the maximum installed engine power from vessel registry. In this inventory, the operating power is output power, or is equivalent to load multiplied by the maximum horsepower.

Propulsion Engine Operating Power

Main engine operating power was calculated using the propeller law[16], which varies engine load based on the cube of vessel speed.

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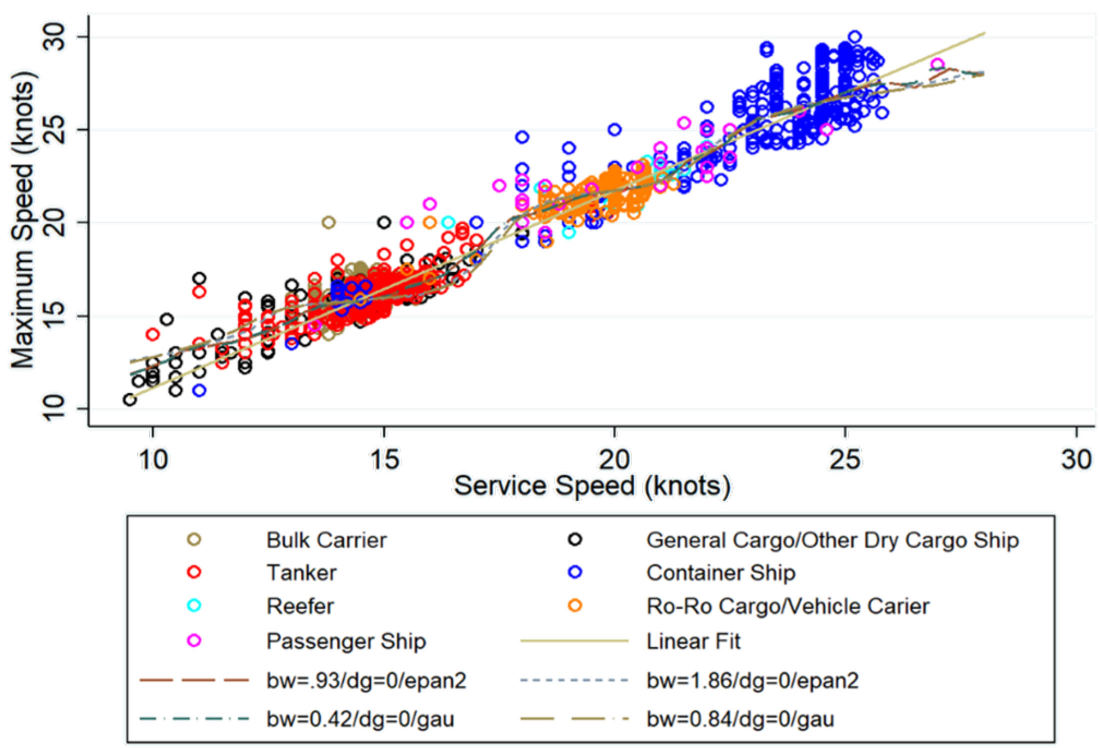
[15] ICCT Feasibility Study, *https://theicct.org/sites/default/files/publications/ICCT_MarineSCR_Mar2014.pdf*
[16] *https://www.man-es.com/docs/default-source/marine/tools/basic-principles-of-ship-propulsion_web_links.pdf?sfvrsn=12d1b862_10*

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

Vessel total installed power was obtained per vessel from IHS registry. If engine max installed power was missing, the average from the 2020 registry data was applied by type and size bin, as shown in the appendix.

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. South Coast AQMD staff conducted a statistical analysis that created linear fit line and non-linear fit curves (via kernel-weighted local polynomial smoothing) from known vessel maximum speed and service speed for 3,176 OGVs of various types (see Figure 5). The linear fit was eventually used to back fill missing maximum speeds in the 2020 registry data.

Figure 5. Relationship between maximum and service speeds from IHS registry data for 3,000+ 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 travelling at maximum speed. Similarly, AIS observed speeds under 0 knots were corrected to be travelling at 0 knots.

Auxiliary Engine Operating Power

Average auxiliary maximum installed power was taken from 2020 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. In rare cases, operating power values were corrected not to exceed to maximum installed power.

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

If engine max 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 2020 update using data from the Vessel Boarding Program.

Table 9. 2020 Vessel Boarding Program updates to auxiliary engine default loads by operating mode.

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier		583	1325.5	954	664
Bulk		255	282.5	522.5	260.5
Bulk - Heavy Load		358.5	949	211	253
Bulk - Self Discharging		305	807	179	305
Container	1	1326	1323.5	772.5	1000
Container	2	1420	1944	696.5	529
Container	3	1540	1596.5	1052	500
Container	4	1447	2381	981.5	882.5
Container	5	1444.5	2341.5	949.5	945
Container	6	1769	2547	1090.5	1266
Container	7	1582	2449.5	934.5	924
Container	8	1553	2485.5	1116.5	1250.5
Container	9	1568.5	2703	1069	1095
Container	10	1515.5	2180	1075	1092
Container	11	1499.5	2044	937.5	1006
Container	12	2061	2643.5	1805.5	1742.5
Container	13	1647.5	2357	1267	1238
Container	14	1593	2112	1218.5	1201.5
Container	17	1617.5	1953.5	1225	1220.5
Cruise	1500	3994	5268	3069	2289
Cruise	2000	7000	9000	5613	-

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Cruise	2500	11000	11350	6900	-
Cruise	3000	9781	8309	6089	5916
Cruise	3500	8282	10369	8292	7475
Cruise	4000	9945	11411	10445	10191
Cruise	4500	12500	14000	12000	9900
Cruise	5000	13000	14500	13000	-
General Cargo		466.5	1104	808.5	180
Miscellaneous		909	979	822	470.5
Reefer		1164	1250.5	1156	1345.5
RoRo		283	848.5	490	283
Tanker	Chemical	464.5	582	1307.5	412
Tanker	Handysize	558.5	599	903.5	560
Tanker	Panamax	485	589.5	826	358.5
Tanker	Aframax	470	587	929.5	428.5
Tanker	Suezmax	737	541	597	573
Tanker	VLCC	580	668	980	508
Tanker	ULCC	779	922	1250	637

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. 2020 Vessel Boarding Program updates to boiler default loads by operating mode.

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier		91.5	183.5	308.5	300.5
Bulk		58	139.5	172	172
Bulk - Heavy Load		35	94	125	125
Bulk - Self Discharging		44	103	132	132
Container	1	139	241	608	306
Container	2	252.5	246	404.5	307
Container	3	271.5	327.5	759	437
Container	4	202.5	368	485	496
Container	5	252	473	534	528.5
Container	6	275.5	554.5	728	726
Container	7	352	601.5	684	680.5
Container	8	256	492.5	608	627
Container	9	432.5	604.5	732.5	705
Container	10	312.5	423.5	573.5	573.5
Container	11	254.5	354.5	365.5	370.5

Vessel Type	Size Bin	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Container	12	350	596.5	683	683
Container	13	230	307.5	537.5	536.5
Container	14	288.5	458.5	546.5	623
Container	17	184	334.5	592	592
Container	19	460	726	761	761
Cruise	1500	992	784	766	867
Cruise	2000	1070	1145	976	1951
Cruise	2500	1382	1773	1506	3005
Cruise	3000	596	602	431	895
Cruise	3500	697	1199	1068	1984
Cruise	4000	401	347	868	989
Cruise	4500	0	0	503	503
Cruise	5000	0	0	503	503
General Cargo		93	114	148	149.5
Miscellaneous		61.5	103	144	144
Reefer		80	149.5	229	229
RoRo		67	148	259	251
Tanker	Chemical	88	133.5	336.5	225.5
Tanker	Handysize	143	143	2564	144
Tanker	Panamax	249	294.5	3170.5	432
Tanker	Aframax	225	235.5	5357.5	384
Tanker	Suezmax	144	198	6118	503
Tanker	VLCC	240	60	6945	503
Tanker	ULCC	238	334	10599	353

Richmond Tanker Boiler Load Adjustment

As noted in the documentation for the most recent berth hoteling emission inventory[17], the operational power of tanker boilers berthing in Richmond were adjusted based unique operational characteristics of vessels at the Richmond Complex. Power provided to the pumps from electrical generators onboard two tanker vessels are coupled with steam turbines served by boilers, rather than auxiliary engines. Per supporting data provided by Chevron Richmond Refinery, these two vessels introduced in 2018 account for 70 percent of their terminal crude deliveries – as confirmed in CARB activity baseline data. Auxiliary operational power from compression ignition diesel engines is assumed to be zero for these vessels during berth hotelling operations in Richmond.

Additionally, the operational power for boilers during this time is increased by the equivalent amount (based on the average operational power for tanker auxiliary engines at Richmond,

[17] 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*

or 1,480 kW), 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 are 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 particulate matter.

Cruise COVID-19 Pandemic Load Adjustment

The COVID-19 pandemic had a significant impact on cruise ship energy consumption due to voluntary suspended vessel operations reducing the need to power onboard entertainment facilities in the 2020 inventory base year. An analysis by Starcrest Consulting Group estimated the change in energy needs when cruise ships suspend major onboard operations, where the Port of Los Angeles had an average of 27-percent reduction in cruise ship energy consumption[18], and the Port of Long Beach had an average of 31-percent reduction in cruise ship energy consumption[19]. Based on the total calls of cruise vessels at both ports combined, the average energy reduction applied to cruise ships statewide in the 2020 base year was 28.78-percent of business-as-usual energy consumption for auxiliary engines and boilers.

2.7 Forecasting Future Year Emissions

The OGV statewide inventory was forecasted to 2050 from the 2020 base year using a static age distribution model, which maintains the age distribution of vessels observed in the 2020 base year 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, and cruise vessels were adjusted in 2020 base year for COVID-19 pandemic impacts to loads, as detailed in the subsections below.

2.7.1 Base Year Age Distribution

The 2020 base year showed the majority of OGVs visiting California were Tier I vessels (age 10-20) with very few Tier III visits (age 0-3). As shown in the figure below, a large number of OGVs were built in 2015 before the Tier III engine standard came into effect. Additionally, the base year data revealed a small but still significant portion fleet operators holding on to vessels greater than 25 years in age. Figure 6 and Figure 7 show the age distribution in aggregate and by vessel type.

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

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

Figure 6. Age distribution of the combined 1,469 OGVs observed within 100 nm from California shoreline in base year 2020.

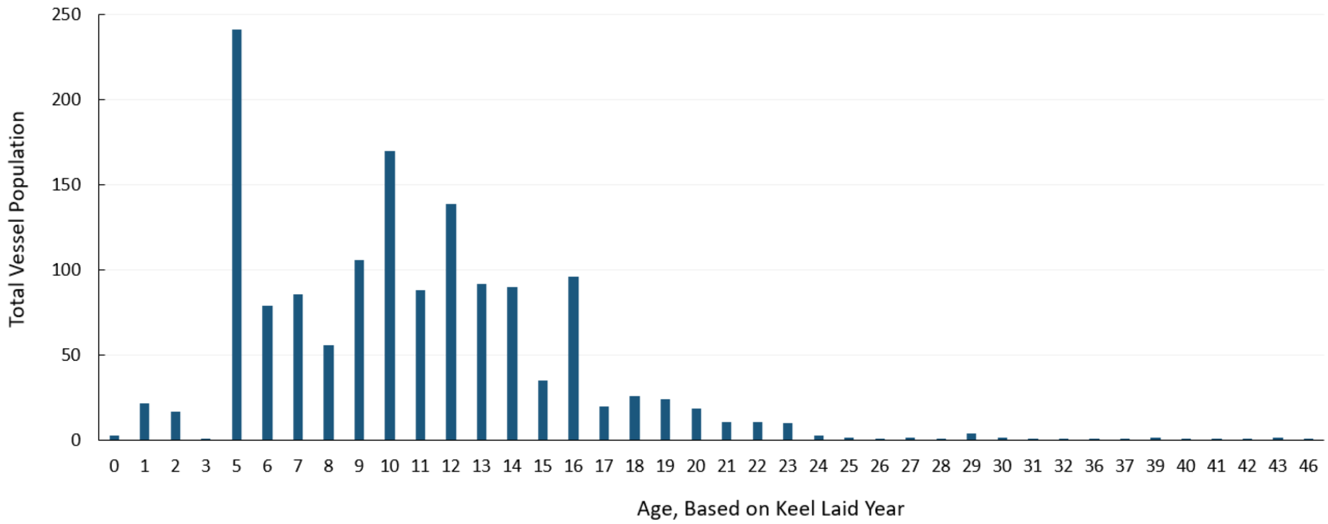
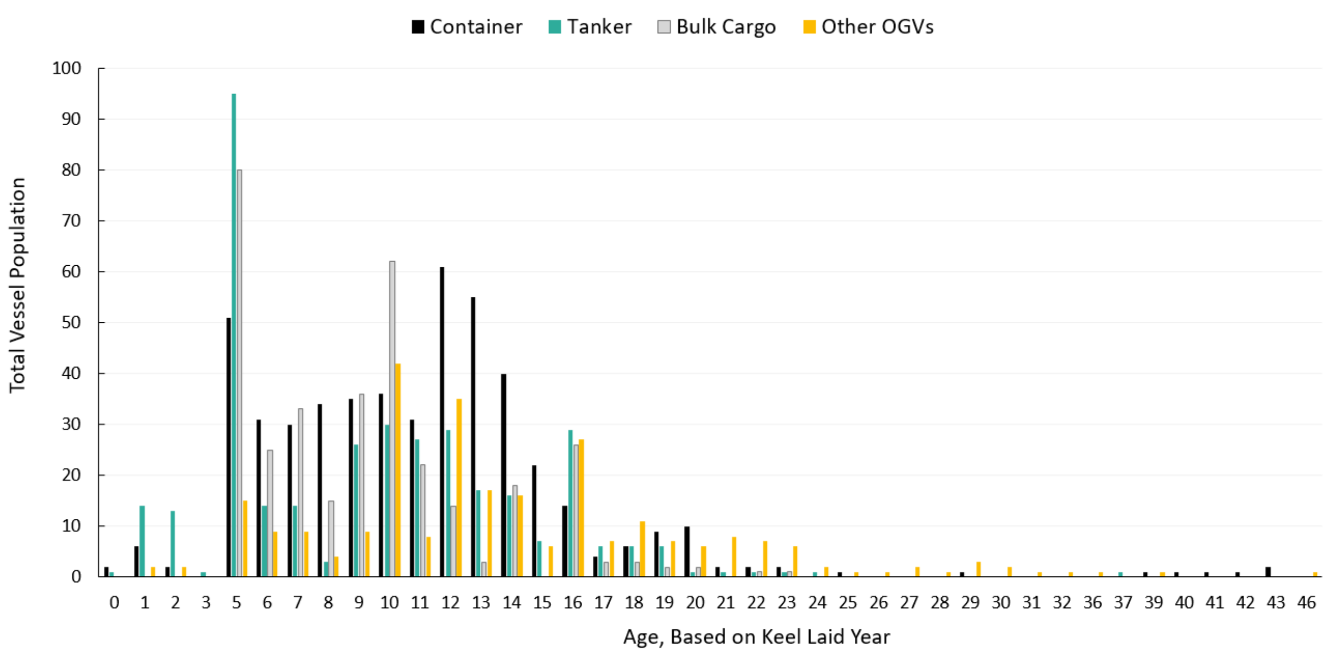


Figure 7. Age distribution of 1,469 OGVs observed within 100 nm from California shoreline in base year 2020 by vessel type.



2.7.2 Growth Rates

Freight Analysis Framework v4.4 and Tioga Report

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 2045 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, construction, among others.

Water-based transports were assigned to vessel types based on commodity as detailed in the table below:

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
Container	Printed products
Container	Textiles/leather
Container	Tobacco products
Container	Waste/scrap
Container	Wood products
General cargo	Chemical products

Vessel Type	FAF Commodity Type
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

FAF forecast annual growth rates for 2045 were assumed to remain constant through 2050, as shown in the Appendix for all vessel types. Tioga report[20] was used for containership annual growth in the Oakland region beginning in calendar year 2026, as shown in Table 12 for containerships. The Tioga report was a location-specific growth study conducted for the Bay Conservation and Development Commission, and therefore was able to consider more specific factors than the FAF analysis. The FAF data was used until 2025 as the Tioga report had high growth forecasts for 2020 and the early 2020s, which have not matched observed data and current short-term forecasts.

Table 12. Annual growth rates applied to containerships based on Freight Analysis Framework (FAF4.4) and Tioga for Oakland regions in calendar years 2026+.

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
2016	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2017	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2018	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2019	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2020	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2021	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2022	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2023	Container	1.035241	1.033217	1.033501	1.035472	1.023334
2024	Container	1.035241	1.033217	1.033501	1.035472	1.023334
2025	Container	1.035241	1.033217	1.033501	1.035472	1.023334
2026	Container	1.035241	1.033217	1.033501	1.035472	1.016967 *
2027	Container	1.035241	1.033217	1.033501	1.035472	1.016967 *
2028	Container	1.036429	1.034335	1.034971	1.036552	1.016967 *
2029	Container	1.036429	1.034335	1.034971	1.036552	1.016967 *

[20] Tioga Report, *https://www.bcdc.ca.gov/seaport/2020-05-11-Seaport-Revised-Regional-Cargo-Forecast-Capacity-Study.pdf*

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
2030	Container	1.036429	1.034335	1.034971	1.036552	1.016967 *
2031	Container	1.036429	1.034335	1.034971	1.036552	1.019624 *
2032	Container	1.036429	1.034335	1.034971	1.036552	1.019624 *
2033	Container	1.036810	1.034439	1.035547	1.037948	1.019624 *
2034	Container	1.036810	1.034439	1.035547	1.037948	1.019624 *
2035	Container	1.036810	1.034439	1.035547	1.037948	1.019624 *
2036	Container	1.036810	1.034439	1.035547	1.037948	1.024776 *
2037	Container	1.036810	1.034439	1.035547	1.037948	1.024776 *
2038	Container	1.042258	1.037759	1.042296	1.045389	1.024776 *
2039	Container	1.042258	1.037759	1.042296	1.045389	1.024776 *
2040	Container	1.042258	1.037759	1.042296	1.045389	1.024776 *
2041	Container	1.042258	1.037759	1.042296	1.045389	1.023461 *
2042	Container	1.042258	1.037759	1.042296	1.045389	1.023461 *
2043	Container	1.008434	1.038663	1.058817	1.064134	1.023461 *
2044	Container	1.008434	1.038663	1.058817	1.064134	1.023461 *
2045	Container	1.008434	1.038663	1.058817	1.064134	1.023461 *
2046	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2047	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2048	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2049	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2050	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *

2.7.3 Containership Capacity Trends

Historical SPBP Vessel Calls, 2005 – 2019

Based on 2005 to 2019 data on container vessels that visit the Port of Los Angeles[21] and the Port of Long Beach[22], containerships with less than 8000 TEU capacity have been calling less frequently to SPBPs while containerships with more than 8000 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 kW-hr energy consumption per TEU overall[23]. Figure 8 below depicts these trends over time.

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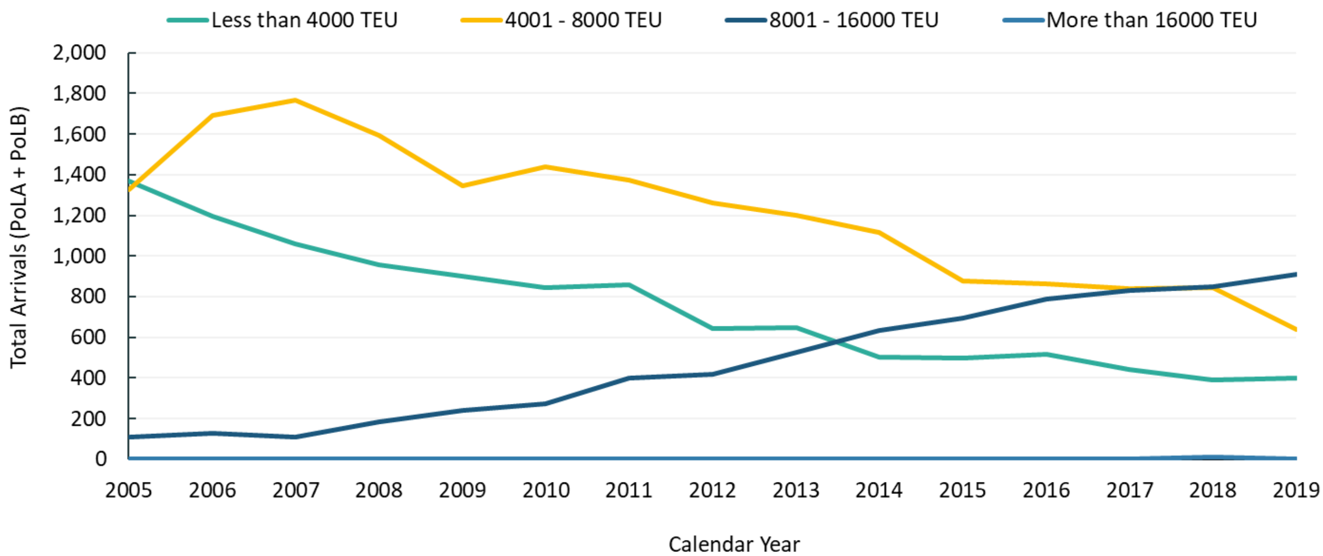
[21] Port of Los Angeles Emissions Inventories, *https://www.portoflosangeles.org/environment/air-quality/air-emissions-inventory*

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

[23] 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*

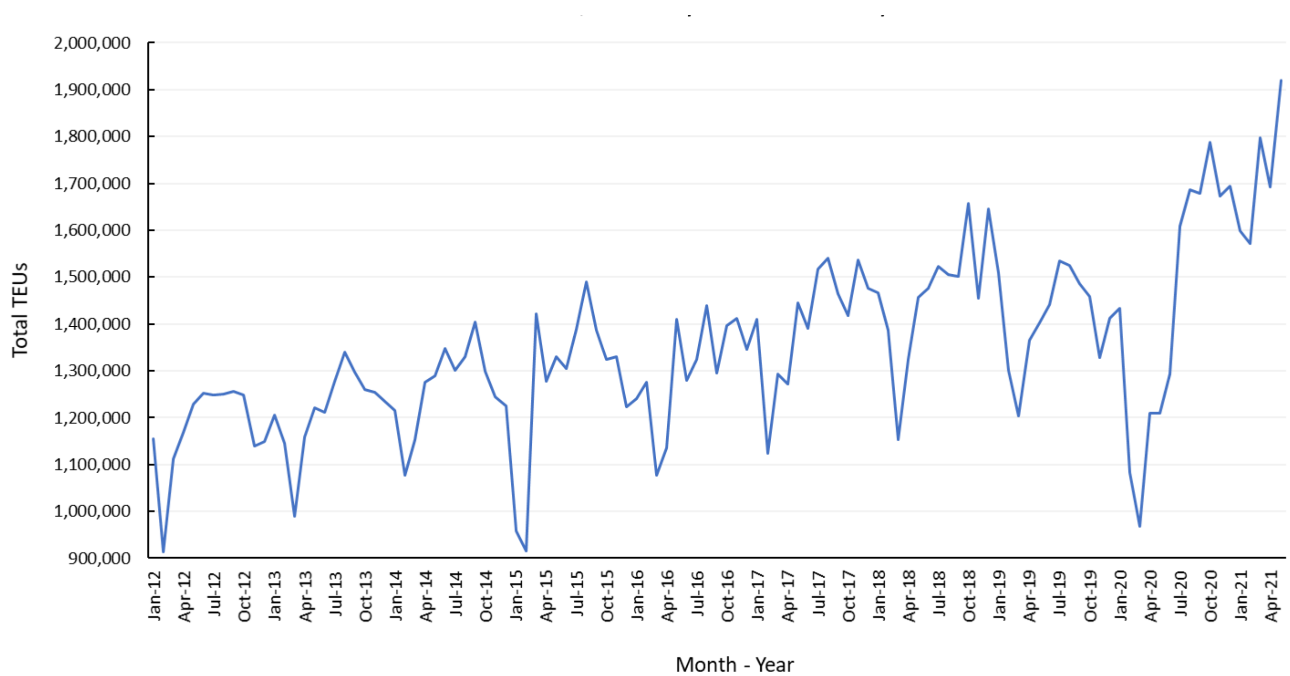
Figure 8. Container vessel visit trends by TEU size bin



Historical Monthly TEUs at Major Ports, 2012 – 2020

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

Figure 9. San Pedro Bay Ports combined monthly total TEUs from January 2012 through May 2021



Containership Growth Capacity Adjustment

Annual growth rates were applied to containerships based on TEU capacity necessary to meet TEU delivery demands according to FAF. Based on the historical trends, containerships with capacities less than 8000 TEU are not projected to grow into the future, and instead maintain their current vessel visit levels.

The growth rate of vessels over 8000 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 8000 TEU capacity were 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 8000 TEU capacity were increased until total TEUs delivered from *all* containerships increased by 2 percent. If over 8000 TEU vessels had been responsible for half of total TEU deliveries 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.

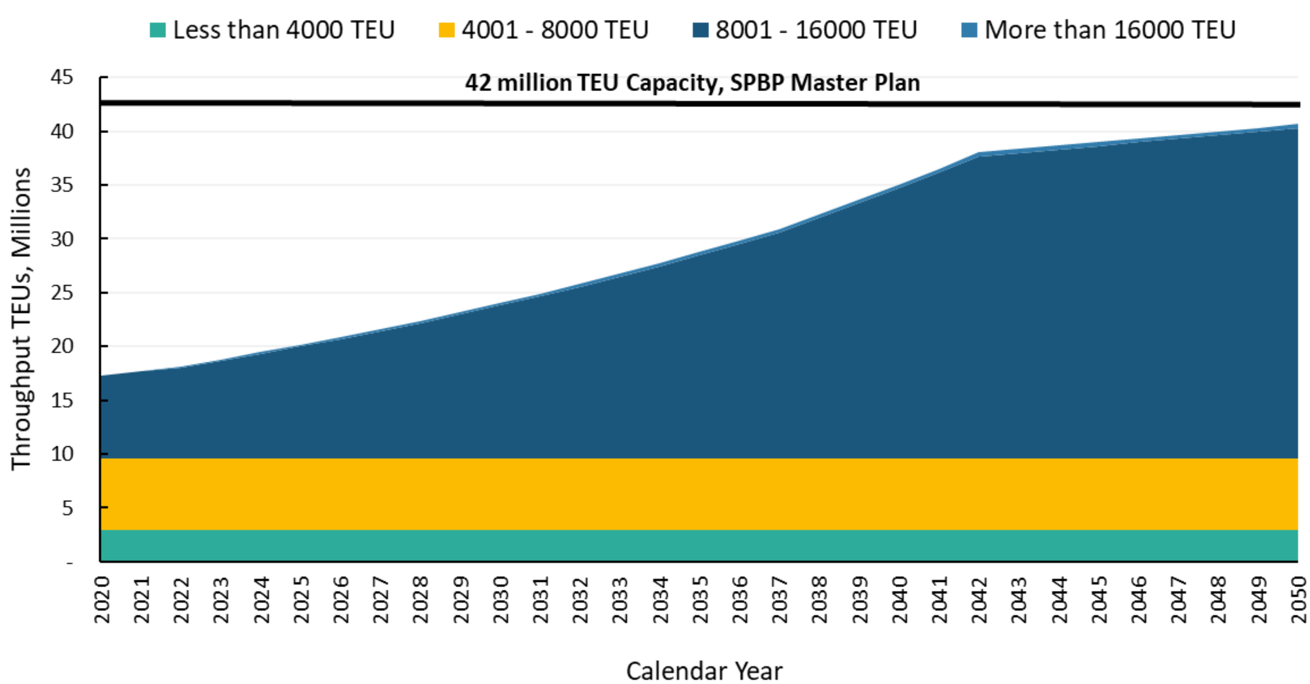
Table 13. Growth Rate for Container Vessels over 8000 TEU Capacity

Year	Percent Annual Growth
2020	3.3%
2021	3.3%
2022	3.2%
2023	4.9%
2024	4.8%
2025	4.8%
2026	4.7%
2027	4.6%
2028	4.8%
2029	4.7%
2030	4.7%
2031	4.6%
2032	4.6%
2033	4.6%
2034	4.5%
2035	4.5%
2036	4.5%
2037	4.4%
2038	5.0%
2039	5.0%
2040	5.0%
2041	4.9%
2042	4.9%

Year	Percent Annual Growth
2043	1.0%
2044	1.0%
2045	1.0%
2046	1.0%
2047	1.0%
2048	1.0%
2049	1.0%
2050	1.0%

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[24] prior to 2050 (the last year of the inventory forecast).

Figure 10. San Pedro Bay Ports (SPBP) forecasted containership throughput and maximum capacity (million TEUs).



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

2.7.4 Tier Assumptions

Mercator Report, Tier III Delay

The marine engine standards[25] require installation of Tier III engines in all new marine vessels after 2016. However, according to an analysis conducted by Starcrest Consulting Group[26] 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 seen 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.

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 Starcest's VBP data provided engine operation characteristics. The emissions factors were adopted from US EPAs latest 2020 guidance document, except for ROG TOG and NH3 factors that remain unchanged from the prior updates to the OGV inventory. The 2020 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 2016 updates to OGV emissions at Berth, as shown in the figure below. Additionally, port congestion impacts are incorporated into the figures as reference using the 10 tpd average increase in NOx emissions from containerships anchored near SPBP in 2021.

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

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

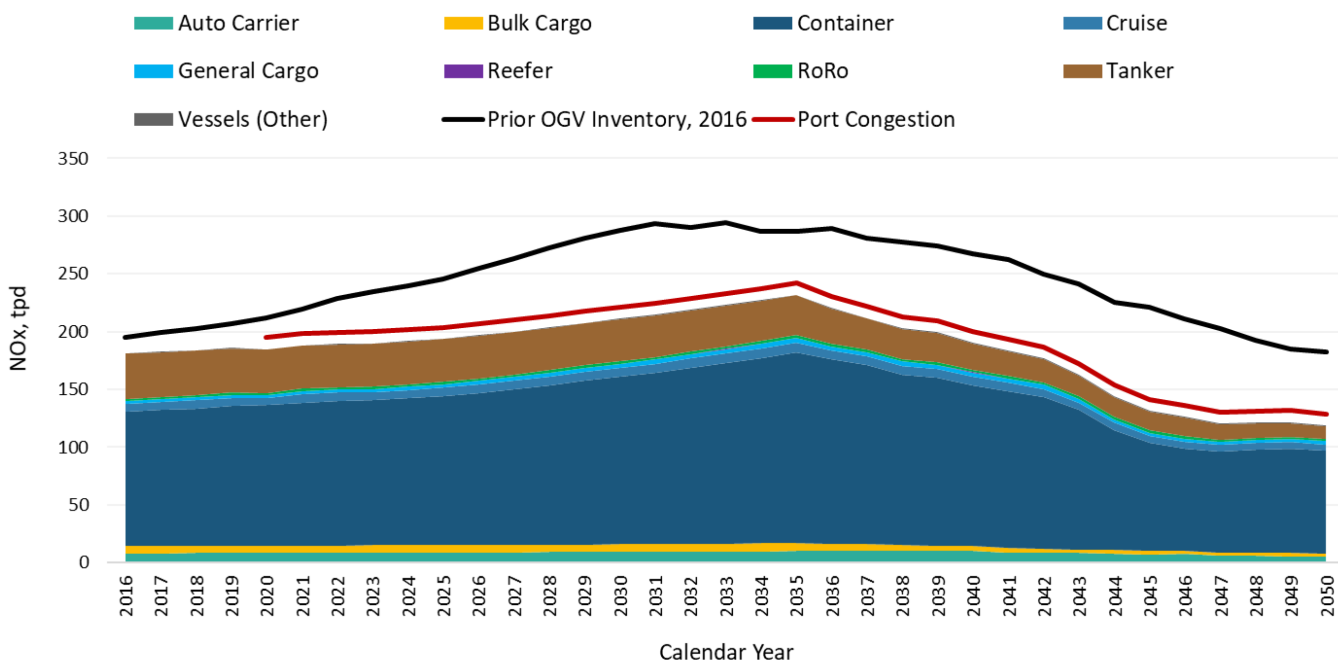


Table 14. Statewide OGV base year 2020 emissions in tons per day (tpd) by air district out to 100 nautical miles from California shoreline.

Air District, Out to 100 nm	NOx	PM_{10}	CO	N_2O	VOC	CH_4	CO_2
Bay Area AQMD	41.276	0.640	4.708	0.103	1.628	0.031	2,101.389
Mendocino County APCD	4.417	0.058	0.445	0.009	0.177	0.003	188.791
Monterey Bay Unified APCD	33.738	0.453	3.481	0.069	1.362	0.026	1,472.555
North Coast Unified AQMD	13.396	0.172	1.309	0.027	0.541	0.010	561.629
Northern Sonoma County APCD	2.573	0.034	0.258	0.005	0.105	0.002	112.392
Sacramento Metropolitan AQMD	0.075	0.001	0.007	0.000	0.003	0.000	3.370
San Diego County APCD	6.421	0.103	0.703	0.017	0.261	0.005	350.420
San Joaquin Valley APCD	0.051	0.001	0.007	0.000	0.002	-	4.706
San Luis Obispo County APCD	11.387	0.153	1.192	0.023	0.460	0.009	493.021
Santa Barbara County APCD	27.794	0.386	3.170	0.055	1.079	0.021	1,216.763
South Coast AQMD	30.215	0.651	4.032	0.121	1.162	0.022	2,310.177
Ventura County APCD	13.406	0.196	1.593	0.028	0.531	0.010	615.853
Yolo/Solano AQMD	0.046	0.001	0.006	0.000	0.002	-	3.965
Statewide Total	184.7942	2.8491	20.9099	0.4578	7.3127	0.1389	9435.0297

Figure 12. South Coast NOx emissions from OGVs out to 100 nautical miles by vessel type

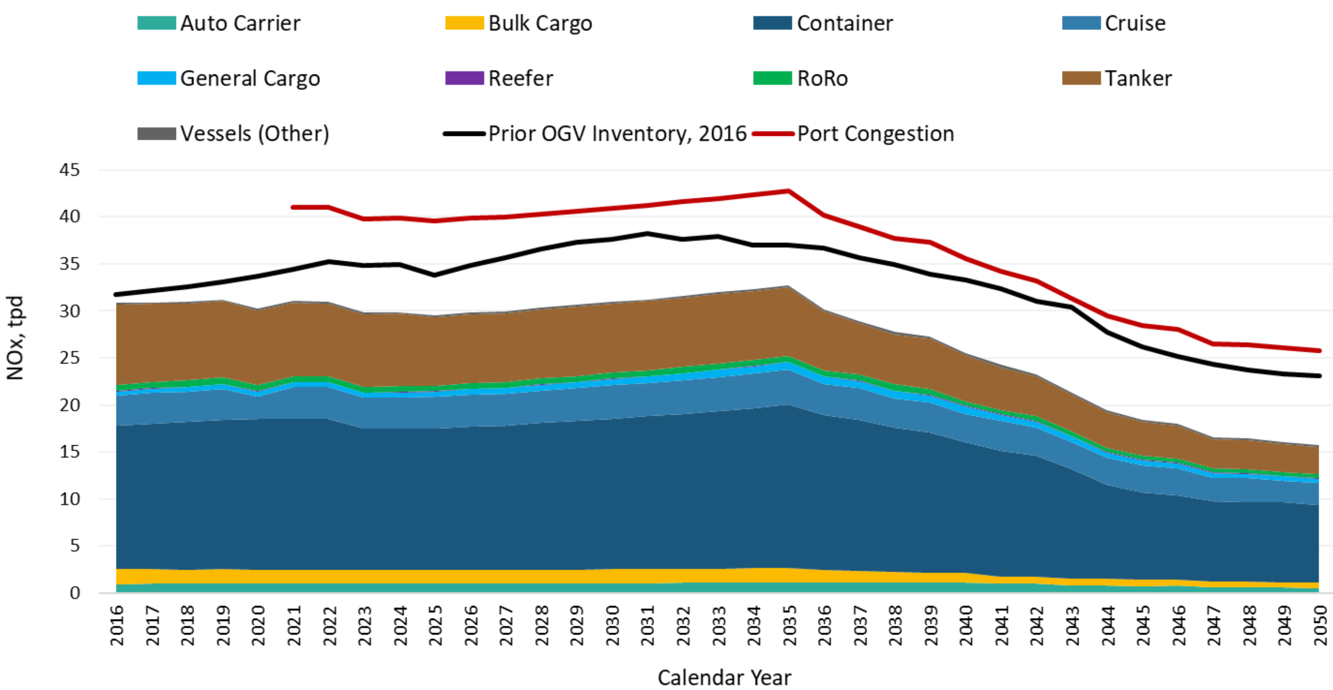
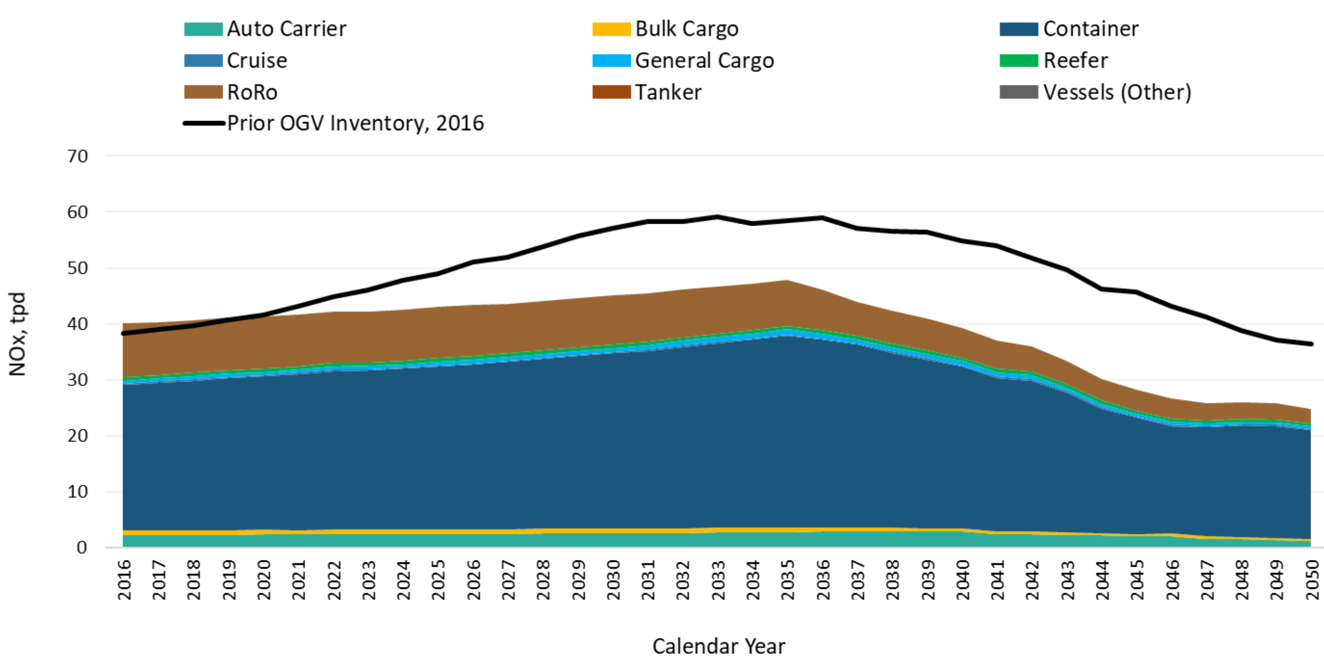


Figure 13. Bay Area NOx emissions from OGVs out to 100 nautical miles by vessel type.

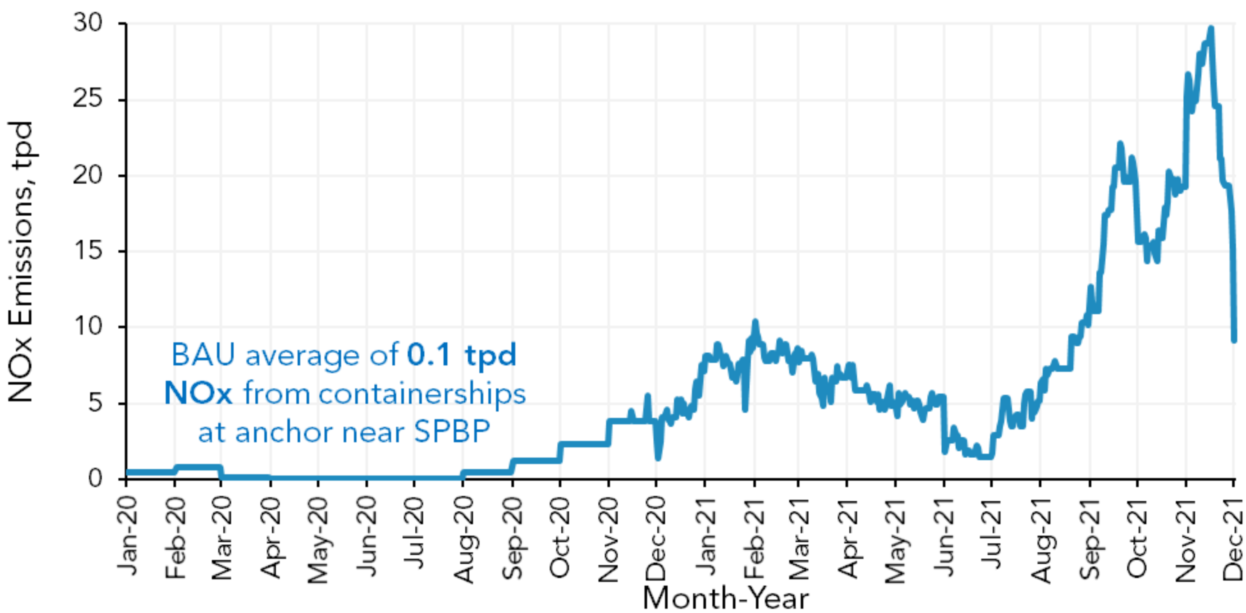


4 Ongoing Monitoring and Potential Future Updates

4.1 Port Congestion Impacts

The COVID-19 Pandemic and related congestions at major California ports have had a substantial impact on the freight system overall. To better understand implications of these changes to local communities and freight movements, CARB staff analyzed impacts on emissions from containerships at anchorage, trucks, and locomotives near major California ports and published several summary documents describing the emissions impact[27]. As of 2021, there has been an averaged increase of 10 tpd NOx emissions from containerships anchored at SPBP, as shown in Figure 14. It is unclear how long these unprecedented changes will last, and CARB staff are currently working towards reasonable adjustments in forecasted years to be incorporated in a future update to the statewide OGV emissions inventory.

Figure 14. NOx emissions from anchored containerships at the San Pedro Bay Ports.



[27] Emissions Impact of Congestion at California Ports, https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/msei-documentation-port-congestion-impacts

5 Appendices

Appendix A. Applied annual growth rates by vessel type and FAF region using FAF v4.4 in addition to Tioga report for Oakland containerships in calendar years 2026+

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
2016	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2017	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2018	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2019	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2020	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2021	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2022	Bulk Cargo	1.001779	1.002170	0.999577	1.001362	1.000933
2023	Bulk Cargo	1.006780	1.013750	1.002756	1.004445	1.006020
2024	Bulk Cargo	1.006780	1.013750	1.002756	1.004445	1.006020
2025	Bulk Cargo	1.006780	1.013750	1.002756	1.004445	1.006020
2026	Bulk Cargo	1.006780	1.013750	1.002756	1.004445	1.006020
2027	Bulk Cargo	1.006780	1.013750	1.002756	1.004445	1.006020
2028	Bulk Cargo	1.005596	1.010664	1.001742	1.003414	1.006765
2029	Bulk Cargo	1.005596	1.010664	1.001742	1.003414	1.006765
2030	Bulk Cargo	1.005596	1.010664	1.001742	1.003414	1.006765
2031	Bulk Cargo	1.005596	1.010664	1.001742	1.003414	1.006765
2032	Bulk Cargo	1.005596	1.010664	1.001742	1.003414	1.006765
2033	Bulk Cargo	1.008323	1.014308	1.005300	1.006313	1.009839
2034	Bulk Cargo	1.008323	1.014308	1.005300	1.006313	1.009839
2035	Bulk Cargo	1.008323	1.014308	1.005300	1.006313	1.009839
2036	Bulk Cargo	1.008323	1.014308	1.005300	1.006313	1.009839
2037	Bulk Cargo	1.008323	1.014308	1.005300	1.006313	1.009839
2038	Bulk Cargo	1.014975	1.024553	1.011213	1.010832	1.013967
2039	Bulk Cargo	1.014975	1.024553	1.011213	1.010832	1.013967
2040	Bulk Cargo	1.014975	1.024553	1.011213	1.010832	1.013967
2041	Bulk Cargo	1.014975	1.024553	1.011213	1.010832	1.013967
2042	Bulk Cargo	1.014975	1.024553	1.011213	1.010832	1.013967
2043	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2044	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2045	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2046	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2047	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2048	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2049	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039

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
2050	Bulk Cargo	1.016183	1.027646	1.011711	1.011059	1.014039
2016	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2017	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2018	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2019	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2020	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2021	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2022	RoRo	1.002778	1.007675	1.004736	1.000841	0.994305
2023	RoRo	1.015880	1.020478	1.016717	0.999138	1.010700
2024	RoRo	1.015880	1.020478	1.016717	0.999138	1.010700
2025	RoRo	1.015880	1.020478	1.016717	0.999138	1.010700
2026	RoRo	1.015880	1.020478	1.016717	0.999138	1.010700
2027	RoRo	1.015880	1.020478	1.016717	0.999138	1.010700
2028	RoRo	1.010639	1.016312	1.011085	1.002545	1.004994
2029	RoRo	1.010639	1.016312	1.011085	1.002545	1.004994
2030	RoRo	1.010639	1.016312	1.011085	1.002545	1.004994
2031	RoRo	1.010639	1.016312	1.011085	1.002545	1.004994
2032	RoRo	1.010639	1.016312	1.011085	1.002545	1.004994
2033	RoRo	1.003401	1.011975	1.004341	1.012006	0.998726
2034	RoRo	1.003401	1.011975	1.004341	1.012006	0.998726
2035	RoRo	1.003401	1.011975	1.004341	1.012006	0.998726
2036	RoRo	1.003401	1.011975	1.004341	1.012006	0.998726
2037	RoRo	1.003401	1.011975	1.004341	1.012006	0.998726
2038	RoRo	1.000106	1.014566	1.001837	1.008423	0.997412
2039	RoRo	1.000106	1.014566	1.001837	1.008423	0.997412
2040	RoRo	1.000106	1.014566	1.001837	1.008423	0.997412
2041	RoRo	1.000106	1.014566	1.001837	1.008423	0.997412
2042	RoRo	1.000106	1.014566	1.001837	1.008423	0.997412
2043	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2044	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2045	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2046	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2047	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2048	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2049	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2050	RoRo	0.989404	1.004773	0.991516	0.996790	0.989441
2016	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280
2017	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280
2018	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280
2019	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280

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
2020	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280
2021	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280
2022	General Cargo	1.030425	1.033502	1.031900	1.028525	1.032280
2023	General Cargo	1.039248	1.041758	1.038997	1.036558	1.040076
2024	General Cargo	1.039248	1.041758	1.038997	1.036558	1.040076
2025	General Cargo	1.039248	1.041758	1.038997	1.036558	1.040076
2026	General Cargo	1.039248	1.041758	1.038997	1.036558	1.040076
2027	General Cargo	1.039248	1.041758	1.038997	1.036558	1.040076
2028	General Cargo	1.041229	1.042495	1.040810	1.038691	1.042066
2029	General Cargo	1.041229	1.042495	1.040810	1.038691	1.042066
2030	General Cargo	1.041229	1.042495	1.040810	1.038691	1.042066
2031	General Cargo	1.041229	1.042495	1.040810	1.038691	1.042066
2032	General Cargo	1.041229	1.042495	1.040810	1.038691	1.042066
2033	General Cargo	1.043180	1.044562	1.042648	1.040960	1.044307
2034	General Cargo	1.043180	1.044562	1.042648	1.040960	1.044307
2035	General Cargo	1.043180	1.044562	1.042648	1.040960	1.044307
2036	General Cargo	1.043180	1.044562	1.042648	1.040960	1.044307
2037	General Cargo	1.043180	1.044562	1.042648	1.040960	1.044307
2038	General Cargo	1.049650	1.052198	1.049997	1.048217	1.051310
2039	General Cargo	1.049650	1.052198	1.049997	1.048217	1.051310
2040	General Cargo	1.049650	1.052198	1.049997	1.048217	1.051310
2041	General Cargo	1.049650	1.052198	1.049997	1.048217	1.051310
2042	General Cargo	1.049650	1.052198	1.049997	1.048217	1.051310
2043	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2044	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2045	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2046	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2047	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2048	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2049	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2050	General Cargo	1.036479	1.039449	1.037524	1.037226	1.038014
2016	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2017	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2018	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2019	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2020	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2021	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2022	Tanker	0.992197	0.998650	1.007600	1.018872	1.000321
2023	Tanker	1.009875	1.007013	1.028867	1.029811	1.006956
2024	Tanker	1.009875	1.007013	1.028867	1.029811	1.006956

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
2025	Tanker	1.009875	1.007013	1.028867	1.029811	1.006956
2026	Tanker	1.009875	1.007013	1.028867	1.029811	1.006956
2027	Tanker	1.009875	1.007013	1.028867	1.029811	1.006956
2028	Tanker	1.002351	0.995208	1.037168	1.027761	0.994900
2029	Tanker	1.002351	0.995208	1.037168	1.027761	0.994900
2030	Tanker	1.002351	0.995208	1.037168	1.027761	0.994900
2031	Tanker	1.002351	0.995208	1.037168	1.027761	0.994900
2032	Tanker	1.002351	0.995208	1.037168	1.027761	0.994900
2033	Tanker	0.999484	0.984444	1.019344	1.013489	0.988111
2034	Tanker	0.999484	0.984444	1.019344	1.013489	0.988111
2035	Tanker	0.999484	0.984444	1.019344	1.013489	0.988111
2036	Tanker	0.999484	0.984444	1.019344	1.013489	0.988111
2037	Tanker	0.999484	0.984444	1.019344	1.013489	0.988111
2038	Tanker	1.000746	0.983423	1.033738	1.017805	0.985815
2039	Tanker	1.000746	0.983423	1.033738	1.017805	0.985815
2040	Tanker	1.000746	0.983423	1.033738	1.017805	0.985815
2041	Tanker	1.000746	0.983423	1.033738	1.017805	0.985815
2042	Tanker	1.000746	0.983423	1.033738	1.017805	0.985815
2043	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2044	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2045	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2046	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2047	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2048	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2049	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2050	Tanker	0.999100	0.984024	1.023914	1.020470	0.984152
2016	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2017	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2018	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2019	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2020	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2021	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2022	Reefer	1.039518	1.041192	1.039723	1.039714	1.038565
2023	Reefer	1.039134	1.037998	1.039112	1.039114	1.036807
2024	Reefer	1.039134	1.037998	1.039112	1.039114	1.036807
2025	Reefer	1.039134	1.037998	1.039112	1.039114	1.036807
2026	Reefer	1.039134	1.037998	1.039112	1.039114	1.036807
2027	Reefer	1.039134	1.037998	1.039112	1.039114	1.036807
2028	Reefer	1.039711	1.037556	1.039565	1.039533	1.036459
2029	Reefer	1.039711	1.037556	1.039565	1.039533	1.036459

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
2030	Reefer	1.039711	1.037556	1.039565	1.039533	1.036459
2031	Reefer	1.039711	1.037556	1.039565	1.039533	1.036459
2032	Reefer	1.039711	1.037556	1.039565	1.039533	1.036459
2033	Reefer	1.041518	1.039169	1.041363	1.041358	1.038335
2034	Reefer	1.041518	1.039169	1.041363	1.041358	1.038335
2035	Reefer	1.041518	1.039169	1.041363	1.041358	1.038335
2036	Reefer	1.041518	1.039169	1.041363	1.041358	1.038335
2037	Reefer	1.041518	1.039169	1.041363	1.041358	1.038335
2038	Reefer	1.045906	1.043067	1.045776	1.045805	1.040168
2039	Reefer	1.045906	1.043067	1.045776	1.045805	1.040168
2040	Reefer	1.045906	1.043067	1.045776	1.045805	1.040168
2041	Reefer	1.045906	1.043067	1.045776	1.045805	1.040168
2042	Reefer	1.045906	1.043067	1.045776	1.045805	1.040168
2043	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2044	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2045	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2046	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2047	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2048	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2049	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2050	Reefer	1.036699	1.034459	1.036697	1.036630	1.036722
2016	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2017	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2018	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2019	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2020	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2021	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2022	Container	1.023224	1.022060	1.023618	1.023883	1.023334
2023	Container	1.035241	1.033217	1.033501	1.035472	1.023334
2024	Container	1.035241	1.033217	1.033501	1.035472	1.023334
2025	Container	1.035241	1.033217	1.033501	1.035472	1.023334
2026	Container	1.035241	1.033217	1.033501	1.035472	1.016967 *
2027	Container	1.035241	1.033217	1.033501	1.035472	1.016967 *
2028	Container	1.036429	1.034335	1.034971	1.036552	1.016967 *
2029	Container	1.036429	1.034335	1.034971	1.036552	1.016967 *
2030	Container	1.036429	1.034335	1.034971	1.036552	1.016967 *
2031	Container	1.036429	1.034335	1.034971	1.036552	1.019624 *
2032	Container	1.036429	1.034335	1.034971	1.036552	1.019624 *
2033	Container	1.036810	1.034439	1.035547	1.037948	1.019624 *
2034	Container	1.036810	1.034439	1.035547	1.037948	1.019624 *

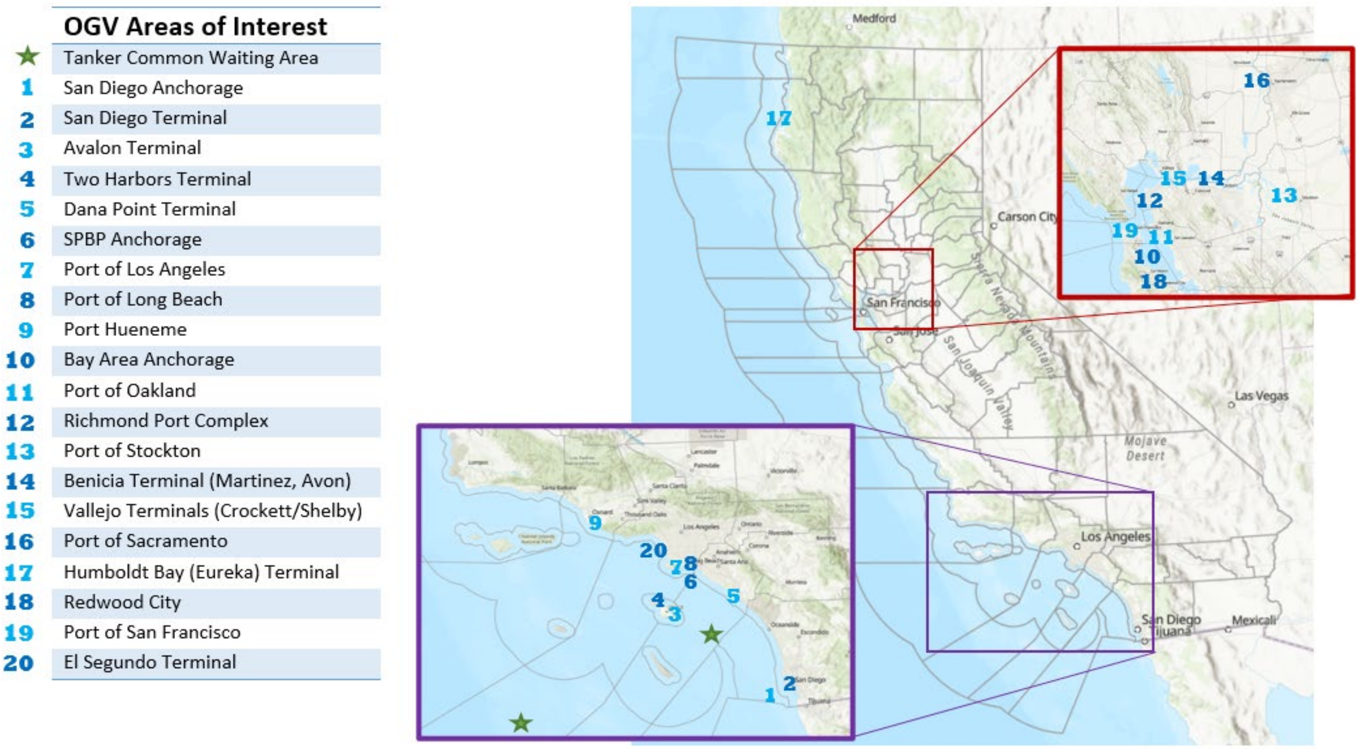
Year	Vessel Type	Los Angeles-Long Beach, CA	Remainder of California	Sacramento-Roseville, CA	San Diego-Carlsbad-San Marcos, CA	San Jose-San Francisco-Oakland, CA
2035	Container	1.036810	1.034439	1.035547	1.037948	1.019624 *
2036	Container	1.036810	1.034439	1.035547	1.037948	1.024776 *
2037	Container	1.036810	1.034439	1.035547	1.037948	1.024776 *
2038	Container	1.042258	1.037759	1.042296	1.045389	1.024776 *
2039	Container	1.042258	1.037759	1.042296	1.045389	1.024776 *
2040	Container	1.042258	1.037759	1.042296	1.045389	1.024776 *
2041	Container	1.042258	1.037759	1.042296	1.045389	1.023461 *
2042	Container	1.042258	1.037759	1.042296	1.045389	1.023461 *
2043	Container	1.008434	1.038663	1.058817	1.064134	1.023461 *
2044	Container	1.008434	1.038663	1.058817	1.064134	1.023461 *
2045	Container	1.008434	1.038663	1.058817	1.064134	1.023461 *
2046	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2047	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2048	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2049	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *
2050	Container	1.008434	1.038663	1.058817	1.064134	1.023013 *

Appendix B. 2020 IHS global registry ship types with statewide inventory vessel classification

Vessel Type	Registry Type
Auto Carrier	Vehicles Carrier
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

Vessel Type	Registry Type
Reefer	Reefer
RoRo	Ro-Ro Cargo Ship
RoRo	Container Ship (Fully Cellular/Ro-Ro Facility)
RoRo	Yacht Carrier, semi submersible
RoRo	General Cargo Ship (with Ro-Ro 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
Vessels (Other)	Unknown

Appendix C. Map of marine vessel regional areas of interest



Appendix D. 2020 IHS registry data vessel averages by type and size bin for vessels within 100 nm of California

Vessel Type	Size Bin	Average of Engines RPM	Average of Main Engine Total Installed kW	Average of Auxiliary Engine Total Installed kW
Auto Carrier		105.0819672	14342.20609	1472.738462
Bulk Cargo		112.5671378	9113.54139	644.873403
Container	1	166.7142857	9984.00000	1026.000000
Container	2	142.8000000	20156.96154	2334.062500
Container	3	100.8888889	25204.70213	1778.850000
Container	4	101.8977273	36229.15909	1975.097222
Container	5	100.9468085	43999.36170	2246.819672
Container	6	97.9861111	58108.97222	2297.902439
Container	7	99.7882352	56742.04706	2934.086207
Container	8	98.0800000	65703.65333	3179.365079
Container	9	92.0337078	59108.55056	3647.169935
Container	10	90.7317073	58868.46341	3379.844156
Container	11	96.9705882	60811.44118	3645.161290
Container	12	88.0000000	55485.50000	4160.000000
Container	13	97.5178571	68283.57143	3575.963636

Vessel Type	Size Bin	Average of Engines RPM	Average of Main Engine Total Installed kW	Average of Auxiliary Engine Total Installed kW
Container	14	85.94827586	55859.18966	3676.840000
Container	15	78.00000000	46288.33333	3571.333333
Container	16	100.00000000	75275.00000	3571.333333
Container	17	83.66666667	60530.00000	4500.000000
Container	18	102.00000000	80080.00000	4320.000000
Container	19	80.85714286	61892.85714	4485.714286
Container	23	80.00000000	75570.00000	4466.666667
Cruise		1049.010526	30972.56731	2043.954545
General Cargo		238.0351351	7969.00266	757.1854545
Reefer		130.3783784	12062.63158	1115.962963
RoRo		297.3200000	23789.77143	1709.750000
Tanker	Aframax	218.0800000	17964.44231	1244.842697
Tanker	Handysize	125.4554054	9006.79082	971.2874074
Tanker	Panamax	151.5299145	11817.65254	904.9478261
Tanker	Suezmax	100.5052632	17860.28421	1105.340909
Tanker	ULCC	71.9000000	27816.52000	1555.560000
Tanker	VLCC	71.3870967	25495.40323	1295.762712
Vessels (Other)		1445.4769230	5102.60365	321.716417