2023 AIR EMISSIONS INVENTORY

DRAFT

PORT CORPUS CHRISTI®

Prepared by:

STARCREST CONSULTING GROUP, LLC
ENVIRONMENTAL MANAGEMENT • AIR QUALITY • CLIMATE • SUSTAINABILITY

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Starcrest would like to thank the following Port of Corpus Christi staff members for assistance during the development of the emissions inventory:

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Acronyms and Abbreviations

AIS	automatic information system
ATB	articulated tug and barge
BSFC	brake specific fuel consumption
CF	control factor
CHE	cargo handling equipment
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CCTR	Corpus Christi Terminal Railroad
D	distance
DPM	diesel particulate matter
DWT	deadweight tonnage
E	emissions
ECA	Emission control area
EEAI	Energy and Environmental Analysis, Inc.
EF	emission factor
EI	emissions inventory
EPA	U.S. Environmental Protection Agency
FCF	fuel correction factor
g/bhp-hr	grams per brake horsepower-hour
g/hr	grams per hour
g/kW-hr	grams per kilowatt-hour
g/mi	grams per mile
GIS	geographic information system
GHG	greenhouse gas
GWP	global warming potential
HDV	heavy-duty vehicle
hp	horsepower
hrs	hours
IMO	International Maritime Organization
KCS	Kansas City Southern (rail company)
kW	kilowatt
kW-hr	kilowatt hour
lbs/day	pounds per day
LF	load factor
LLA	low load adjustment
Lloyd's	Historical name for marine vessel data licensed from IHS Markit
LNG	liquefied natural gas

LPG	liquefied petroleum gas
MCR	maximum continuous rating
mph	miles per hour
MMGTM	million gross ton-miles
MMSI	maritime mobile service identity
MOVES	Motor Vehicle Emissions Simulator, EPA model
MY	model year
N_2O	nitrous oxide
nm	nautical miles
NO_x	oxides of nitrogen
OGV	ocean-going vessel
PM	particulate matter
PM_{10}	particulate matter less than 10 microns in diameter
$PM_{2.5}$	particulate matter less than 2.5 microns in diameter
PCCA	Port of Corpus Christi Authority
ppm	parts per million
RoRo	roll-on roll-off vessel
rpm	revolutions per minute
S	sulfur
SO_x	oxides of sulfur
TCEQ	Texas Commission on Environmental Quality
TEU	twenty-foot equivalent unit
tonnes	metric tons
tpy	tons per year
U.S.	United States
ULSD	ultra low sulfur diesel
UP	Union Pacific Railroad
USCG	U.S Coast Guard
VBP	vessel boarding program
VMT	vehicle miles of travel
VOC	volatile organic compound
ZH	zero hour

EXECUTIVE SUMMARY

The Port of Corpus Christi undertook this Air Emissions Inventory (EI or inventory) update study to estimate Port-related mobile source emissions that occurred in 2023, and to compare those emissions to the previous inventory (2020). The first activity-based air emissions inventory the Port conducted was 10 years ago (2013 calendar year). Both public and private terminals are included in this inventory. The geographical domain is the extent of Nueces and San Patricio counties for the landside emissions and the over the water boundary is Corpus Christi Bay and extends three nautical miles beyond the shoreline of Mustang Island into the Gulf of Mexico.

The Port of Corpus Christi has continued to see port expansion and cargo growth since the previous air emissions inventory which was conducted for calendar year 2020. Cargo throughput increased 27% in tons of cargo from 2020 to 2023. Ocean-going vessel arrivals increased 12% with larger tankers visiting the Port and staying longer at berth.

Table ES.1: 2020-2023 Cargo Volume Vessel Arrivals Comparison

Year	Cargo (short tons)	Cargo (barrels)	OGV Arrivals
2020	159,713,040	968,280,326	2,143
2023	203,041,052	1,232,184,299	2,409
Change (%)	**27%**	**27%**	**12%**

The 2020 vs 2023 comparison of the total emissions inventoried is summarized in Table ES.2 and excludes recreational vessel emissions, which are not tied to the activity from commercial cargo volume changes. Overall absolute emissions are higher in 2023 as compared to 2020. The increase in emissions is mainly due to more tankers and harbor craft activity in 2023. The tugboat and towboat activity increase is due to more barge activity and dredging activity in 2023 as compared to 2020.

Table ES.2: 2020-2023 Total Emissions Comparison without Recreational Vessel Emissions

Year	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020	3,867	96	90	71	123	628	139	367,637
2023	4,181	103	98	75	135	813	150	459,842
Change	**314**	**8**	**7**	**5**	**12**	**185**	**11**	**92,205**
Change (%)	**8%**	**8%**	**8%**	**6%**	**10%**	**29%**	**8%**	**25%**

Despite the 27% increase in cargo throughput since 2020, the NO_x and PM emissions increases are in the 6-8% range due to fleet turnover for trucks, locomotives, tugboats and ocean-going vessels. Newer engines have lower NO_x and PM engine standards. In 2023, there were more tankers using alternative fuel, such as LNG, and ocean-going vessels with Tier III engines which have 75% lower NO_x emissions standards.

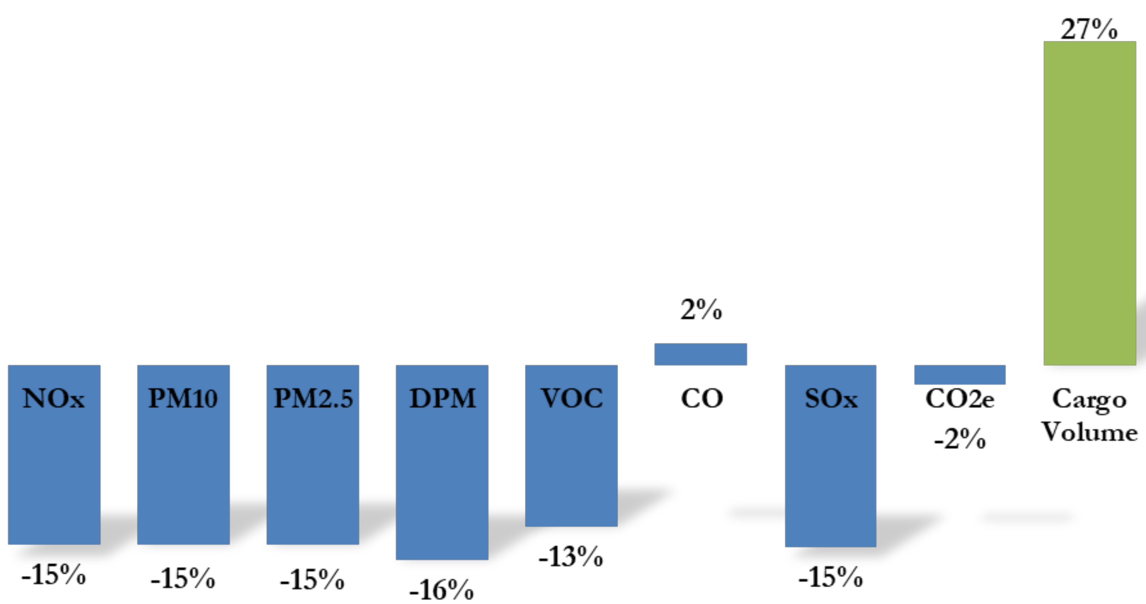
Table ES.3 and Figure ES.1 show the emissions efficiency metric comparison that further highlights the emissions increase in 2023 is at a lower rate than the rate of growth in cargo throughput. Emissions per 100,000 tons of cargo throughput are lower in 2023 than in 2020, except for CO. This shows an improvement in efficiency as there are less emissions emitted per ton of cargo moved at the Port. In other words, more cargo was moved in 2023 than in 2020, but less emissions per 100,000 tons of cargo due to the improvements made to lower emissions.

Table ES.3: 2020-2023 Emissions Efficiency Metric Comparison

	Emissions per 100,000 tons of cargo							
Year	**NO_x**	**PM_{10}**	**$PM_{2.5}$**	**DPM**	**VOC**	**CO**	**SO_x**	**CO_2e**
2020	2.42	0.060	0.057	0.044	0.077	0.393	0.087	230
2023	2.06	0.051	0.048	0.037	0.067	0.400	0.074	226
Change (%)	**-15%**	**-15%**	**-15%**	**-16%**	**-13%**	**2%**	**-15%**	**-2%**

The slight increase in CO emissions per tons of cargo metric presented in Figure ES.1 is due to engine standards changing mainly for NO_x and PM pollutants and not CO. Thus, newer engines have lower NO_x and PM engine standards while CO remains relatively the same over the years.

Figure ES.1: 2020-2023 Emissions Efficiency Metric Comparison



SECTION 1 INTRODUCTION

This section describes the rationale behind the 2023 Corpus Christi Air Emissions Inventory which includes maritime-related emissions in Nueces and San Patricio counties. It also describes the scope and geographical domain.

1.1 Reason for Study

The Port of Corpus Christi undertook this Air Emissions Inventory (EI or inventory) update study to estimate Port-related mobile source emissions that occurred in 2023, and to compare those emissions to the previous inventory and to the total regional emissions within the two-county area. The emissions inventory is the foundation for the air quality analysis and strategy development that is necessary to achieve and measure maritime-related emission reductions. The Port of Corpus Christi has continued to see port expansion and cargo growth since the previous air emissions inventory which was conducted for calendar year 2020. The comparison of 2023 emissions with the 2020 emissions will assist the Port staff in understanding how port growth and emission reduction strategies have affected maritime-related emissions and their relationship to emissions in the area as a whole.

The maritime-related emissions should be viewed in the context of being a part of the region's total air emissions. Other (non-marine) categories that contribute to area emissions, but not part of this report, include point sources (refineries, manufacturing facilities, etc.); on-road mobile sources (e.g., cars, trucks, buses and motorcycles); non-road equipment (farming and construction equipment, etc.); and stationary area sources (open burning, auto body shops, etc.). The Texas Commission on Environmental Quality (TCEQ) inventories these sources of emissions.

An emissions inventory is a very useful tool to quantify mass emissions and track emission changes over time from a variety of emission sources in a geographic area and to help prioritize those sources for potential emission reduction measures. The first detailed activity-based emissions inventory the Port conducted was for the 2013 calendar year.

1.2 Scope of Study

The scope of the study is described below in terms of the pollutants quantified, the year of operation used as the basis of emission estimates, the emission source categories that are included and excluded, and the geographical extent of activities included in the inventory.

1.2.1 Pollutants

Exhaust emissions of the following pollutants are estimated:

- Criteria pollutants, surrogates, and precursors
  - Oxides of nitrogen (NO_x)
  - Sulfur dioxide (SO_2)
  - Particulate matter (PM) (10-micron (PM_{10}), 2.5-micron ($PM_{2.5}$))
  - Volatile organic compounds (VOCs)
  - Carbon monoxide (CO)

- The toxic air pollutant diesel particulate matter (DPM)[1], which is the particulate matter emitted from diesel-fueled internal combustion engines
- Greenhouse gases (GHGs)
    - Carbon dioxide (CO_2)
    - Methane (CH_4)
    - Nitrous oxide (N_2O)

Most maritime-related sources of GHG emissions involve fuel combustion, thus the combustion-related emissions of CO_2, CH_4, and N_2O are included in this inventory. Because each greenhouse gas differs in its effect on the atmosphere, estimates of greenhouse gas emissions are presented in units of carbon dioxide equivalents, which weigh each gas by its global warming potential (GWP) value. To normalize these values into a single greenhouse gas value, CO_2e, the GHG emission estimates are multiplied by the following GWP values[2] and summed.

- CO_2 – 1
- CH_4 – 28
- N_2O - 265

The resulting CO_2e emissions are presented in tonnes (metric tons) throughout the report, whereas all other annual emissions are presented as tons (short tons).

1.2.2 Temporal Extent

This study is based on activity that occurred in calendar year 2023. To the extent practical, the emission estimates are based on activities that occurred during this period. If information specific to 2023 was not available, reasonable estimates of operational characteristics were developed. These cases are named in the text for each emission source category.

1.2.3 Emission Source Categories

This study includes the following emission source categories:

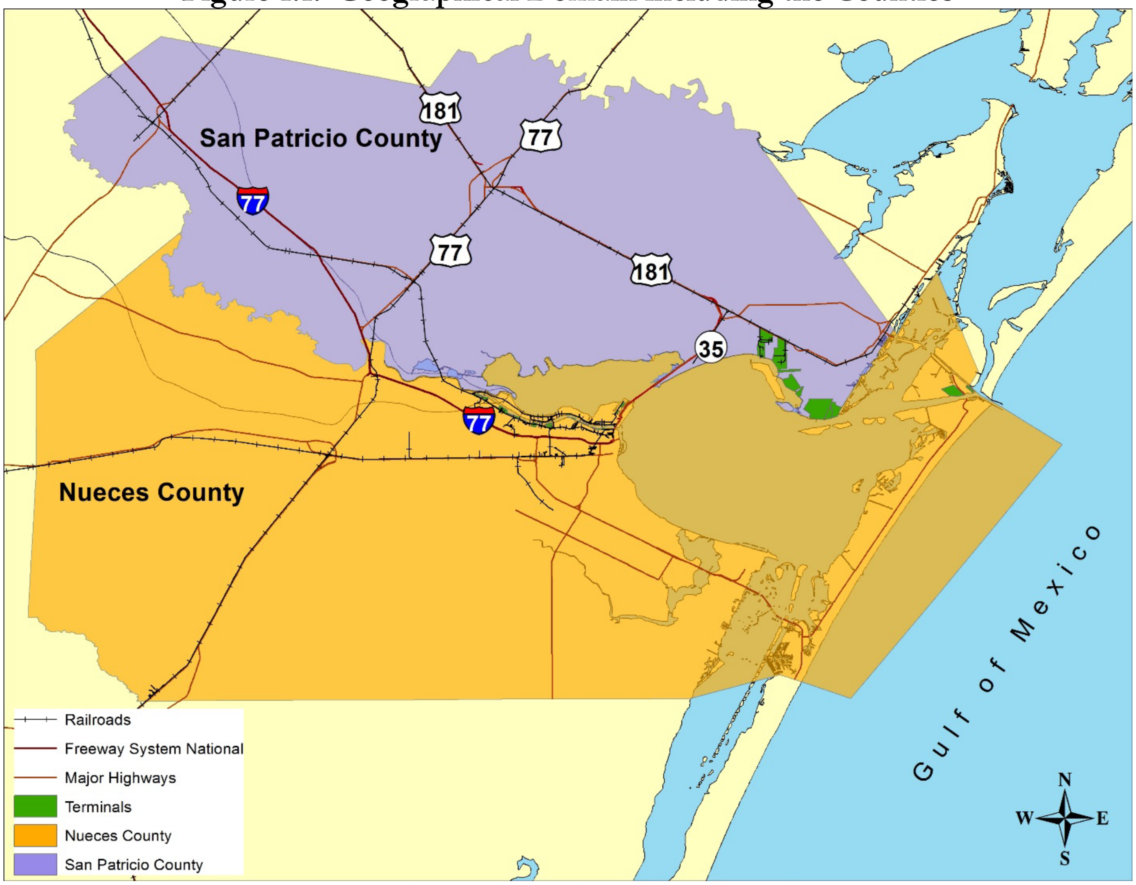
- Ocean-going vessels
- Commercial harbor craft
- Recreational vessels
- Cargo handling equipment
- Locomotives
- Heavy-duty vehicles

[1] Diesel particulate matter is on EPA's Mobile Sources List of Toxics. *www.epa.gov/otaq/toxics.htm*
[2] U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022*, April 2024.

1.3 Geographical Domain

Figure 1.1 illustrates the geographical domain for the inventory which includes the public and private facilities for the Port of Corpus Christi which are in two counties, Nueces and San Patricio. The shaded areas show the county boundaries for Nueces and San Patricio Counties.

Figure 1.1: Geographical Domain including the Counties



Cargo Handling Equipment
The geographical domain for cargo handling equipment is the boundary of the Port and its associated terminals.

Locomotives
The geographical domain for locomotives is the extent of Nueces and San Patricio counties. Emissions from switching locomotives were estimated for on-dock and off-dock rail yards and emissions from line-haul locomotives were estimated for all rail lines within the two counties. This source category includes all locomotive emissions, both maritime-related and non-maritime related.

Heavy-duty Vehicles
The geographical domain for heavy-duty vehicles is the extent of Nueces and San Patricio counties. Emissions from heavy-duty on-road trucks hauling cargo were estimated for maritime-related on-road activity to and from the county lines.

The geographical domain for ocean-going vessels (OGVs) and harbor vessels includes Corpus Christi Bay and extends three nautical miles beyond the shoreline of Mustang Island into the Gulf of Mexico. Figure 1.1 illustrates the marine-side geographical domain. The shaded areas show the approach zone, maneuvering zone and the various terminals that are included in this inventory.

Figure 1.1: Marine-side Geographical Domain

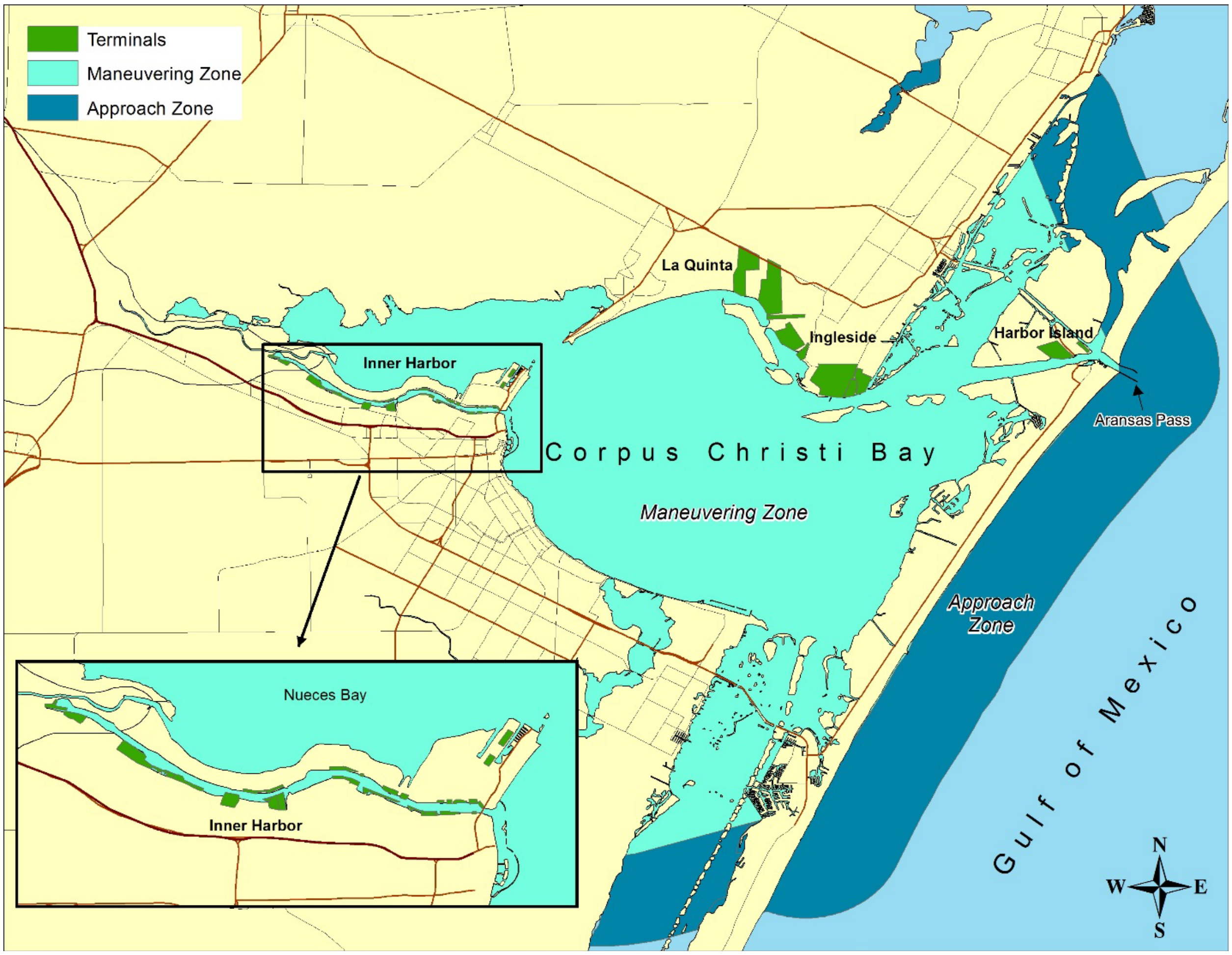


Table 1.1 lists the terminals and other facilities that are included in this inventory. Each terminal may have emissions associated with one or more of the emission source categories. Both public and private terminals are included in this inventory. The source category sections include more information on the data collected in order to be able to estimate emissions. In general, the terminals were contacted for equipment and truck activity data; automatic Information System (AIS) data was used for the vessel activity data (ocean-going vessels and harbor craft); and the locomotive companies and provided the locomotive data.

Table 1.1: List of Terminals

Name	Location	Type	Name	Location	Type
ADM/Growmark	Inner Harbor	Bulk Materials	Valero	Inner Harbor	Bulk Liquid
Vulcan Materials	Inner Harbor	Bulk Materials	Fordyce Co.	Inner Harbor	Mooring
PCCA Bulk Docks	Inner Harbor	Bulk Materials	G&H Towing	Inner Harbor	Mooring
PCCA Cargo Docks	Inner Harbor	Bulk Materials	US Coast Guard	Inner Harbor	Mooring
Fordyce	Inner Harbor	Dry Cargo	EMAS	Ingleside	Mooring
Bay Inc	Inner Harbor	Dry Cargo	Enbridge	Ingleside	Bulk Liquid
Heldenfels	Inner Harbor	Dry Cargo	Flint Ingleside	Ingleside	Bulk Liquid
J. Bludworth	Inner Harbor	Dry Dock	Oxychem	Ingleside	Bulk Liquid
Buckeye	Inner Harbor	Bulk Liquid	MODA	Ingleside	Bulk Liquid
Citgo Docks	Inner Harbor	Bulk Liquid	South Texas Gateway	Ingleside	Bulk Liquid
Eagle Ford	Inner Harbor	Bulk Liquid	ArcelorMittal	La Quinta	Bulk Materials
Equistar	Inner Harbor	Bulk Liquid	Gulf Coast Growth Ventures	La Quinta	Bulk Materials
Epic	Inner Harbor	Bulk Liquid	Cheniere	La Quinta	Bulk Liquid
Flint Hills Docks	Inner Harbor	Bulk Liquid	Oxychem	La Quinta	Bulk Liquid
Kirby Marine	Inner Harbor	Bulk Liquid	Kiewit Offshore Services	La Quinta	Dry Cargo
Nu Star Logistics	Inner Harbor	Bulk Liquid	Signet Maritime	La Quinta	Mooring
PCCA Oil Docks	Inner Harbor	Bulk Liquid	Rincon A	Rincon	Dry Cargo

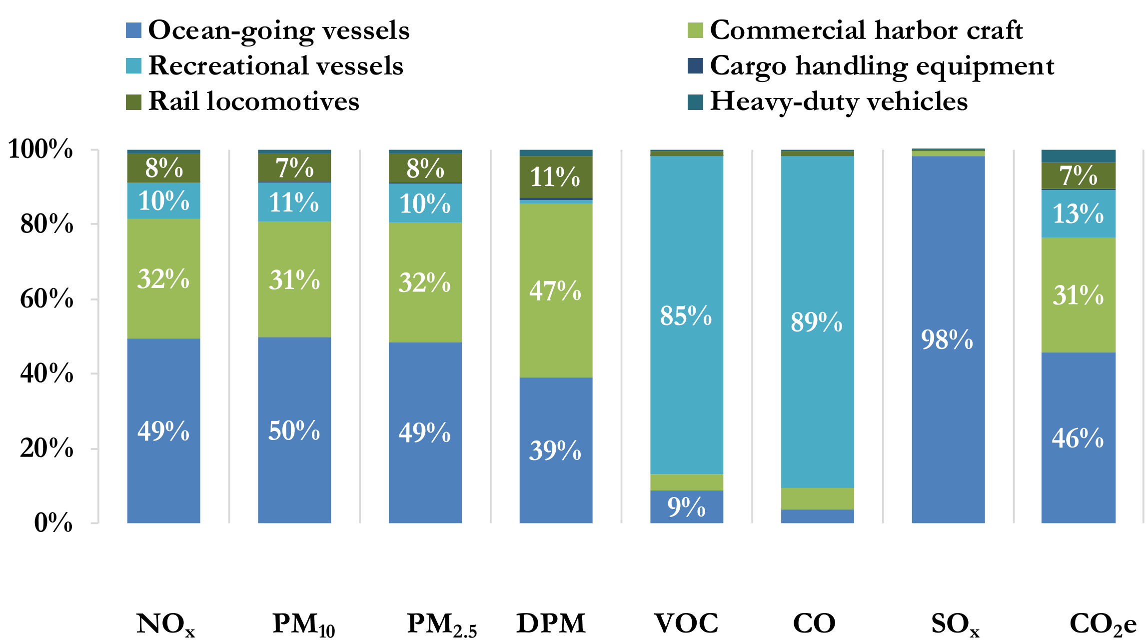
Section 2 Summary Results

The total emissions from mainly maritime-related mobile sources in Nueces and San Patricio counties are summarized in Table 2.1. Please note that the locomotive emissions include both maritime and non-maritime related line haul emissions for the two counties due to data constraints of not being able to separate just the maritime related emissions, thus the maritime-related emissions due include some non-maritime related locomotive emissions. Figure 2.1 shows the emissions distribution for 2023. Ocean-going vessels and commercial harbor craft contribute most of the maritime-related emissions, except for VOC and CO. Recreational vessels contribute the most of VOC and CO emissions.

Table 2.1: 2023 Maritime-related Emissions

Sources	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Ocean-going vessels	2,283	58	53	30	78	267	148.2	240,302
Commercial harbor craft	1,488	36	35	36	40	413	1.6	162,685
Recreational vessels	445	12	11	1	773	6,296	0.4	66,846
Cargo handling equipment	5	0	0	0	0	4	0.0	1,617
Rail locomotives	359	8	8	8	14	108	0.4	37,631
Heavy-duty vehicles	46	1	1	1	3	22	0.1	17,607
Total	**4,626**	**116**	**109**	**76**	**909**	**7,109**	**150.7**	**526,688**

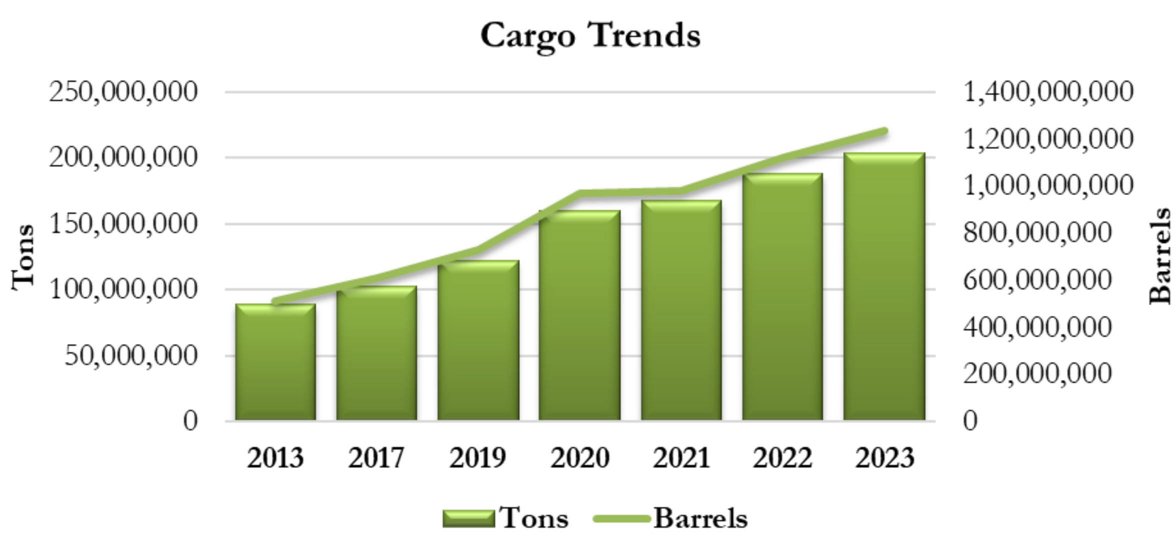
Figure 2.1: 2023 Maritime-related Emissions Distribution



Comparison of 2023 Emissions to 2020

Comparing 2023 to 2020, the Port of Corpus Christi continued to increase in cargo throughput with a 27% tonnage growth since 2020. The Port completed a couple of phases of the Ship Channel Improvement Project in 2023 and is continuing with its infrastructure improvements. Figure 2.2 illustrates the upward tonnage and barrels trend for the Port of Corpus Christi which has become one of the largest crude oil exporters in the United States since the export ban was lifted at the end of 2015.[3]

Figure 2.2: Port of Corpus Christi Cargo Tonnage and Barrels Trend



As illustrated in Table 2.2, cargo throughput increased 27% in tons of cargo since 2023. Ocean-going vessel arrivals increased 12% with larger tankers visiting the Port and staying longer at berth.

Table 2.2: 2020-2023 Cargo Volume Vessel Arrivals Comparison

Year	Cargo (short tons)	Cargo (barrels)	OGV Arrivals
2020	159,713,040	968,280,326	2,143
2023	203,041,052	1,232,184,299	2,409
Change (%)	**27%**	**27%**	**12%**

The 2020 vs 2023 comparison of maritime-related emissions is summarized in Table 2.3 and excludes recreational vessel emissions, which are not tied to the activity from commercial cargo volume changes. In order to maintain consistency between the years, the 2020 emissions were recalculated using the latest methodology.

[3] *www.portofcc.com/port-corpus-christi-the-1-u-s-crude-oil-export-port-video/*

Overall emissions are higher in 2023 as compared to 2020. The increase in emissions is mainly due to more tanker activity and increased harbor craft activity in 2023. Cargo handling equipment emissions are lower for all pollutants due to lower activity for 2023 and fleet turnover to newer equipment. The NO_x and PM emissions are lower for locomotives and trucks due to changes in locomotive fleet and truck fleet turnover. In 2023, these sources have cleaner engines with lower NO_x and PM engine standards. The SO_x and CO_2e emissions are higher in 2023 for locomotives and trucks due to the increased activity because of higher cargo throughput.

The CO_2e emissions, which usually follow the activity trends more closely than other pollutants due to lack of emissions standards for CO_2, are 25% higher in 2023. In other words, if activity is higher, CO_2e emissions will be higher by similar percent change since newer engines may have lower NOx and PM engine standards, but the CO_2 emissions rate remains relatively the same for newer equipment and vehicles if using same fuel. The overall NO_x and PM emissions are higher by 8% in 2023 due to more vessel activity which resulted in higher ocean-going vessels and commercial harbor craft emissions.

Table 2.3: 2020-2023 Maritime-related Emissions Comparison without Recreational Vessels, tons and metric tons

	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e MT
2020								
Ocean-going vessels	2,198	53	48	28	73	200	137.8	208,506
Commercial harbor craft	1,217	29	28	29	30	303	1.1	107,793
Cargo handling equipment	20	3	3	3	2	6	0.0	2,544
Locomotives	385	9	9	9	15	99	0.4	34,767
Heavy-duty vehicles	47	2	1	2	3	19	0.1	14,027
Total	**3,867**	**96**	**90**	**71**	**123**	**628**	**139**	**367,637**
2023								
Ocean-going vessels	2,283	58	53	30	78	267	148.2	240,302
Commercial harbor craft	1,488	36	35	36	40	413	1.6	162,685
Cargo handling equipment	5	0	0	0	0	4	0.0	1,617
Locomotives	359	8	8	8	14	108	0.4	37,631
Heavy-duty vehicles	46	1	1	1	3	22	0.1	17,607
Total	**4,181**	**103**	**98**	**75**	**135**	**813**	**150**	**459,842**
Change between 2020 and 2023 (percent)								
Ocean-going vessels	4%	9%	9%	7%	7%	33%	8%	15%
Commercial harbor craft	22%	22%	22%	21%	35%	36%	51%	51%
Cargo handling equipment	-75%	-85%	-85%	-85%	-79%	-44%	-41%	-36%
Locomotives	-7%	-9%	-9%	-9%	-9%	8%	8%	8%
Heavy-duty vehicles	-2%	-14%	-14%	-14%	1%	15%	24%	26%
Total	**8%**	**8%**	**8%**	**6%**	**10%**	**29%**	**8%**	**25%**

Note: Table excludes recreational vessel emissions

Section 8 includes more information on energy consumption comparison by source category that contributed to the emission changes. Major highlights include:

General Highlights

- Cargo throughput increased 27% in tons of cargo and in barrels since 2020.

Ocean-going vessels

- Absolute OGV emissions increased in 2023 compared to 2020 but increased relatively less than growth in cargo volumes and vessel movements. The absolute emissions increase was due to 12% more vessel arrivals in 2023, and more time spent at berth for the larger tankers.
- The percentage of vessels with Tier III engines was higher in 2023 than in 2020. In 2023, 20% of vessels had Tier III engines as compared to 6% in 2020. Tier III engines have 75% lower NO_x emission standards than lower Tier engines.
- In 2023, there were 93 vessels, primarily LNG carriers, using alternative fuel liquified natural gas (LNG) for the auxiliary engines and boilers. In 2020, LNG carriers were modeled using marine gas oil (MGO) in port, so the 2020 inventory results show 0 vessels using LNG fuel.
- Data on whether a tanker is loading or unloading is taken into consideration in the emissions estimates. The tanker's engines are only needed to unload and in 2023, only 10% of the calls unloaded, while the remaining 90% of the time at berth tankers were loading (no tanker engines required). In 2020, 20% of the calls unloaded liquid cargo.

Commercial Harbor Craft

- The overall energy consumption (measured as horsepower hours) increased by 51% for commercial harbor craft showing increased activity in 2023 as compared to 2020.
- In 2023, there are 10% newer (Tier 2-4) harbor craft than in 2020. This contributed to the NO_x and PM emissions only increasing by 22% in 2023 despite the 51% increase in activity.
- The 51% increase in CO_2e emissions is consistent with the 51% higher activity in 2023.

Cargo Handling Equipment

- The overall energy consumption (as measured by horsepower hours) decreased 39% due to decreased hours of engine use in 2023 as compared to 2020.
- Emissions decreased significantly for NO_x and PM emissions in 2023 due to fleet turnover to cleaner engines and the decreased activity.
- Emissions decreased across the board for all pollutants due to the lower energy use.

Railroad Locomotives

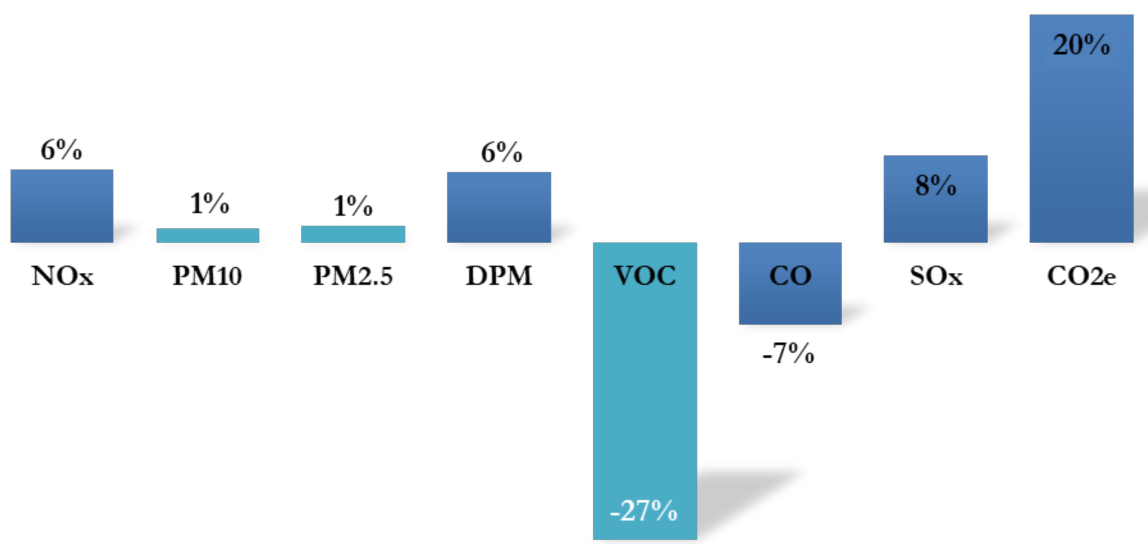
- Locomotive activity was 6% higher in 2023.
- Locomotive switching emissions increased for all pollutants.
- Locomotive line-haul emissions are lower for NO_x and PM due to repowered locomotives with cleaner engine Tiers.
- The GHG emissions are 8% higher in 2023 due to increased activity.

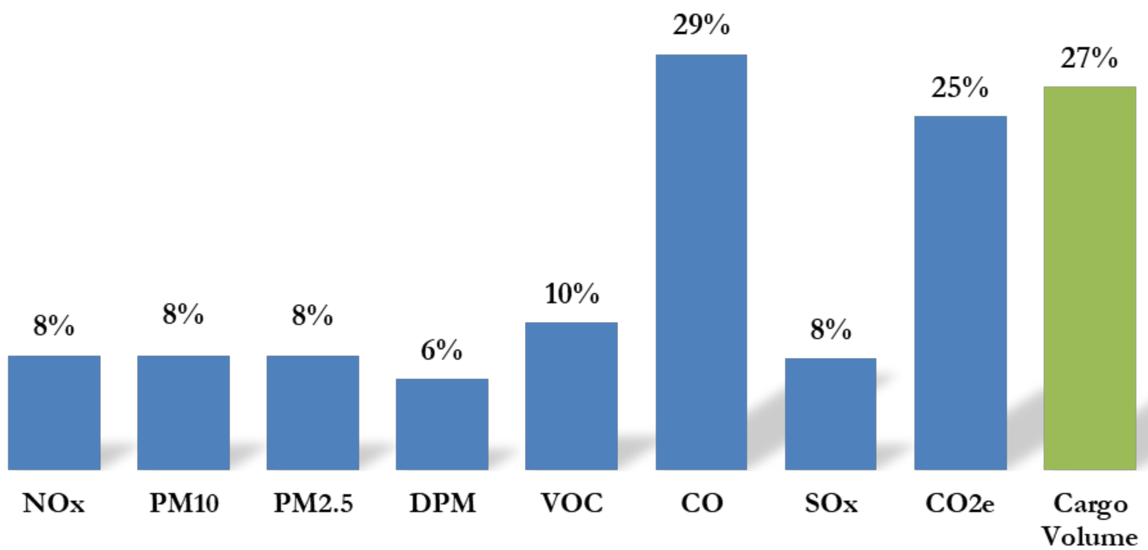
Trucks

- The truck count and vehicle miles traveled are 30 to 32% higher respectively in 2023.
- The NO_x and PM emissions are 2 to 14% lower in 2023 due to Port truck fleet turnover.
- The GHG emissions are 26% higher in 2023 due to increased activity.

Figure 2.3 illustrates the emissions change comparing 2023 to 2020. The top figure includes recreational vessels for sake of completeness, while the figure below it only includes the commercial vessel emissions (i.e., without recreational vessels) and has a column for the cargo volume in barrels. The bottom figure illustrates that with a 27% increase in cargo volume, emissions increased 6% - 29% in 2023 as compared to 2020.

Figure 2.3: Emissions Comparison





Emissions Metrics

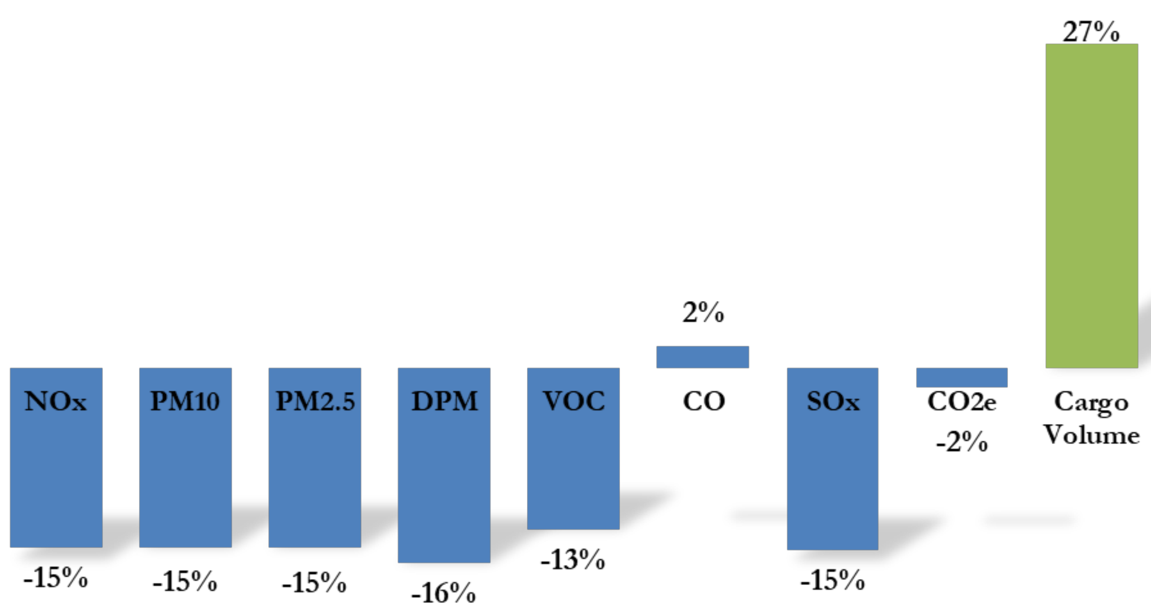
Table 2.4 and Figure 2.4 show the emissions efficiency metric comparison that further highlights the emissions increase in 2023 is at a lower rate than the rate of growth in cargo throughput. Emissions per 100,000 tons of cargo throughput are lower in 2023 than in 2020, except for CO. This shows an improvement in efficiency as there are less emissions emitted per ton of cargo moved at the Port. In other words, more cargo was moved in 2023 than in 2020, but less emissions per 100,000 tons of cargo due to the improvements made to lower emissions.

Table 2.4: 2020-2023 Emissions Efficiency Metric Comparison

Year	Emissions per 100,000 tons of cargo							
	NO_x	PM_{10}	$PM_{2.5}$	DPM	VOC	CO	SO_x	CO_2e
2020	2.42	0.060	0.057	0.044	0.077	0.393	0.087	230
2023	2.06	0.051	0.048	0.037	0.067	0.400	0.074	226
Change (%)	**-15%**	**-15%**	**-15%**	**-16%**	**-13%**	**2%**	**-15%**	**-2%**

The slight increase in CO emissions per tons of cargo metric presented in Figure 2.4 is due to engine standards changing mainly for NO_x and PM pollutants and not CO. Thus, newer engines have lower NO_x and PM engine standards while CO remains relatively the same over the years.

Figure 2.4: 2020-2023 Emissions Efficiency Metric Comparison



2023 Regional Emissions

Part of the scope of this study was to obtain and summarize the TCEQ emissions inventory categories for air quality planning purposes. The TCEQ emission estimates for Nueces and San Patricio counties were compiled and provided by TCEQ for point sources (2022) and 2020 updates for on-road, non-road and area sources. At the time of this report publication, the 2023 TCEQ emissions were not finalized yet and thus the TCEQ updated 2020 and 2022 emission estimates are used for comparison. Please note this table will be updated in early 2025 when TCEQ provides the 2023 emissions.

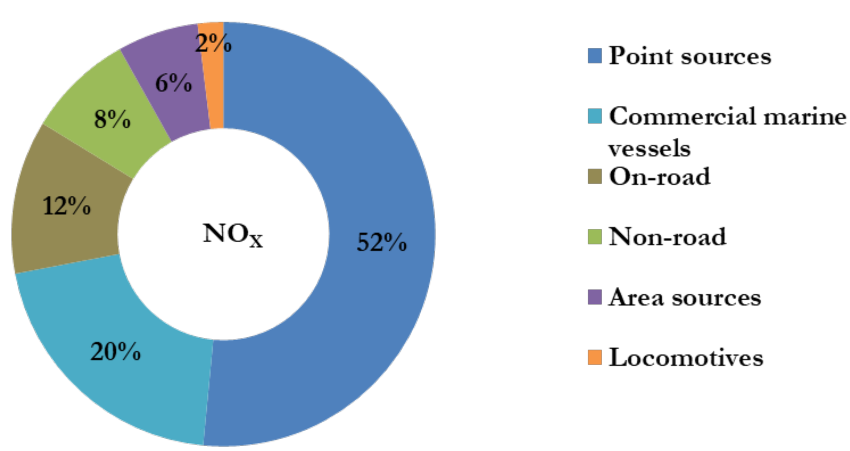
Table 2.5 lists the emission source category, the latest inventory year, and the estimated emissions for Nueces and San Patricio Counties. Please note that the 2023 commercial marine vessel and locomotive emissions from this inventory were used in place of the TCEQ emissions because they represent all emissions from these categories in the two counties and are the most current. The commercial marine vessels include both the OGV and commercial harbor craft emissions and were estimated using the methodology explained in Section 3 and 4 of this report.

Table 2.5: Nueces and San Patricio County Regional Emissions

Source	Year	Source	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	VOC tons	CO tons	SO_2 tons
Point sources	2022	TCEQ	9,484	2,351	1,895	4,470	11,555	846
On-road	2020	TCEQ	2,158	207	71	763	16,254	11
Non-road	2020	TCEQ	1,494	120	114	1,454	16,351	18
Area sources	2020	TCEQ	1,139	15,754	2,554	8,845	1,578	74
Commercial marine vessels	2023	PCCA EI	3,771	93	88	119	680	150
Locomotives	2023	PCCA EI	359	8	8	14	108	0
Total			**18,405**	**18,533**	**4,730**	**15,665**	**46,526**	**1,099**

The pie charts in Figures 2.5 through 2.9 summarize the distribution of regional emissions for each of the pollutants in 2023. The percentage distribution of each source category varies by pollutant. Due to rounding, the percent values may not add up to 100%. Commercial marine vessels account for 20% of the NO_x emissions in the region.

Figure 2.5: Regional NO_x Emissions Distribution



For Figures 2.6 to 2.8, emissions for commercial marine vessels and locomotives were combined as they only account for 1% of PM and VOC, and 2% of CO emissions in the region.

Figure 2.6: Regional PM_{10} Emissions Distribution

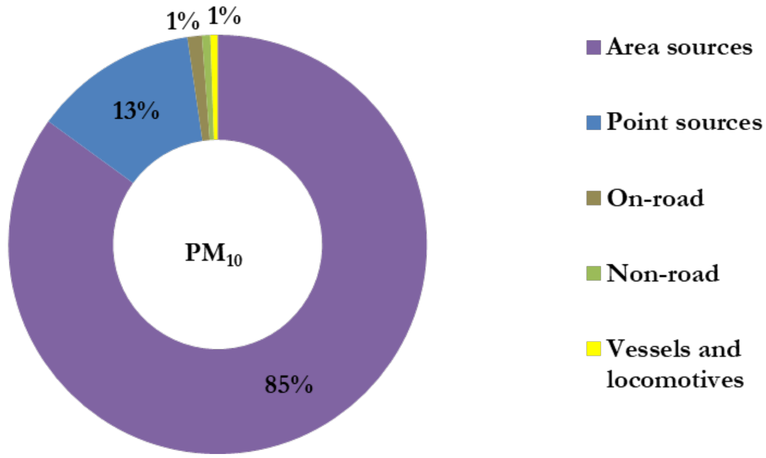


Figure 2.7: Regional VOC Emissions Distribution

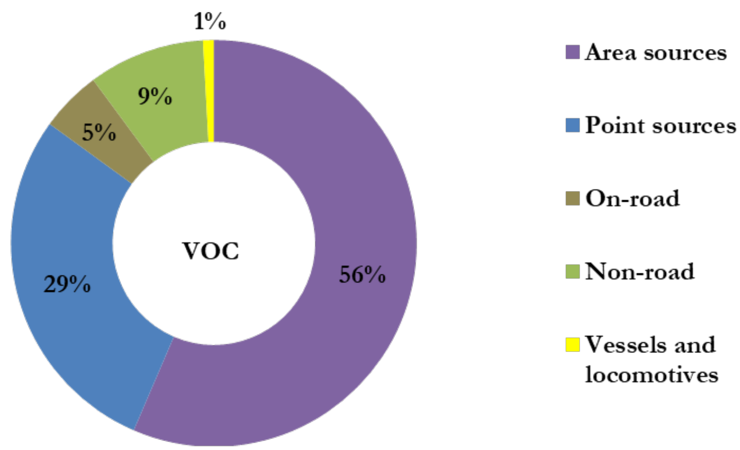


Figure 2.8: Regional CO Emissions Distribution

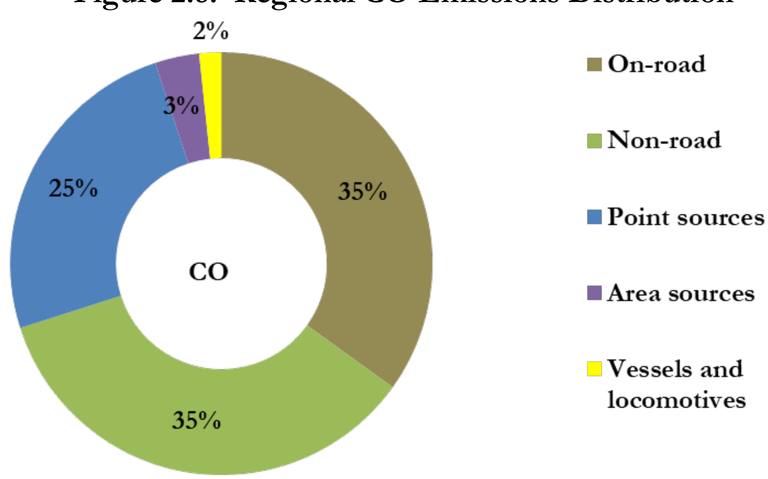
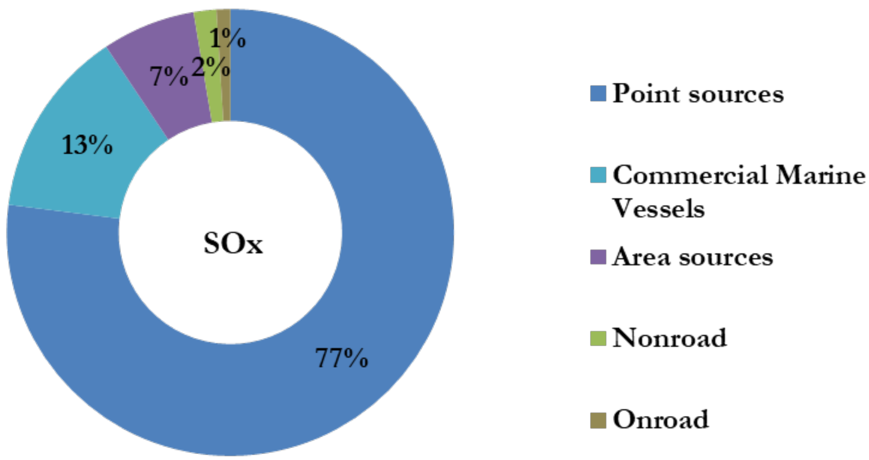


Figure 2.9 illustrates that the commercial marine vessels account for 13% of the SO_x emissions in the region.

Figure 2.9: Regional SO_x Emissions Distribution



SECTION 3 OCEAN-GOING VESSELS

This section includes emissions estimates for the ocean-going vessels (OGV or vessels) source category and is organized into the following subsections: source description (3.1), data and information acquisition (3.2), operational profiles (3.3), emissions estimation methodology (3.4), and OGV emission estimates (3.5).

3.1 Source Description

Based on vessel activity processed from Automatic Identification System (AIS) data, there were a total of 2,409 vessel arrivals to the Port in 2023. In 2023, the Port recorded 5,692 barge activities. The emissions associated with barge calls are addressed in Section 4, Harbor Vessels. Barges are not self-propelled, and they do not have a propulsion engine. The emissions for barges come from the tugboats, towboats or push boats that tow or push the barge(s).

The following vessel types, included in this section and that called the Port in 2023 are:

- **Auto carrier** – vehicle carrier that can accommodate vehicles and large wheeled equipment.
- **Bulk carrier** – vessels with open holds to carry various bulk dry goods, such as grain, salt, sugar, petroleum coke, and other fine-grained commodities.
- **General cargo** – vessels that are designed to carry a diverse range of cargo in their hold and on their decks, such as bulk metals, machinery, and palletized goods.
- **Ocean-going tugboat (ATB/ITB)** – includes integrated tug barges (ITB) and articulated tug barges (ATB) only. These barges have a notch in their stern to enable a special tug to connect to the barge, creating one single vessel.
- **Tanker** – vessels that transport liquids in bulk, such as oil, liquefied petroleum gas (LPG), liquefied natural gas (LNG), chemicals, or other specialty goods such as asphalt. Oil tankers are classified based on their size.

Vessel activities for vessels that called at the Port were identified as the following trip types:

- Arrivals – inbound trips from the inventory boundary to berth
- Departures – outbound trips from a berth to the inventory boundary
- Shifts – intra-port trips between terminals within the inventory domain

Table 3.1 presents the number of arrivals, departures, and shifts associated with the vessel types that called the Port in 2023. Larger tankers, such as Suezmax, VLCC, ULCC and tankers with LNG cargo called the Port in 2023 more than in 2020 when the last inventory was conducted.

Table 3.1: Arrivals, Departures, and Shifts by Vessel Type

Vessel Type	Arrivals	Departures	Shifts	Total
Auto Carrier	7	8	0	15
Bulk	138	138	26	302
Bulk - Heavy Load	2	2	0	4
Bulk - Self Discharging	8	8	0	16
Container 1000	1	1	0	2
General Cargo	59	59	3	121
ATB/ITB	135	134	39	308
RoRo	4	4	0	8
Tanker - Chemical	544	547	102	1,193
Tanker - Asphalt	16	17	0	33
Tanker - LNG	213	212	1	426
Tanker - LPG	143	144	9	296
Tanker - Handysize	62	63	18	143
Tanker - Panamax	72	70	19	161
Tanker - Aframax	421	419	26	866
Tanker - Suezmax	282	281	13	576
Tanker - VLCC	286	286	4	576
Tanker - ULCC	16	16	0	32
Total	**2,409**	**2,409**	**260**	**5,078**

Figure 3.1 shows the percentage of calls by vessel type. Tankers (85%) made up the majority of the calls, followed by bulk carriers (6%); ATBs (6%); general cargo (3%); and auto carriers/RoRos (0.5%).

Figure 3.1: 2023 Distribution of Calls by Vessel Type

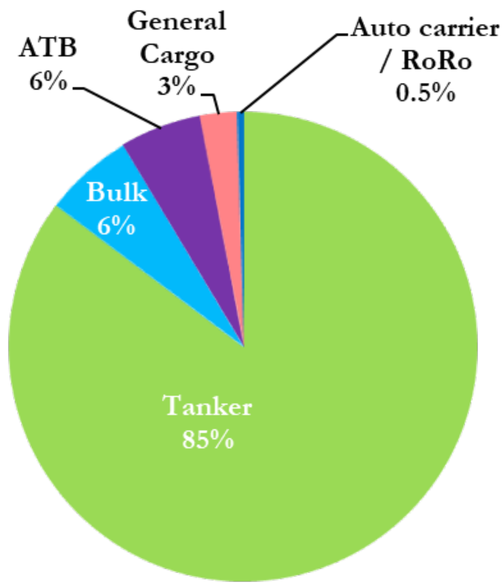


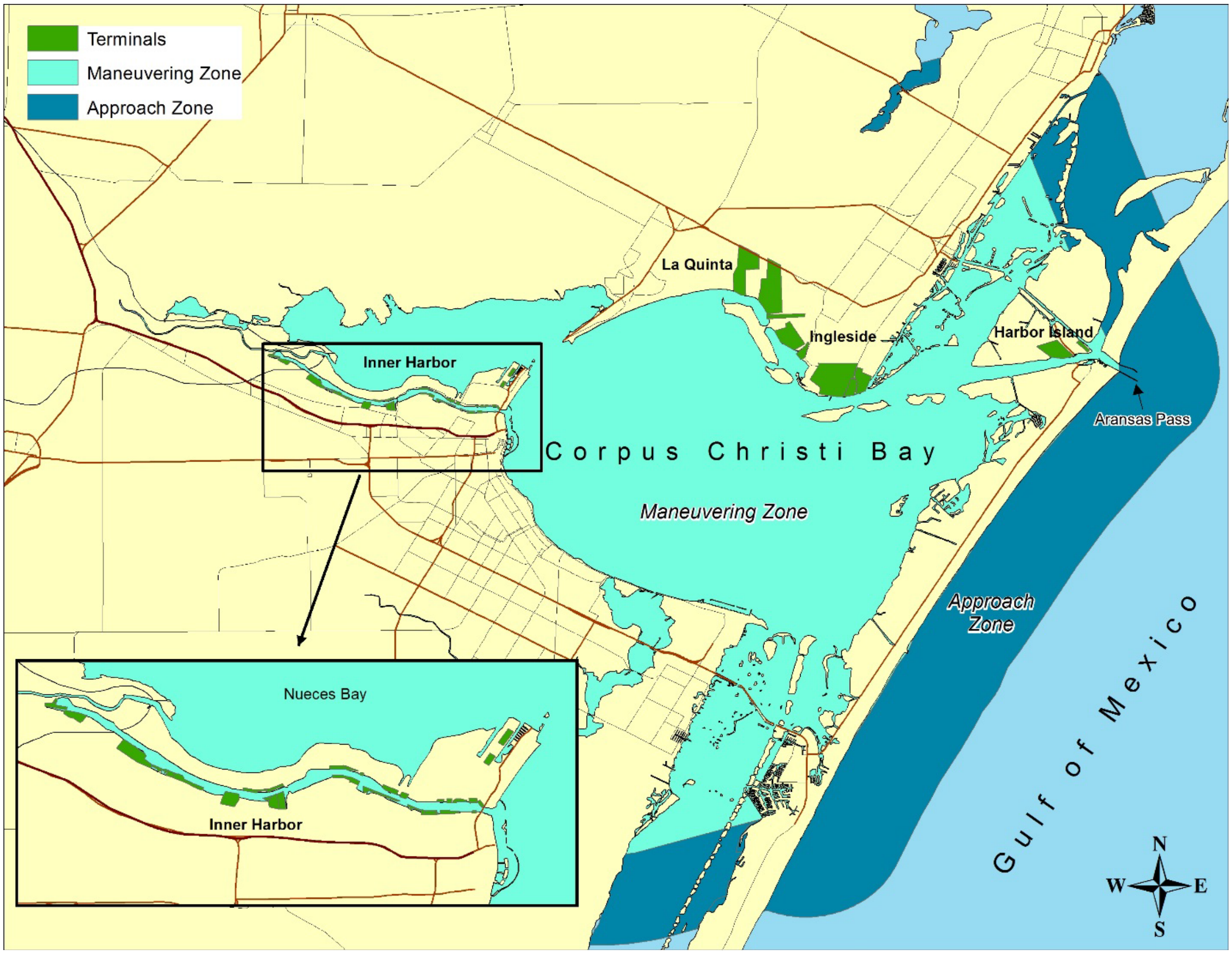
Table 3.2 presents the hoteling times at berth in 2023. The average time spent at berth are slightly higher in 2023 than 2020, especially for the larger tankers and bulk vessels. The average stay is two days with a maximum of 17 days for a tanker in 2023. For bulk vessels, the average is five days. The one containership vessel in the inventory showing high hours with a total of 89 days at berth, was due to the fact that it malfunctioned and needed to come in to berth for repairs. The engines were not used while the vessel was at berth.

Table 3.2: Hotelling Times at Berth, hours

Vessel Type	Min Hrs	Max Hrs	Avg Hrs	Vessel Count	Avg Days
Auto Carrier	17	73	46	6	1.9
Bulk	2	851	126	125	5.3
Bulk - Heavy Load	72	175	124	2	5.1
Bulk - Self Discharging	7	28	19	3	0.8
Container 1000	2,148	2,148	2,148	1	89.5
General Cargo	1	300	59	48	2.5
ATB/ITB	1	202	33	28	1.4
RoRo	8	43	28	3	1.1
Tanker - Chemical	1	277	46	324	1.9
Tanker - Asphalt	20	44	29	8	1.2
Tanker - LNG	2	139	34	87	1.4
Tanker - LPG	11	244	34	25	1.4
Tanker - Handysize	2	103	46	29	1.9
Tanker - Panamax	1	140	43	40	1.8
Tanker - Aframax	1	191	45	195	1.9
Tanker - Suezmax	1	283	50	138	2.1
Tanker - VLCC	1	424	52	185	2.2
Tanker - ULCC	41	168	62	11	2.6

The geographical domain includes Corpus Christi Bay and extends three nautical miles beyond the shoreline of Mustang Island into the Gulf of Mexico. The three nautical mile line defines the edge of the county boundary. Figure 3.2 illustrates the outer limit of the geographic domain on the ocean side for commercial marine vessels.

Figure 3.2: Geographic Domain



The OGV geographic domain is classified into operating zones for approaching and maneuvering activity. The approach zone extends three nautical miles from the shoreline into the Gulf of Mexico. Ships traveling in the approach zone are considered to be traveling in restricted waters as they are near the pilot boarding area. The maneuvering zone is comprised of the area inside Corpus Christi Bay. Most vessels travel from the approach zone through Aransas Pass and enter the maneuvering zone when traveling to or from a berth. Anchorage activities were located outside of the geographical boundary, so they are not included in this report.

3.2 Data and Information Acquisition

The OGV emission estimates presented in this report are primarily based on vessel activity data, vessel operational data, and vessel parameter data. Activity data sources include AIS data and wharfinger vessel call data. The AIS data was used for identifying vessels operating within the geographical domain and spatially processed using Geographic Information System (GIS) analysis to determine discrete vessel activity parameters including speed over water and time spent operating in the approach and maneuvering zones, as well as hotelling time at a berth. This data was collected through the AIS receiver network administered by the U.S. Coast Guard (USCG) and compiled into files comprised of unique AIS records within the inventory domain. The Port also provided wharfinger data detailing vessel calls to terminals, which was used as a secondary data source to verify the vessel activity resulting from AIS data processing. The wharfinger data also provided information on tanker loading events while at-berth.

Vessel operational data includes auxiliary engine and boiler loads sourced from Starcrest's Vessel Boarding Program (VBP). The VBP program collects data from ships' engineers at various ports to determine these loads, measured in kilowatts, across the various operational modes. If a vessel that calls the port has corresponding data in the VBP, that data is used for auxiliary and boiler load values. If there is no applicable data in the VBP dataset, a default value is used that is an average of all the VBP data collected to date for that particular vessel type, size range and operational mode. If a vessel type or size has too little VBP data to calculate a reasonable default, an average of defaults used for other ports' EIs is used. Other vessel specific parameter data is obtained under license from IHS Markit and includes vessel type, engine type, propulsion engine horsepower, keel laid date, as well as other parameters such as alternative fuel capable engines.

3.3 Operational Profiles

Emission estimates have been developed for the three combustion emission source types associated with marine vessel operations: main (or propulsion) engines, auxiliary engines, and, for OGVs, auxiliary boilers. Based on the geographical domain and operational information, the following vessel operational modes define the characteristics of a vessel's operation within the emission inventory domain:

1. *Maneuvering* — Vessel movements inside the EI geographical boundary, after the vessel enters the EI geographic domain or approaching a terminal or before the vessel departs the EI geographical boundary or a terminal. Additional power is typically brought online since the vessel is preparing to or traveling in restricted waters. For this EI, maneuvering zone also includes "approach" zone, the area where the vessel is entering or departing the EI geographical boundary as shown in Figure 3.2.
2. *At-Berth* — When a ship is stationary at the dock/berth.
3. *Shift* — When a ship moves from one berth to another within the geographical boundary.

Operating data and the methods of estimating emissions are discussed below for the three emission source types – differences in estimating methods between the various modes are discussed where appropriate. Fuel sulfur content plays an important role in marine vessel emissions. The 2023 emission estimates are calculated based on the assumption that traditionally fueled vessels were operated using marine gas oil (MGO) with an average sulfur content (S) of 0.1% per IMO's requirement for the North American Emissions Control Area (ECA). Dual fuel capable LNG vessels are also calling the Port and their emissions are estimated based on the assumption that LNG fuel is used by the vessel engines as further described in Section 3.4.4.

3.4 Emission Estimation Methodology

In general, emissions are estimated as a function of vessel power demand expressed in kW-hr multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). Emission factors and emission factor adjustments for different fuel usage (see section 3.4.4), for different propulsion engine load (see section 3.4.5), or emissions controls (see section 3.4.10) are also accounted when estimating OGV emissions.

Equations 3.1 and 3.2 are the basic equations used in estimating emissions by mode.

Equation 3.1

$$\boldsymbol{E_i = Energy_i \times EF \times FCF \times CF}$$

Where:

E_i = Emissions by mode
$Energy_i$ = Energy demand by mode, calculated using Equation 3.2 below as the energy output of the engine(s) or boiler(s) over the period of time, kW-hr
EF = emission factor, expressed in terms of g/kW-hr
FCF = fuel correction factor, dimensionless. FCFs are used if the EF is based on a fuel not actually used by the vessel in the year the EI is being calculated. For this EI, FCFs are 1.0 for all pollutants.
CF = control factor(s) for emission reduction technologies, dimensionless. For this EI, no CFs are used.

The 'Energy' term of the equation is where most of the location-specific information is used. Energy by mode is calculated using Equation 3.2:

Equation 3.2

$$\boldsymbol{Energy_i = Load \times Act}$$

Where:

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

The emissions estimation methodology for propulsion engines can be found in subsections 3.4.1 to 3.4.5, for auxiliary engines can be found in subsection 3.4.6, and for auxiliary boilers can be found in subsection 3.4.7. Propulsion engines are also referred to as main engines. Incinerators are not included in the emissions estimates because incinerators interviews with the vessel operators and marine industry indicate that vessels do not use their incinerators while at-berth or near coastal waters.

3.4.1 Propulsion Engine Maximum (MCR) Continuous Rated Power

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

3.4.2 Propulsion Engine Load Factor

Propulsion engine load factor is estimated using the Propeller Law, which shows that propulsion engine load, varies with the cube of actual speed over maximum rated speed of the vessel. The Propeller Law equation is illustrated below.

Equation 3.3

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

Where:

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

For the purpose of estimating emissions, the load factor has been capped at 1.0 so that there are no calculated propulsion engine load factors greater than 100% (i.e., calculated load factors above 1.0 are assigned a load factor of 1.0).

In discussions with the Pilots at other ports with confined channels, it was determined that OGVs traveling in the maneuvering zone (excluding approach zone) of a confined channel experience the phenomenon of "squat" in which the ships encounter additional resistance. It was approximated from the Pilots that vessels traveling at or above 5 knots in the channels would need an additional average engine load of 10%. Therefore, Equation 3.4 was used in the maneuvering zone for vessels traveling at or greater than 5 knots.

Equation 3.4

$$LFx = LF + 10\%$$

Where:

LFx = calculated load factor for maneuvering zone in the channel at or greater than 5 knots
LF = load factor as calculated using Equation 3.3

3.4.3 Propulsion Engine Activity

Activity is measured in hours of operation within the geographical boundary. At-berth times are determined from the date and time stamps in the AIS data when a vessel is determined to be at a terminal. The maneuvering time within the geographical boundary is estimated using equation 3.5, which divides the segment distance traveled by ship at its over water speed.

Equation 3.5

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

Where:

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

Distance and actual speeds are derived from AIS data point locations and associated over the water speed.

3.4.4 Engine Emission Factors

IMO has established NO_x emission standards for marine diesel engines.[4] NO_x emission factors are based on the IMO Tier of the vessel engines, which is based on the keel laid data provided in the IHS data. For regulatory purposes, all diesel cycle fuel oil/marine distillate fueled engines are divided into Tier 0 to Tier III as per the NO_x standards and by engine rated speed, in revolutions per minute or rpm, as listed below:

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

[4] *www.dieselnet.com/standards/inter/imo.php*

Emission factors for all engine types used in this study were obtained from equations or values included in EPA's document entitled "Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions," dated September 2020 (EPA's EI Guidance Document)[5]. Table 3.3 lists the emission factors for propulsion engines using 0.1% sulfur which is the fuel that is used to be compliant with the IMO North American ECA requirement.

Table 3.3: OGV Emission Factors for Diesel Propulsion, Steam (Boiler) Propulsion and Gas Turbine Engines, g/kW-hr

Engine Category	Tier	Model Year Range	NO_x	PM_{10}	$PM_{2.5}$	HC	CO	SO_x	CO_2	N_2O	CH_4
Slow Speed Main	0	1999 and older	17.0	0.18	0.17	0.60	1.40	0.36	593	0.029	0.012
Slow Speed Main	I	2000 to 2010	16.0	0.18	0.17	0.60	1.40	0.36	593	0.029	0.012
Slow Speed Main	II	2011 to 2015	14.4	0.18	0.17	0.60	1.40	0.36	593	0.029	0.012
Slow Speed Main	III	2016 and newer	3.4	0.18	0.17	0.60	1.40	0.36	593	0.029	0.012
Medium Speed Main	0	1999 and older	13.2	0.19	0.17	0.50	1.10	0.40	657	0.029	0.012
Medium Speed Main	I	2000 to 2010	12.2	0.19	0.17	0.50	1.10	0.40	657	0.029	0.012
Medium Speed Main	II	2011 to 2015	10.5	0.19	0.17	0.50	1.10	0.40	657	0.029	0.012
Medium Speed Main	III	2016 and newer	2.6	0.19	0.17	0.50	1.10	0.40	657	0.029	0.012
Gas Turbine		All	5.7	0.01	0.01	0.10	0.20	0.59	962	0.075	0.002
Steamship Main		All	2.0	0.20	0.19	0.10	0.20	0.59	962	0.075	0.002

Published documents from engine manufacturers[6] and classification societies[7] suggest that Tier III propulsion engines will not meet Tier III emission standards when operating below 25% main engine load because the exhaust heat does not reach the necessary temperature for selective catalytic reduction (SCR) or exhaust gas recirculation (EGR) systems to effectively reduce emissions. As such, when Tier III main engines operated below 25% within the emissions inventory domain, the default Tier II NO_x emission factors were used in emission calculations. The vessels are operating at lower loads within the Inner Harbor and Corpus Christi Bay due to lower speeds as compared to open ocean, thus 59% of the movements occurred at lower load with main engines using Tier II emission factors. Table 3.4 shows the 2023 vessel Tier count for diesel propulsion engines. It shows that 60% percent of the vessels calling the Port in 2023 are Tier II and newer, compared to 48% in 2020. Table 3.5 lists the emission factors for auxiliary engines using 0.1% sulfur.

Table 3.4: 2023 Vessel Tier Count and Percent

	Tier 0	Tier I	Tier II	Tier III
Count	32	477	499	252
Percent	3%	38%	40%	20%

[5] *www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance*
[6] MAN Diesel & Turbo, "Tier III Two-Stroke Technology."
[7] DNV-GL, "NO_x Tier III Update: Choices and challenges for on-time compliance," November 2017.

Table 3.5: Emission Factors for Auxiliary Engines using 0.1% S, g/kW-hr

Engine Category	Tier	Model Year Range	NO_x	PM_{10}	$PM_{2.5}$	HC	CO	SO_x	CO_2	N_2O	CH_4
Medium Auxiliary	0	1999 and older	13.8	0.19	0.17	0.40	1.10	0.42	696	0.029	0.008
Medium Auxiliary	I	2000 to 2010	12.2	0.19	0.17	0.40	1.10	0.42	696	0.029	0.008
Medium Auxiliary	II	2011 to 2015	10.5	0.19	0.17	0.40	1.10	0.42	696	0.029	0.008
Medium Speed Main	III	2016 and newer	2.6	0.19	0.17	0.40	1.10	0.42	696	0.029	0.008
High Auxiliary	0	1999 and older	10.9	0.19	0.17	0.40	0.90	0.42	696	0.029	0.008
High Auxiliary	I	2000 to 2010	9.8	0.19	0.17	0.40	0.90	0.42	696	0.029	0.008
High Auxiliary	II	2011 to 2015	7.7	0.19	0.17	0.40	0.90	0.42	696	0.029	0.008
High Auxiliary	III	2016 and newer	2.0	0.19	0.17	0.40	0.90	0.42	696	0.029	0.008

In addition to the auxiliary engines that are used to generate electricity for on-board uses, most OGVs have one or more boilers used for fuel heating and for producing hot water and steam. Table 3.6 shows the emission factors used for the auxiliary boilers.

Table 3.6: Emission Factors for OGV Auxiliary Boilers using 0.1% S, g/kW-hr

Engine Category	Model Year Range	NO_x	PM_{10}	$PM_{2.5}$	HC	CO	SO_x	CO_2	N_2O	CH_4
Auxiliary Boiler	All	2.0	0.20	0.19	0.10	0.20	0.59	962	0.075	0.002

In 2023, there were 93 vessels that used LNG. Dual fuel capable LNG cargo vessels were assumed to be using LNG fuel in 2023 in auxiliary engines and boilers, while non-LNG cargo ships with dual fuel engines were contacted to find out if they used LNG in 2023 for any or all of their port calls, and in which engines. Most vessels using LNG reported switching from LNG to traditional fuels in the main engine before slowing down to approach the port but were able to run the auxiliary engines, and boiler as needed, on LNG throughout the emissions inventory domain and port stay. Dual fuel vessels require a pilot fuel for ignition, therefore a 3.5% MGO pilot fuel was also used when vessels were using LNG as a primary fuel. This is an average percentage developed from interviews with various dual fuel vessel operators.

Tables 3.7 and 3.8 list the emission factors for engines and steam boilers using LNG fuel per EPA's Ports EI Guidance for most pollutants, except for the SO_x EF which is from the IMO 4th GHG Study[8] and 3.5% MGO as pilot fuel. The brake specific fuel consumption (BSFC) used for LNG fuel in this report is 166 g/kWh.

Table 3.7: Emission Factors for Propulsion Engines and Steam Boilers using LNG fuel and 3.5% MGO as Pilot Fuel, g/kWh

Engine Category	IMO Tier	Range Year	NO_x	PM_{10}	$PM_{2.5}$	DPM	HC	CO	SOx	CO_2	N_2O	CH_4
Slow speed propulsion	Tier 0	1999 and older	1.85	0.035	0.033	0.006	0.02	1.30	0.018	461.3	0.029	0.00
Slow speed propulsion	Tier I	2000 to 2011	1.81	0.035	0.033	0.006	0.02	1.30	0.018	461.3	0.029	0.00
Slow speed propulsion	Tier II	2011 to 2016	1.76	0.035	0.033	0.006	0.02	1.30	0.018	461.3	0.029	0.00
Slow speed propulsion	Tier III	2016 and newer	1.37	0.035	0.033	0.006	0.02	1.30	0.018	461.3	0.029	0.00
Medium speed propulsion	Tier 0	1999 and older	1.72	0.035	0.033	0.007	0.02	1.29	0.019	463.5	0.029	0.00
Medium speed propulsion	Tier I	2000 to 2011	1.68	0.035	0.033	0.007	0.02	1.29	0.019	463.5	0.029	0.00
Medium speed propulsion	Tier II	2011 to 2016	1.62	0.035	0.033	0.007	0.02	1.29	0.019	463.5	0.029	0.00
Medium speed propulsion	Tier III	2016 and newer	1.35	0.035	0.033	0.007	0.02	1.29	0.019	463.5	0.029	0.00
Steam boilers	na	na	1.32	0.035	0.032	0.000	0.00	1.26	0.026	474.2	0.075	0.00

Table 3.8: Emission Factors for Auxiliary Engines using LNG fuel and 3.5% MGO as Pilot Fuel, g/kWh

Engine Category	IMO Tier	Range Year	NO_x	PM_{10}	$PM_{2.5}$	DPM	HC	CO	SOx	CO_2	N_2O	CH_4
Medium speed Auxiliary	Tier 0	1999 and older	1.74	0.035	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
Medium speed Auxiliary	Tier I	2000 to 2011	1.68	0.035	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
Medium speed Auxiliary	Tier II	2011 to 2016	1.62	0.035	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
Medium speed Auxiliary	Tier III	2016 and newer	1.35	0.035	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
High speed Auxiliary	Tier 0	1999 and older	1.64	0.036	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
High speed Auxiliary	Tier I	2000 to 2011	1.60	0.036	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
High speed Auxiliary	Tier II	2011 to 2016	1.52	0.036	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00
High speed Auxiliary	Tier III	2016 and newer	1.32	0.036	0.033	0.007	0.01	1.29	0.02	464.9	0.029	0.00

3.4.5 Propulsion Engines Low Load Emission Factor Adjustments

Studies conducted by EPA and San Pedro Bay Ports (SPBP) have shown that slow speed main engine emissions vary by engine load. Based on these studies, pollutant specific load adjustment multipliers as a function of main engine load are being established and used in conjunction with emission factors to estimate OGV emissions. Emissions test results of the SPBP study observed significant difference in magnitude than the base emission factors for HC and CO. Based on the SPBP study, in addition to load adjustment factors, emission factor adjustments (EFA) are applied to the base HC and CO emission factors. Please refer to Appendix A for the equations and tables that show the values used.

[8] IMO, *https://www.imo.org/en/ourwork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx*

3.4.6 Auxiliary Engine Load Defaults

The primary data source for auxiliary load data is from the Vessel Boarding Program (VBP) where data is collected on operations by mode for ships that visited and their sister ships. The IHS Markit database contains limited auxiliary engine installed power information and no information on use by mode, because neither the IMO nor the classification societies require vessel owners to provide this information. Under VBP, information is collected for the vessel and sister vessels on auxiliary engine and boiler loads at various modes of vessel operations. Actual VBP data by vessel type, by emissions source and by mode, if available, is used when estimating auxiliary engine emissions. If actual VBP data is not available, average auxiliary engine load defaults derived from VBP data for vessels calling the Port were used by vessel type and mode. If average auxiliary engine load defaults specific to a vessel type are not available, an average of the latest published defaults for other ports by vessel type and mode is used. Table 3.9 summarizes the auxiliary engine load defaults by mode used for this study by vessel subtype.

Table 3.9: Average Auxiliary Engine Load Defaults, kW

Vessel Type	Sea	Maneuvering	Berth Hotelling
Auto Carrier	590	1,187	1,048
Bulk	259	377	369
Bulk - Heavy Load	462	1,223	272
Bulk - Self Discharging	500	625	1,000
Container 1000	960	1,280	658
General Cargo	471	1,098	778
ATB/ITB	112	112	411
RoRo	590	1,187	1,048
Tanker - Chemical	427	510	1,048
Tanker - Asphalt	500	750	500
Tanker - LNG	2,913	3,204	3,826
Tanker - LPG	550	700	1,000
Tanker - Handysize	584	682	1,188
Tanker - Panamax	483	571	817
Tanker - Aframax	492	594	913
Tanker - Suezmax	661	679	909
Tanker - VLCC	746	879	1,104
Tanker - ULCC	983	1,100	1,650

3.4.7 Auxiliary Boiler Load Defaults

Similar to auxiliary engine loads, the primary data source for the Ports' EI related auxiliary boiler load data is VBP. If actual VBP data is not available, average auxiliary boiler engine load defaults derived from VBP data or an average of defaults for other ports by vessel type is used.[9] The auxiliary boiler load defaults in kilowatts used for each vessel type are presented in Table 3.10 for most vessels and Table 3.11 for diesel-electric vessels. Auxiliary boilers are not typically used when the main engine load is greater than 20% due to heat recovery systems that are used to produce steam while the ship is underway. If the main engine load is less than or equal to 20%, the maneuvering boiler load defaults are used. Articulated tug barges (ATBs) do not use boilers for pumping cargo; therefore, their boiler energy default is zero.

Table 3.10: Auxiliary Boiler Load Defaults, kW

Vessel Type	Sea	Maneuvering	Berth Hotelling
Auto Carrier	91	186	313
Bulk	39	92	123
Bulk - Heavy Load	35	94	125
Bulk - Self Discharging	0	36	144
Container 1000	104	209	455
General Cargo	72	161	207
ATB/ITB	0	0	0
RoRo	91	186	313
Tanker - Chemical	85	134	446
Tanker - Asphalt	690	690	875
Tanker - LNG	0	145	548
Tanker - LPG	50	144	187
Tanker - Handysize	110	228	2,358
Tanker - Panamax	184	306	3,261
Tanker - Aframax	164	241	5,700
Tanker - Suezmax	3	93	7,984
Tanker - VLCC	253	201	9,478
Tanker - ULCC	191	287	8,621

[9] *www.polb.com/environment/air#emissions-inventory* and *www.portoflosangeles.org/environment/air-quality/air-emissions-inventory*

Tankers, when discharging liquid bulk, have much higher auxiliary boiler usage rates, as shown in Table 3.10, than the other vessel types. Tankers' boilers produce steam for steam-powered liquid cargo pumps when discharging, steam powered inert gas fans, and for heating. Less steam is needed when liquid cargo is being loaded. Since loading and discharging data was available for the tankers that visited the Port, a lower boiler load of 875 kW was used for tankers known to be loading cargo while at berth, except for chemical tankers and LNG tankers which used the loads as listed. The data showed that almost 90% of the tanker calls were loading and the other 10% were unloading or discharging cargo.

Table 3.11 presents the auxiliary boiler load defaults in kilowatts for diesel-electric vessels.

Table 3.11: Auxiliary Boiler Load Defaults for Diesel Electric Tankers, kW

Vessel Type	Sea	Maneuvering	Berth Hotelling
Tanker - Chemical	0	145	220
Tanker - LNG	0	145	220

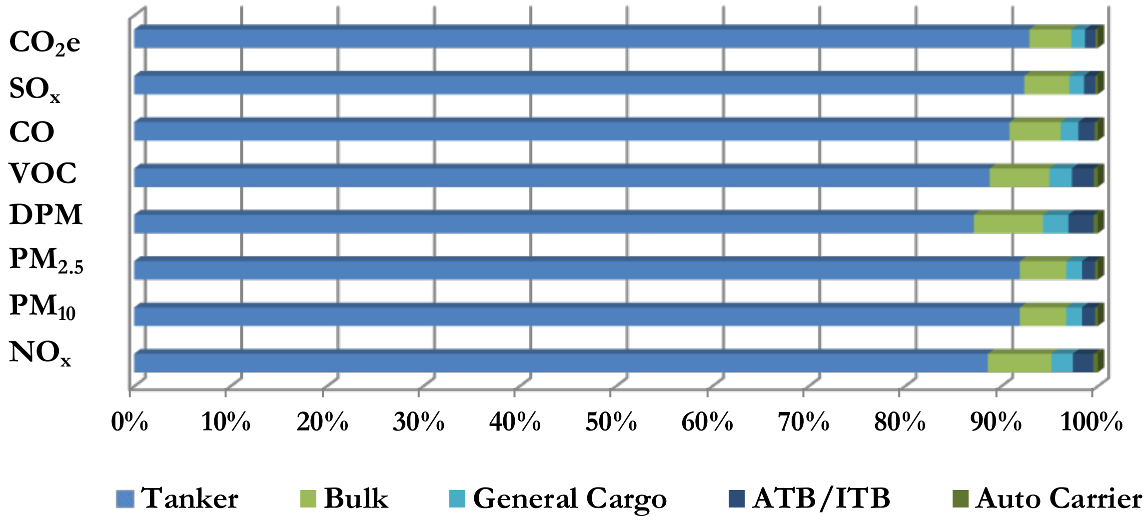
3.5 OGV Emission Estimates

The emission estimates presented in this document are listed in various ways to provide the reader a better understanding of emissions by vessel type, engine source, and mode of operation. Table 3.12 and Figure 3.3 show that tankers have the highest emissions at the Port (over 89%).

Table 3.12: 2023 OGV Emissions of Criteria Pollutants by Vessel Type

Vessel Type	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Auto Carrier/ RoRo	11	0	0	0	0	1	0	612
Bulk	151	3	3	2	5	14	7	10,436
General Cargo	51	1	1	1	2	5	2	3,441
ATB/ITB	49	1	1	1	2	5	2	2,580
Tanker	2,022	53	49	26	70	243	137	223,234
Total	**2,283**	**58**	**53**	**30**	**78**	**267**	**148**	**240,302**

Figure 3.3: Distribution of OGV Emissions by Vessel Type and Pollutant



The emissions are presented by engine type in Table 3.13 and by operating mode in Table 3.14. Auxiliary engines have the highest criteria pollutant emissions, while boilers have the highest GHG emissions.

Table 3.13: OGV Emissions of Criteria Pollutants by Emission Source Type

Emission Source	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Main Engines	654	5	5	5	13	46	15	22,859
Auxiliary Engines	1,362	26	24	25	52	188	56	97,817
Boilers	267	27	25	0	13	33	77	119,625
Total	**2,283**	**58**	**53**	**30**	**78**	**267**	**148**	**240,302**

Based on the geographical scope of the study which is mainly within the port complex extending out to 3 nm, the hoteling mode has the highest emissions when compared to maneuvering. Maneuvering includes emissions from vessels approaching, departing, and shifting to or from the Port.

Table 3.14: OGV Emissions of Criteria Pollutants by Operating Mode

Operating Mode	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Hotelling	1,543	51	47	23	62	207	129	210,149
Maneuvering	740	7	6	6	16	60	19	30,152
Total	**2,283**	**58**	**53**	**30**	**78**	**267**	**148**	**240,302**

SECTION 4 HARBOR VESSELS

This section presents emission estimates for the harbor vessels and recreational vessel source categories and is organized into the following subsections: source description (4.1), data and information acquisition (4.2), emissions estimation methodology (4.3), commercial harbor craft emission estimates (4.4) and the recreational vessels emission estimates (4.5).

4.1 Source Description

Emissions from the following types of diesel-fueled commercial harbor craft were quantified:

- **Commercial fishing vessels** – Commercial fishing vessels are vessels primarily engaged in commercial fishing and are home ported in San Patricio and Nueces Counties.
- **Crew and supply vessels** – These supply vessels make numerous trips back and forth from a terminal or home berth to anchorage and offshore platforms. For this inventory, these vessels are included in the tugboat category.
- **Excursion vessels** – Excursion vessels include charter vessels for hire by the general public for private tours and sport fishing.
- **Ferry vessels** – The ferries connect Mustang Island and Port Aransas with the mainland via Aransas Pass, and transport cars and passengers seven days a week, twenty-four hours a day.
- **Government vessels** – The government vessels include the pilot boats and workboats.
- **Tugboats** – The tugboats include vessels that assist and escort the ocean-going vessels calling at the Port. They provide harbor towing at the Port during arrival, departure, and shifts. In addition, there are general tugboats that provide other types of services or work.
- **Towboats** – Towboats include self-propelled ocean tugs, pushboats, and towboats that tow/push barges, moving cargo such as bunker fuels and grains. Pushboats are similar to towboats, except as the name implies, they push barges rather than tow them. They can be used to move bulk liquids, scrap metal, bulk materials, rock, sand, and other materials.

In addition to the diesel fueled commercial harbor craft, recreational vessels for both Nueces and San Patricio counties were included in this inventory. The recreational vessel counts and emissions are included in section 4.5.

4.2 Data and Information Acquisition

Tables 4.1 and 4.2 summarize the characteristics of main and auxiliary engines respectively, by vessel type for commercial harbor craft operating at the two counties in 2023. Averages of the model year, horsepower, or operating hours are used as default values when vessel specific data is not available. In 2023, 736 discrete vessels were included, 30% more than in 2020. The barge activity has increased at the Port over the years and this impacts the number of tugboats and towboats included in the inventory. In 2023, there were 5,692 recorded barge movements. The "na" in the table is for information not available such as commercial fishing engine model year or not applicable for excursion and government auxiliary engines.

Table 4.1: 2023 Main Engine Characteristics by Commercial Harbor Craft Type

	Propulsion Engines								
Harbor	Model year			Horsepower			Annual Operating Hours		
Craft Type	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Commercial fishing	na	na	na	500	500	500	50	50	50
Excursion	1961	2015	1987	240	800	549	50	50	50
Ferry	2010	2020	2018	350	755	594	2,762	5,005	4,124
Government	1987	2008	1999	225	750	505	500	2,500	1,300
Tugboat	1976	2020	2016	1950	3,386	2,860	0	817	1,403
Towboats	1956	2023	2005	280	2,000	1,078	0	1,705	76

Table 4.2: 2023 Auxiliary Engine Characteristics by Commercial Harbor Craft Type

	Auxiliary Engines								
Harbor	Model year			Horsepower			Annual Operating Hours		
Craft Type	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Commercial fishing	na	na	na	40	40	40	50	50	50
Excursion	na	na	na	na	na	na	0	5,496	53
Ferry	2007	2017	2010	98	113	107	2,245	2,502	2,416
Government	na	na	na	na	na	na	na	na	na
Tugboat	1976	2020	2016	100	201	145	0	6,373	1,403
Towboats	1956	2023	2005	92	92	92	0	8,636	76

The data for excursion vessels, ferries, government vessels, and some of the tugboat companies that are tenants was acquired by contacting individual companies and they in turn provided fleet information for the vessels and engines.

For commercial fishing vessels, the U.S. Coast Guard Sector Corpus Christi Uninspected Vessels Division provided an estimate of the count of fishing vessels in San Patricio and Nueces counties in 2020 and the count remained the same for 2023. The hours and horsepower are averages based on discussions with local commercial fishing operators. The hours are low because these vessels mainly work outside of the study area.

For 2023 EI, the Port provided an extensive tugboat/towboat dataset that included vessel characteristics, which were matched to the 2023 towboat/tugboat list. In addition, IHS data and the past 2020 data were used to determine number of propulsion engines, model year and horsepower.

The horsepower is total propulsion horsepower for the vessel. Information on several vessels via various towboat operators' websites and IHS indicated that, on average, the vessels have 1.8 main engines. Most vessels have twin propulsion engines, but the average is lower (1.8) due to some vessels only have one propulsion engine. Therefore, as a default, the total propulsion horsepower was divided by 1.8 and assigned to each propulsion engine to determine emission factors. The auxiliary engine horsepower was not available. This information was obtained for several vessels via various towboat operators' websites and the average horsepower (92 hp) based on the collected data was used for auxiliary engines which are mainly used for house load.

For towboats and additional tugboats, AIS data was used to identify activity (hours) in three zones by Maritime Mobile Service Identity (MMSI) numbers. The zones are at berth, maneuvering, and in the approach zone.

- At berth - Hours in this zone were assumed for one auxiliary engine.
- Maneuvering - Hours in this zone were assumed for one auxiliary engine and two main engines.
- Approach - Hours in this zone were assumed for one auxiliary engine and two main engines.

4.3 Emission Estimation Methodology

The basic equation used to estimate harbor vessels' emissions is:

Equation 4.1

$$\boldsymbol{E = kW \times Act \times LF \times EF \times FCF}$$

Where:

E = emissions, g/year
kW = rated horsepower of the engine converted to kilowatts
Act = activity, hours/year
LF = load factor
EF = emission factor, g/kW-hr
FCF = fuel correction factor

The total annual hours were used to calculate commercial harbor craft emissions. The calculated emissions were converted to tons per year by dividing the emissions by 2,000 lb/ton x 453.59 g/lb. For the tugboat hours, the average maneuvering time of all OGVs from AIS was used to calculate the time spent for assist and escort operations for the entire year since the tugboat companies did not provide the annual hours during data collection.

The emission factors used for harbor craft are listed in Table 4.3 and 4.4 for ultra-low sulfur diesel (ULSD) fueled propulsion and auxiliary engines, respectively. A fuel correction factor of 0.938 was used for NO_x emissions to reflect the reductions for using TxLED fuel. The emission factors units are in grams per kilowatt-hour. These emissions factors were obtained from EPA's document entitled "Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions."[10]

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

Table 4.3: Harbor Craft Emission Factors for Propulsion Engines using ULSD, g/kW-hr

kW Range	Year Range	NO_x	PM_{10}	$PM_{2.5}$	VOC	CO	SO_x	CO_2	N_2O	CH_4
Tier 0 Engines										
37 < kW ≤ 600	≤2003	10.08	0.24	0.23	0.29	1.62	0.01	679	0.03	0.01
600 < kW ≤ 1000	≤2003	10.25	0.21	0.20	0.28	1.65	0.01	679	0.03	0.01
1000 < kW ≤ 1400	≤2003	10.45	0.22	0.21	0.27	1.71	0.01	679	0.03	0.01
1400 < kW ≤ 2000	≤2003	11.80	0.20	0.19	0.24	2.03	0.01	679	0.03	0.01
2000 < kW ≤ 3700	≤2003	13.36	0.21	0.20	0.14	2.48	0.01	679	0.03	0.01
2000 < kW ≤ 3700	2004-2006	10.55	0.21	0.20	0.14	2.48	0.01	679	0.03	0.01
3,701+	≤2003	13.36	0.21	0.20	0.14	2.48	0.01	679	0.03	0.01
3,701+	2004-2006	10.55	0.21	0.20	0.14	2.48	0.01	679	0.03	0.01
Tier 1 Engines										
37 < kW ≤ 600	2004-2006	6.50	0.13	0.12	0.23	1.17	0.01	679	0.03	0.01
600 < kW ≤ 1000	2004-2006	7.83	0.16	0.16	0.24	1.44	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2004-2006	7.28	0.15	0.14	0.22	1.39	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2004-2006	9.66	0.20	0.19	0.24	2.03	0.01	679	0.03	0.01
Tier 2 Engines										
37 < kW ≤ 600	2007-2012	6.06	0.12	0.12	0.22	1.10	0.01	679	0.03	0.01
600 < kW ≤ 1000	2007-2012	6.06	0.12	0.12	0.20	1.12	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2007-2011	6.22	0.14	0.13	0.19	1.18	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2007-2011	6.79	0.18	0.18	0.18	1.40	0.01	679	0.03	0.01
2000 < kW ≤ 3700	2007-2015	8.33	0.31	0.30	0.14	2.00	0.01	679	0.03	0.01
3,701+	2007-2015	8.33	0.31	0.30	0.14	2.00	0.01	679	0.03	0.01
Tier 3 Engines										
37 < kW ≤ 600	2013	5.67	0.11	0.10	0.18	1.10	0.01	679	0.03	0.01
37 < kW ≤ 600	2014-2021	4.69	0.07	0.07	0.11	1.10	0.01	679	0.03	0.01
600 < kW ≤ 1000	2013	5.30	0.09	0.09	0.15	1.12	0.01	679	0.03	0.01
600 < kW ≤ 1000	2014-2021	4.74	0.07	0.07	0.10	1.12	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2013	5.66	0.10	0.10	0.16	1.18	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2014-2016	4.83	0.07	0.07	0.10	1.18	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2013	5.40	0.10	0.10	0.10	1.40	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2014-2015	5.27	0.10	0.10	0.10	1.40	0.01	679	0.03	0.01
Tier 4 Engines										
600 < kW ≤ 1000	2017+	1.3	0.03	0.03	0.04	1.1	0.01	679	0.031	0.01
1000 < kW ≤ 1400	2017+	1.3	0.03	0.03	0.04	1.2	0.01	679	0.031	0.01
1400 < kW ≤ 2000	2016+	1.3	0.03	0.03	0.03	1.40	0.01	679	0.03	0.01
2000 < kW ≤ 3700	2016+	1.3	0.03	0.03	0.02	2.00	0.01	679	0.03	0.01
3,701+	2016+	1.3	0.03	0.03	0.02	2.00	0.01	679	0.03	0.01

Table 4.4: Harbor Craft Emission Factors for Auxiliary Engines using ULSD, g/kW-hr

kW Range	Year Range	NO_x	PM_{10}	$PM_{2.5}$	VOC	CO	SO_x	CO_2	N_2O	CH_4
Tier 0 Engines										
37 < kW ≤ 600	≤2003	10.08	0.29	0.28	0.30	1.57	0.01	679	0.03	0.01
600 < kW ≤ 1000	≤2003	10.41	0.21	0.21	0.28	1.62	0.01	679	0.03	0.01
1000 < kW ≤ 1400	≤2003	10.95	0.19	0.19	0.28	1.78	0.01	679	0.03	0.01
1400 < kW ≤ 2000	≤2003	10.08	0.24	0.23	0.28	1.80	0.01	679	0.03	0.01
Tier 1 Engines										
37 < kW ≤ 600	2005-2006	6.10	0.16	0.15	0.26	0.96	0.01	679	0.03	0.01
600 < kW ≤ 1000	2004-2006	7.62	0.17	0.16	0.25	1.32	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2004-2006	9.19	0.19	0.19	0.28	1.78	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2004-2006	9.20	0.19	0.18	0.28	1.80	0.01	679	0.03	0.01
Tier 2 Engines										
37 < kW ≤ 600	2007-2012	5.96	0.15	0.15	0.25	0.93	0.01	679	0.03	0.01
600 < kW ≤ 1000	2007-2011	6.10	0.14	0.13	0.22	0.90	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2007-2011	6.10	0.14	0.13	0.22	0.90	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2007-2011	6.10	0.14	0.13	0.22	0.90	0.01	679	0.03	0.01
Tier 3 Engines										
37 < kW ≤ 600	2013+	4.58	0.08	0.08	0.13	0.93	0.01	679	0.03	0.01
600 < kW ≤ 1000	2014-2017	4.82	0.08	0.08	0.12	0.90	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2013-2015	4.88	0.08	0.08	0.12	0.90	0.01	679	0.03	0.01
Tier 4 Engines										
600 < kW ≤ 1000	2018+	1.30	0.03	0.03	0.04	0.90	0.01	679	0.03	0.01
1000 < kW ≤ 1400	2017+	1.30	0.03	0.03	0.04	0.90	0.01	679	0.03	0.01
1400 < kW ≤ 2000	2016+	1.30	0.03	0.03	0.04	0.90	0.01	679	0.03	0.01

Engine load factors represent the average load of an engine or the percentage of rated engine power that is used during the engine's normal operation. Table 4.5 summarizes the average engine load factors for the harbor craft vessel types for their propulsion and auxiliary engines based on the latest EPA Ports EI Guidance document.

Table 4.5: Commercial Harbor Craft Load Factors

Harbor Craft Type	Propulsion Engine	Auxiliary Engine
Commercial fishing	0.52	0.43
Ferry and excursion	0.42	0.43
Government	0.45	0.43
Tugboat	0.50	0.43
Towboat and pushboat	0.68	0.43

4.4 Commercial Harbor Craft Emission Estimates

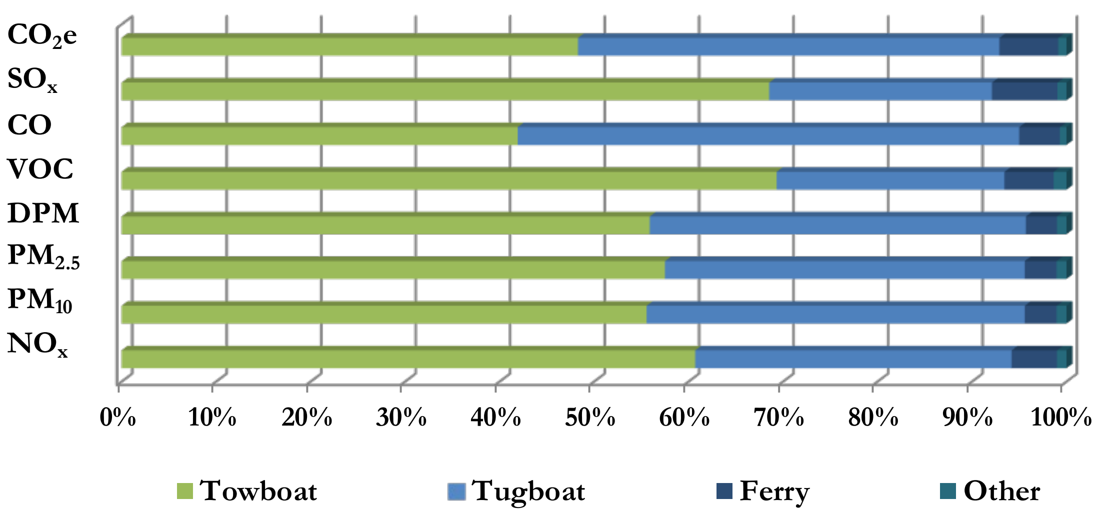
Table 4.6 presents the emissions for commercial harbor craft by vessel type, not including recreational vessels. Towboats and tugboats have the highest emissions compared to all commercial harbor craft due to greater activity (kW-hrs) in the area as compared to the other vessel types.

Table 4.6: Commercial Harbor Craft Emissions

Vessel Type	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Commercial fishing	4	0.1	0.1	0.1	0.1	1	0.0	285
Excursion	2	0.1	0.0	0.0	0.1	0	0.0	139
Ferry	75	1.2	1.2	1.2	2.1	18	0.1	10,130
Government	10	0.2	0.2	0.2	0.4	2	0.0	986
Tugboat	506	14.4	13.2	14.2	9.7	219	0.3	72,561
Towboat	891	20.0	20.0	20.0	28.0	173	1.0	78,584
Total	**1,488**	**36.0**	**34.8**	**35.8**	**40.4**	**413**	**1.5**	**162,685**

Figure 4.1 presents the distribution of emissions by harbor craft type. The other vessels in the Figure include government, commercial fishing and excursion vessels.

Figure 4.1: Commercial Harbor Craft Emissions



For greater granularity, the commercial harbor craft emissions are shown in Table 4.7 as associated with the Port of Corpus Christi (PCCA) or not (non-PCCA). Those that are associated with the Port are vessels that are either tenants or known to be berthed within the geographical domain, and commercial harbor craft (mainly tugboats and towboats) that were towing a barge that called a Port berth. The non-PCCA emissions are from commercial harbor craft (mainly tugboats and towboats) that transited the area, such as those transiting the Gulf Intracoastal Waterway (GIWW), but did not stop at a Port berth.

Table 4.7: PCAA and non-PCAA Commercial Harbor Craft Emissions

Entity	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
PCCA	540	13	12	13	14	179	1	68,390
Non-PCCA	947	23	22	23	26	234	1	94,294
Total	**1,488**	**36**	**35**	**36**	**40**	**413**	**1.6**	**162,685**

4.5 Recreational Vessel Emission Estimates

The total recreational vessel population for Nueces and San Patricio counties was obtained from the Texas Parks and Wildlife's Boat Registration Records. Total population was distributed by vessel type using the population distribution from MOVES4 model. Fleet average emission factors in grams per hour for exhaust and running loss and in grams per vessel for evaporative emissions by vessel types and fuel types were obtained from MOVES4 model run for Nueces and San Patricio Counties. The vessel type and fuel specific grams per hour emission factors were multiplied by the number of vessels and activity hours in each category to obtain total recreational vessel emissions. The activity hours were estimated to be 240 hours/year for each recreational vessel. The 2023 recreational vessel emissions are presented in Table 4.8.

Table 4.8: Recreational Vessel Emissions

Vessel Type	Engine Type	Vessel Count	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Outboard	Gasoline	8,574	234	9.0	8.2	0.0	633	3,856	0.2	36,486
Inboard/Sterndrive	Gasoline	1,908	128	1.8	1.6	0.0	80	1,538	0.1	19,550
Personal Water Craft	Gasoline	1,159	49	0.6	0.6	0.0	59	894	0.0	6,937
Inboard/Sterndrive	Diesel	343	33	0.8	0.8	0.8	2	8	0.0	3,856
Outboard	Diesel	11	0	0.0	0.0	0.0	0	0	0.0	18
Total		**11,995**	**445**	**12.2**	**11.3**	**0.8**	**773**	**6,296**	**0.4**	**66,846**

SECTION 5 CARGO HANDLING EQUIPMENT

This section presents emissions estimates for the cargo handling equipment source category and is organized into thefollowing subsections: source description (5.1), data and information acquisition (5.2), emissions estimation methodology (5.3), and the cargo handling equipment emission estimates (5.4).

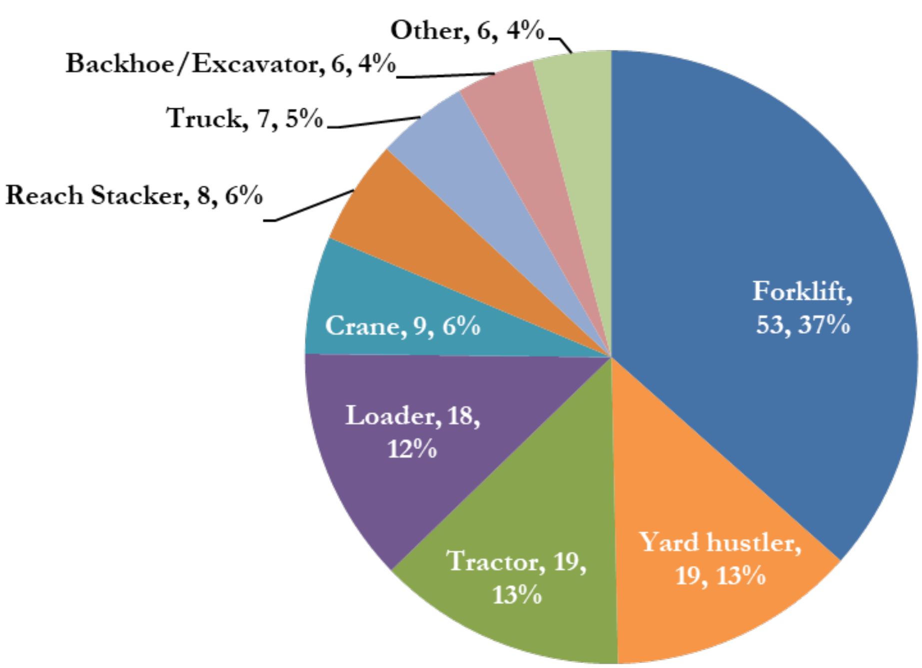
5.1 Source Description

Emissions from the following types of diesel-fueled cargo handling equipment (CHE) were quantified:

- Forklift
- Tractor
- Yard hustler
- Skid steer loader
- Loader
- Reach stacker
- Crane
- Sweeper
- Aerial lift
- Truck
- Backhoe and excavator

Figure 5.1 presents the distribution of the 145 pieces of cargo handling equipment inventoried for the Port in 2023 that were owned and operated by the Port and tenants. The “other” category in the figure includes three sweepers and three aerial lifts. Forklifts and yard hustlers are 50% of the equipment count at the Port.

Figure 5.1: 2023 Distribution of Cargo Handling Equipment



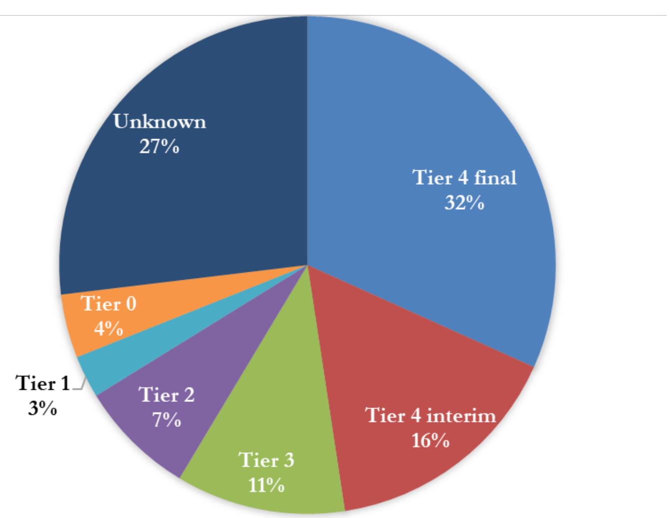
5.2 Data and Information Acquisition

Table 5.1 summarizes the characteristics of the CHE operating at the Port in 2023. Averages of the model year, horsepower, or operating hours are used as default values when equipment specific data is not available. Figures 5.2 summarize the distribution of diesel CHE engines by off-road standards[11] (Tier 0, 1, 2, 3, 4 interim, and 4 final) based on model year and horsepower range. Unknown in the figure represents the percent of the equipment where MY and/or HP information was not available to determine engine tier and a default was provided.

Table 5.1: 2023 Equipment Characteristics

Equipment	Count	Power (hp)			Model Year			Annual Activity Hours		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
Backhoe	3	78	88	83	2009	2018	2013	0	200	72
Crane	9	228	550	410	1976	2022	1996	0	162	68
Excavator	3	105	308	173	2019	2019	2019	96	96	96
Forklift	53	41	370	125	1981	2023	2010	0	1,200	239
Loader	13	128	541	223	2006	2021	2015	0	4,000	746
Manlift (Aerial lift)	3	82	250	147	2007	2014	2011	40	45	43
Reach Stacker	8	350	388	383	2012	2018	2015	42	1,006	342
Skid Steer Loader	5	64	92	83	2008	2017	2012	2	100	67
Sweeper	3	74	74	74	2010	2014	2012	472	472	472
Tractor	19	50	50	50	2012	2022	2015	16	159	57
Truck	7	128	410	340	2011	2016	2013	9	472	241
Yard hustler	19	160	420	197	2000	2023	2015	0	268	73
Total	**145**									

Figure 5.2: 2023 CHE Diesel Tier Count Distribution



[11] EPA, *Nonroad Compression-Ignition Engines- Exhaust Emission Standards,* June 2004

5.3 Emission Estimation Methodology

Emissions were estimated using EPA's MOVES4 model[12] which is designed to accommodate a wide range of off-road equipment types and recognize a defined list of equipment designations. The pieces of terminal equipment identified at the terminals were categorized into the most closely corresponding MOVES4 equipment type. Table 5.2 presents equipment types by Source Classification Code (SCC), load factor, and MOVES4/NONROAD category common name and the load factors.

Table 5.2: MOVES/NONROAD Engine Source Categories

Equipment Type	SCC	Load Factor	NONROAD Category
Aerial lift, manlift	2270003010	0.21	Aerial lift
Backhoe, loader	2270002066	0.21	Tractors/Loaders/Backhoes
Crane	2270002045	0.43	Cranes
Forklift, diesel	2270003020	0.59	Forklifts
Skid-steer loader	2270002072	0.21	Skid-steer loader
Sweeper	2270003030	0.43	Sweeper / scrubber
Reach stacker	2270003040	0.43	General industrial equipment
Top loader	2270003040	0.43	General industrial equipment
Tractor	2270003070	0.39	Terminal tractor
Truck	2270002051	0.59	Off-highway trucks
Yard hustler	2270003070	0.39	Terminal tractor

Equipment-specific power and activity was obtained through surveys. Defaults were used if the power or activity information was missing. For each calendar year, the MOVES4 model has option to output emissions factors in grams/hp-hr by calendar year for each of the MOVES4 equipment types by horsepower groups and model year. The model year groups are aligned with EPA's nonroad equipment emissions standards. MOVES4 emission factors reflect the actual ULSD fuel used in 2023. The estimates of CHE emissions from each piece of equipment are based on its model year, horsepower rating, annual hours of operation, and equipment-specific load factor assumptions.

MOVES4 was run for calendar year 2023 with default conditions to obtain emission factors in grams/hp-hr. A control factor was applied to equipment identified as being equipped with on-road engines. The MOVES4 EFs are based on ULSD. A fuel correction factor of 0.938 (6.2% reduction) was used for NO_x emissions to reflect the reductions for using TxLED fuel.

[12] EPA MOVES, *www.epa.gov/otaq/models/moves/*

The general form of the equation used for estimating CHE emissions is:

Equation 5.1

$$E = Power \times Activity \times LF \times EF \times CF \times Fuel\ Adjustment$$

Where:

E = emissions, grams or tons/year
Power = rated power of the engine, hp or kW
Activity = equipment's engine activity, hr/year
LF = load factor (ratio of average load used during normal operations as compared to full load at maximum rated horsepower, it is an estimate of the average percentage of an engine's rated power output that is required to perform its operating tasks), dimensionless
EF = emission factor, grams of pollutant per unit of work, g/hp-hr or g/kW-hr
CF = control factor to reflect changes in emissions due to installation of emission reduction technologies not originally reflected in the emission factors.
Fuel Adjustment = Fuel Adjustments are used if the EF used is based on fuel that is different than the actual fuel used.

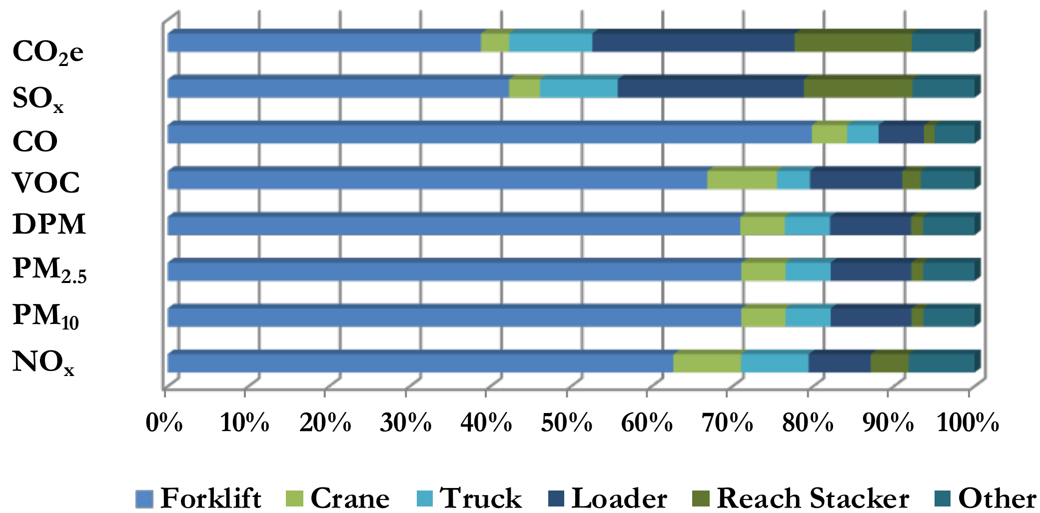
5.4 Cargo Handling Equipment Emission Estimates

Table 5.3 presents the estimated cargo handling equipment emissions. Forklifts have the highest emissions at the Port of Corpus Christi, followed by cranes and trucks. The forklifts have high emissions due to the large count at the Port. The mobile cranes and trucks have high emissions due to high horsepower and older equipment. In Figure 5.3, the other equipment include sweeper, tractor, yard hustler, skid steer loader, manlifts, backhoe, and excavator.

Table 5.3: Cargo Handling Equipment Emissions

Equipment Type	Equipment Count	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Backhoe	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
Crane	9	0.40	0.03	0.02	0.03	0.04	0.16	0.00	56
Excavator	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11
Forklift	53	3.01	0.33	0.32	0.32	0.29	2.89	0.00	628
Loader	13	0.37	0.05	0.04	0.05	0.05	0.20	0.00	405
Manlift (Aerial lift)	3	0.01	0.00	0.00	0.00	0.00	0.01	0.00	3
Reach Stacker	8	0.23	0.01	0.01	0.01	0.01	0.05	0.00	235
Skid Steer Loader	5	0.02	0.00	0.00	0.00	0.00	0.03	0.00	4
Sweeper	3	0.15	0.01	0.01	0.01	0.01	0.06	0.00	27
Tractor	19	0.11	0.01	0.01	0.01	0.01	0.04	0.00	19
Truck	7	0.40	0.03	0.02	0.03	0.02	0.14	0.00	167
Yard hustler	19	0.09	0.01	0.01	0.01	0.01	0.04	0.00	59
Total	**145**	**4.80**	**0.46**	**0.44**	**0.46**	**0.44**	**3.63**	**0.01**	**1,617**

Figure 5.3: CHE Emissions Distribution by Equipment Type



SECTION 6 RAILROAD LOCOMOTIVES

This section presenting emission estimates for the railroad locomotives emission source category is organized into the following subsections: source description (6.1), data and information acquisition (6.2), emissions estimation methodology (6.3), and the locomotive emission estimates (6.4).

6.1 Source Description

Locomotive operations typically consist of activities referred to as line haul and switching. Line haul refers to the movement of cargo over long distances (e.g., cross-country) and occurs within a port, marine terminal, or rail yard as the initiation or termination of a line haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas. Switching generally refers to the assembling and disassembling of trains, sorting of the railcars of inbound cargo trains into contiguous "fragments" for delivery to recipients and the short distance hauling of rail cargo within a port or rail yard.

Locomotives used for line haul operations are typically powered by diesel engines of over 4,000 horsepower, while switching locomotive engines are smaller, typically producing 1,200 to 3,000 horsepower. Older line haul locomotives have often been converted to switch duty as newer line haul locomotives with more horsepower become available. Locomotive engines are operated in a series of discrete power steps called notches which range from positions one through eight. This differs from the finely adjustable throttle controls used in automobiles and most powered equipment. Many locomotives also have a setting called dynamic braking, which is a means of slowing the locomotive using the drive system.

Corpus Christi is served by three Class I Railroads which include Union Pacific (UP), Burlington Northern Santa Fe (BNSF), and Kansas City Southern (KCS) within Nueces and San Patricio Counties. UP owns the majority of track within the two-county inventory domain, with BNSF and KCS operating on them under trackage rights. KCS also owns a length of track within Nueces County. Watco's Texas Coastal Bend Railroad (TCBR) provided data for its locomotives and are also included in the inventory.

6.2 Data and Information Acquisition

Locomotive engine information and fuel consumption were provided for the TCBR locomotives. The information includes the model, year of manufacture, horsepower, and annual fuel consumption for the combined five locomotives. Similar information was provided by UP for the 2017 emissions inventory for switching locomotives they operate in Nueces County, which was scaled for 2023 as described later in this section.

For line haul operations, UP provided tonnage information for their locomotives operating within the inventory domain, and for locomotives owned by BNSF and KCS operating on UP's rails under trackage rights. Tonnage information related to KCS activity on their own trackage in the two counties was determined from the KCS tonnage reported by UP for the segment intersecting KCS' track.

6.3 Emissions Estimation Methodology

The following text provides a description of the methods used to estimate emissions from switching and line haul locomotives operating within Nueces and San Patricio Counties.

There is no model designed to estimate emissions from locomotives, such as EPA's MOVES3 model that is designed for estimating emissions from non-road equipment like CHE. Therefore, estimates of emissions from switching and line haul locomotives are based on estimates of the horsepower-hours of work performed by locomotives operating in the inventory domain and on emission factors published by EPA.[13] The switching locomotive calculations estimate horsepower-hours worked by each locomotive based on fuel consumption in gallons per year, and combine the horsepower-hour estimates with emission factors in terms of grams of emissions per horsepower-hour (g/hp-hr). Fuel usage is converted to horsepower-hours using conversion factors that equate horsepower-hours to gallons of fuel (hp-hr/gal), which represent a property known as brake-specific fuel consumption (BSFC):

Equation 6.1

$$\boldsymbol{Annual\ \ work\ \ in\ hphr\ per\ year\ = \frac{gallons}{year} \times \frac{hphr}{gallon}}$$

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

Equation 6.2

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

Where:

E = emissions, tons per year
Annual work = annual work, hp-hrs/yr
EF = emission factor, grams pollutant per horsepower-hour
(453.59 g/lb x 2,000 lb/ton = tons per year conversion factor

The BSFC value used for the switching locomotive calculations was 15.2 hp-hr/gal, while the value used for the line haul locomotive calculations was 20.8 hp-hr/gal, both from the cited 2009 EPA document.

[13] EPA, *Emission Factors for Locomotives*: EPA-420-F-09-025, Office of Transportation and Air Quality, April 2009 and *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*, April 2021

The EPA emission factors for line haul locomotives cover particulate, NO_x, CO, and HC emissions, published as g/gal factors and converted to g/hp-hr using the BSFC value for line haul noted above, while the emission factors for switching locomotives from the same source are published directly as g/hphr. SO_x emission factors have been developed to reflect the use of 15 ppm ULSD using a simplified mass balance approach. This approach assumes that all of the sulfur in the fuel is converted to SO_2 and emitted during the combustion process. While the mass balance approach calculates SO_2 specifically, it is a reasonable approximation of SO_x. The following example shows the calculation of the SO_x emission factor for switching locomotives. The calculation for line haul locomotives is identical except for the use of the line haul BSFC value.

Equation 6.3

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

In this calculation, 15 ppm S is written as 15 g S per million g of fuel. The value of 15.2 hp-hr/gallon of fuel is the average BSFC noted in EPA's technical literature on locomotive emission factors (EPA, 2009). Two grams of SO_2 is emitted for each gram of sulfur in the fuel because the atomic weight of sulfur is 32 while the molecular weight of SO_2 is 64, meaning that the mass of SO_2 is two times that of sulfur.

Greenhouse gas emission factors from EPA references[14] have been used to estimate emissions of the greenhouse gases CO_2, CH_4, and N_2O from locomotives. Additionally, all particulate emissions are assumed to be PM_{10} and DPM. $PM_{2.5}$ emissions have been estimated as 97% of PM_{10} emissions to be consistent with the $PM_{2.5}$ ratio used by MOVES in estimating $PM_{2.5}$ emissions from other types of nonroad engines.

Table 6.1 lists the emission factors, as g/hphr, used in calculating line haul and switching emissions. The line haul emission factors are composites representing the nation-wide fleet of locomotives in 2023 as estimated by EPA. Because line haul locomotives operate over large parts of the country (for example, UP operates in 23 states) and individual locomotives are generally not dedicated to a particular area, the use of a wide area composite is appropriate for estimating emissions from locomotives that operated within Nueces and San Patricio Counties, in the absence of detailed locomotive records, which are not available. Railroads have historically been reluctant to provide detailed lists of locomotives operating in any particular area given their wide range of operations, so the EPA composites are the best readily available information.

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

The switching emission factors are listed by emission tier levels, which reflect the level of emission control based on the year of manufacture. The oldest locomotives, manufactured before 1973, are termed "uncontrolled" because no emission control standards were applied to them, while Tier 0 applies to locomotives manufactured between 1973 and 2001 with a basic level of emission control. These tier levels account for the switchers operated by TCBR and by UP, although stricter standards will apply when these locomotives are rebuilt.

Table 6.1: Emission Factors for Locomotives, g/hp-hr

	NO_x	PM_{10}	$PM_{2.5}$	VOC	CO g/hphr	SO_x	CO_2	N_2O	CH_4
Line haul									
2023 composite	4.04	0.09	0.09	0.14	1.28	0.005	490	0.012	0.038
Switching									
Uncontrolled	17.4	0.44	0.43	1.01	1.83	0.007	670	0.017	0.052
Tier 0	12.6	0.44	0.43	1.01	1.83	0.007	670	0.017	0.052
Tier 3	4.5	0.08	0.08	0.26	1.83	0.007	670	0.017	0.052

6.4 Locomotive Emission Estimates

The estimated line haul and switching emissions are presented in Table 6.2. Since locomotives are diesel fueled, DPM is the same as PM_{10}.

Table 6.2: Estimated Emissions from Locomotives

Activity Component	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2 tonnes
Line Haul	323	7.2	7.2	7.2	11.2	102.4	0.40	35,887
Switching	36	1.2	1.2	1.2	2.8	5.2	0.02	1,744
Total	**359**	**8.4**	**8.4**	**8.4**	**14.0**	**107.6**	**0.42**	**37,631**

SECTION 7 HEAVY-DUTY VEHICLES

This section presents emission estimates for the heavy-duty vehicles (HDV) emission source category and is organized into the following subsections: emission source description (7.1), data and information acquisition (7.2), emission estimation methodology (7.3), and the heavy-duty vehicles emission estimates (7.4).

7.1 Source Description

Heavy-duty trucks move cargo to and from the terminals and facilities that serve as the bridge between land and sea transportation. They are primarily driven on the public roads near the port and on highways within the inventory domain as they arrive from or depart to locations within and outside the domain. The vehicles are usually not under the direct control of the ports, the terminals, or the shippers who use the terminals, but are usually either owner-operated or are components of a carrier fleet. The most common configuration of HDVs in maritime freight service is the articulated tractor-trailer (truck and semi-trailer) having five axles, including the trailer axles. Common trailer types in the study area include tankers, dry bulk carriers, and flatbeds.

7.2 Data and Information Acquisition

HDV emission estimates are based on the number of miles traveled by the trucks within the inventory domain, which is a function of the number of trips made to and from the Port's terminals and facilities and the distance traveled within the domain on each trip. The other major variable that contributes to the emission estimates is the range of model years of the trucks making the trips, since emission standards result in newer trucks that emit lower levels of some pollutants than earlier model year trucks.

Information on the number of truck trips was obtained by contacting each facility directly and requesting information on whether their operations included truck traffic and, if so, how many truck visits they had during 2023. Truck visits were estimated for facilities that declined to provide specific numbers by extrapolating from annual cargo throughput information provided by the Port. The extrapolations were based on barrels or tons of throughput depending on whether liquid or bulk cargoes are handled by the facility. This method estimated a total of 62,577 truck visits related to liquid bulk facilities and 178,540 truck visits associated with dry cargo facilities, for a total of 241,117 visits.

The distance traveled on each trip has been estimated using road travel distances from the Port terminals and facilities to the county boundaries that delineate the inventory domain, assuming that the vehicles arrive at the Port from locations outside the inventory area and depart from the Port for destinations outside the inventory area, using major highways toward the north and the east of the Corpus Christi area. These distances were estimated using GIS supplemented by "Google maps"[15] and range from 26 to 57 miles depending on facility and route. The emission factors, discussed in the following section, vary by type of road between highway and unrestricted access road. To accommodate this, the distance estimates were divided into highway and non-highway portions. The overall distances from Port facilities to the inventory domain boundary are generally greater for the northern route versus the eastern route because of the shape of the counties and the location of the highways within the counties. Because detailed information on the actual routes taken by trucks is not available, the northern route distances were used to estimate travel distances, and the number of trips associated with each facility was multiplied by the distance corresponding to the facility to estimate vehicle miles traveled (VMT) during the year. VMT totals of 9.53 million highway miles have been estimated for 2023. A sensitivity analysis on the effect of exclusively using the longer route to estimate VMT indicates a maximum overestimate of 8% compared with exclusively using the shorter route. Since trucks use a combination of the two routes in practice, the actual resulting overestimate is less than 8%.

In addition to VMT, another component of truck operations that results in emissions is idling in place, such as when waiting to unload or load cargo. The emission factors for on-road travel include idling that is incidental to routine driving but idling for longer periods is not included. Truck engines can idle at low speed when waiting in line, for example, or at a higher speed when idling for extended periods and the engine power is needed to run heating or cooling for driver safety or comfort. Emission estimates have been made for low-speed idling at the facilities to account for wait times on loading and unloading. The amount of on-site idling is difficult to determine since few, if any, locations monitor or record duration of idling or wait times. A time estimate of 60 minutes of idling time per truck visit has been included in the estimates, for a total of 241,117 hours in 2023. The time estimate of 60 minutes was based on the average idling times reported for terminals, other than container terminals, in three recent port-related emissions inventories,[16] and on a study published by the Oak Ridge National Laboratory[17] that reported the most common range of idling times for heavy-duty trucks, excluding overnight idling, is in the 15- to 60-minute range.

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[15] *www.google.com/maps*

[16] Port of Los Angeles, *2020 Inventory of Air Emissions*, 2021.
www.portoflosangeles.org/environment/studies_reports.asp
Port Authority of New York & New Jersey, *2019 Multi-Facility Emissions Inventory*, 2020
www.panynj.gov/about/port-initiatives.html
Port of Houston Authority, *2013 Goods Movement Emissions Inventory*, 2017
www.portofhouston.com/inside-the-port-authority/environmental-stewardship/air-quality/

[17] Oak Ridge National Laboratory, *Class-8 Heavy Truck Duty Cycle Project Final Report*, Dec. 2008.
ORNL/TM-2008/122 *www.cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008-122.pdf*

7.3 Emission Estimation Methodology

In general, emissions from HDVs are estimated using the general equation.

Equation 7.1

$$\boldsymbol{E} = \boldsymbol{EF} \times \boldsymbol{A}$$

Where:

E = mass of emissions per defined period (such as a year)
EF = emission factor (mass per unit of distance or time)
A = activity (distance driven, or time at idle, during the defined period)

Emissions are estimated by multiplying the emission factor by the distance driven or the amount of idling time. The units of distance in this inventory are miles, the idling units are hours, and the emission factors are expressed as grams of emissions per mile of travel (g/mile) or grams of emissions per hour of idling (g/hr). Annual emissions are expressed in short tons for the criteria pollutants and metric tons (tonnes) for greenhouse gases.

The emission factors have been developed using the EPA model MOVES4, which estimates emissions and emission factors for on-road vehicles of all types, including HDVs.

The MOVES4 model is EPA's latest iteration in a series of on-road vehicle emission estimating models. The model can be run in such a way as to produce emission estimates for different vehicle types in a given county, and the estimated total number of miles driven in the county. These model outputs are used to calculate g/mile and g/hr emission factors that are used to estimate driving and idling emissions from a particular fleet such as the trucks serving the Port terminals.

The MOVES4 model was run for Nueces and San Patricio Counties using the model's own data related to average road speeds and distribution of truck model years. The emission factors estimated for "rural restricted access" and "rural unrestricted access" roads were used as described above to estimate on-road emissions. The model's design dictates that idling emissions are estimated for single hours rather than a one-year period, so the model was run for a January morning hour and a July afternoon hour to cover the range of typical temperature conditions, and the results of the two runs were averaged to estimate average hourly idling emissions. Table 7.1 lists the emission factors used to estimate emissions.

Table 7.1: Emission Factors for HDVs, grams/mile and grams/hour

Road / Activity Type	NO_x	PM_{10}	$PM_{2.5}$	VOC	CO	SO_x	CO_2	N_2O	CH_4
Rural Restricted Access (g/mi)	2.894	0.067	0.061	0.144	1.537	0.005	1,592	0.191	0.014
Rural Unrestricted Access (g/mi)	3.167	0.074	0.068	0.155	1.736	0.005	1,607	0.193	0.016
Short-Term Idle (g/hr)	59.036	2.466	2.269	5.060	21.566	0.027	7,752	0.723	1.473

7.4 Heavy-duty Vehicles Emission Estimates

The estimated on-road and idling emissions are presented in Table 7.2. Since virtually all of the HDVs involved with port-related transportation are diesel fueled, DPM is the same as PM_{10}.

Table 7.2: Estimated Emissions from HDVs

Activity Component	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2 tonnes
On-road driving	31	0.7	0.7	0.7	1.5	16.4	0.06	15,681
On-site idling	16	0.7	0.6	0.7	1.3	5.7	0.01	1,926
Total	**46**	**1.4**	**1.3**	**1.4**	**2.9**	**22.1**	**0.06**	**17,607**

SECTION 8 COMPARISON OF 2023 AND 2020 EMISSION ESTIMATES

This section provides a comparison of the emission estimates for 2023 and 2020 by source category. For all source categories, CO_2e emissions were recalculated for 2020 based on updated GWP values recommended by USEPA. Except for CHE and harbor craft, emissions estimation methodology changed for the three remaining source categories that affected other pollutants between 2020 and 2023 inventories. Therefore, 2020 emissions have been recalculated to incorporate the latest 2023 methodology to provide a valid basis for comparison. The 2020 emissions included in this report will not match the emissions in the 2020 EI report because of the recalculation. The methodology changes include EPA's MOVES4, which is used for several of the source categories and GHG emissions updates for GWP factors that impact CO_2e emissions. Due to rounding, the values in the tables below may not add up to the whole number values for the percentage change or total emissions in the last row of each table.

Table 8.1 presents the total net change in emissions for all source categories in 2023 compared to 2020, including recreational vessels. Overall emissions are higher in 2023 as compared to 2020 for most pollutants, except VOC and CO. VOC emissions are lower in 2023 due tosignificant decrease in recreational vessel emissions change.

Table 8.1: 2020-2023 Emissions Comparison including Recreational Vessels, Tons, metric tons and %

Year	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020	4,344	114	107	72	1,240	7,679	140	437,422
2023	4,626	116	109	76	909	7,109	151	526,688
Change	**282**	**1**	**2**	**4**	**-330**	**-570**	**11**	**89,266**
Change (%)	**6%**	**1%**	**1%**	**6%**	**-27%**	**-7%**	**8%**	**20%**

Table 8.2 provides a comparison of cargo volumes in short tons and barrels between 2020 and 2023. Compared to 2020, cargo in short tons was up by 27% and cargo in barrels was up 27% due to the significant growth seen at the Port between 2020 and 2023.

Table 8.2: 2020-2023 Cargo Volumes Comparison

Year	Cargo (short tons)	Cargo (barrels)
2020	159,713,040	968,280,326
2023	203,041,052	1,232,184,299
Change (%)	**27%**	**27%**

Table 8.3 provides the emissions comparison for the sources tied to cargo volume, without including recreational vessels. The overall emissions are higher in 2023 as compared to 2020, without recreational vessels. The increase in emissions is mainly due to larger sized tanker arrivals, increased harbor craft, locomotive and HDV activity. Locomotive and truck emissions are mostly lower in 2023 as compared to 2020 due to the completion of several projects undertaken at the Port to reduce truck and rail emissions. These include building pipelines to move liquid cargo and completing rail projects to move cargo more efficiently. Table 8.3 shows that with the 27% increase in cargo, emissions are up 6% to 25% higher across the board.

Table 8.3: 2020-2023 Emissions Comparison by Source Category without Recreational Vessels, tons, metric tons and %

	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e MT
2020								
Ocean-going vessels	2,198	53	48	28	73	200	137.8	208,506
Commercial harbor craft	1,217	29	28	29	30	303	1.1	107,793
Cargo handling equipment	20	3	3	3	2	6	0.0	2,544
Locomotives	385	9	9	9	15	99	0.4	34,767
Heavy-duty vehicles	47	2	1	2	3	19	0.1	14,027
Total	**3,867**	**96**	**90**	**71**	**123**	**628**	**139**	**367,637**
2023								
Ocean-going vessels	2,283	58	53	30	78	267	148.2	240,302
Commercial harbor craft	1,488	36	35	36	40	413	1.6	162,685
Cargo handling equipment	5	0	0	0	0	4	0.0	1,617
Locomotives	359	8	8	8	14	108	0.4	37,631
Heavy-duty vehicles	46	1	1	1	3	22	0.1	17,607
Total	**4,181**	**103**	**98**	**75**	**135**	**813**	**150**	**459,842**
Change between 2020 and 2023 (percent)								
Ocean-going vessels	4%	9%	9%	7%	7%	33%	8%	15%
Commercial harbor craft	22%	22%	22%	21%	35%	36%	51%	51%
Cargo handling equipment	-75%	-85%	-85%	-85%	-79%	-44%	-41%	-36%
Locomotives	-7%	-9%	-9%	-9%	-9%	8%	8%	8%
Heavy-duty vehicles	-2%	-14%	-14%	-14%	1%	15%	24%	26%
Total	**8%**	**8%**	**8%**	**6%**	**10%**	**29%**	**8%**	**25%**

The following subsections explain the various fleet and activity changes by source category that impacted the emissions for 2023 as compared to 2020.

8.1 Ocean-going Vessels

Total energy consumption (in terms of kW-hr) from OGV for 2020 and 2023 is shown in Table 8.4. There was a 21% increase in total OGV energy consumption in 2023 as compared to 2020. The main engine and auxiliary boiler energy consumption increased by 14% and 11%, respectively. The auxiliary engine energy consumption increased by 33% due to vessels spending more time at berth.

Table 8.4: 2020-2023 OGV Energy Consumption Comparison by Emissions Source, kW-hr

Year	All Emission Sources	Main Engine	Auxiliary Engine	Boiler
2020	255,438,848	31,666,225	112,313,195	111,459,428
2023	309,097,488	36,028,991	149,004,608	124,063,889
Change (%)	**21%**	**14%**	**33%**	**11%**

Table 8.5 shows the vessel activity in 2023 compared to 2020. In 2023, the number of shifts is significantly lower.

Table 8.5: 2020-2023 OGV Movements

Year	Arrivals	Departures	Shifts	Total
2020	2,143	2,070	441	4,654
2023	2,409	2,409	260	5,078
Change	**266**	**339**	**-181**	**424**
Change (%)	**12%**	**16%**	**-41%**	**9%**

Table 8.6 provides a comparison of the engine tier distribution for OGV. In 2023, there are significantly more Tier III vessels. The newer engines have lower NO_x emission standards which reduces the propulsion engine emissions.

Table 8.6: 2020-2023 OGV Propulsion Engine Tier Comparison

Year	Tier 0	Tier I	Tier II	Tier III
2020	3%	49%	42%	6%
2023	3%	38%	40%	20%

The OGV emissions for 2020 were recalculated in 2023 due to reclassification of larger tankers into VLCC and ULCC categories to better reflect their operations. Table 8.7 provides the OGV emissions comparison by engine type. Hotelling times increased in 2023 and there was also more vessel activity.

Table 8.7: 2020-2023 OGV Emissions Comparison by Engine Type, tons, metric tons and %

Year	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020								
Main Engines	595	4	4	4	11	40	13	20,013
Auxiliary Engines	1,360	23	21	23	50	136	53	79,039
Boilers	243	25	23	0	12	25	72	109,454
Total	**2,198**	**53**	**48**	**28**	**73**	**200**	**138**	**208,506**
2023								
Main Engines	654	5	5	5	13	46	15	22,859
Auxiliary Engines	1,362	26	24	25	52	188	56	97,817
Boilers	267	27	25	0	13	33	77	119,625
Total	**2,283**	**58**	**53**	**30**	**78**	**267**	**148**	**240,302**
Change between 2020 and 2023 (percent)								
Main Engines	10%	15%	15%	15%	14%	17%	14%	14%
Auxiliary Engines	0%	10%	10%	6%	5%	38%	6%	24%
Boilers	10%	8%	8%	0%	7%	33%	7%	9%
Total	**4%**	**9%**	**9%**	**7%**	**7%**	**33%**	**8%**	**15%**

8.2 Commercial Harbor Craft

As shown in Table 8.8, the harbor craft overall energy consumption (as measured by kilowatt hours) increased by 51% from 2020 to 2023, resulting in the emissions increase. The average vessel maneuvering time used to calculate the tugboat activity decreased by 4% in 2023 as compared to 2020.

Table 8.8: 2020-2023 Commercial Harbor Craft Energy Consumption Comparison and Vessel Maneuvering Time

Year	Activity (kW-hr)	Maneuvering Time
2020	156,592,985	2.37
2023	236,297,837	2.28
Change	**79,704,853**	**-0.09**
Change (%)	**51%**	**-4%**

Table 8.9 shows the Tier distribution comparison based on vessel activity (kWhr). It shows that in 2023, vessel activity with cleaner engines (Tier 2 to Tier 4) is 60% of the total as opposed to 50% in 2020. Thus, the increase in NO_x and PM emissions is not as high as the activity increase in 2023 compared to 2020 as shown in Table 8.10. Tier 0 engines are used less in 2023 as compared to 2020 which is encouraging.

Table 8.9: 2020-2023 Commercial Harbor Craft Activity Tier Distribution, %

Tier	2020	2023
Tier 0	43%	14%
Tier 1	7%	26%
Tier 2	22%	17%
Tier 3	10%	16%
Tier 4	18%	27%

Table 8.10 shows the harbor craft emissions comparison. The commercial harbor craft emissions were higher in 2023 as compared to 2020. The increase in emissions is due to the higher activity in 2023, mainly by the commercial harbor craft that is not associated with the Port, and lack of emission control standards for CO_2. Due to newer fleet mix and usage in 2023, the NO_x and PM emissions did not increase as much for the other pollutants. The CO_2e emissions increased at same rate as the activity increase.

Table 8.10: 2020-2023 Commercial Harbor Craft Emissions Comparison, tons, MT and %

Year	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020	1,217	29.3	28.4	29.3	29.6	303	1.07	107,793
2023	1,488	36.0	34.8	35.8	40.4	413	1.46	162,685
Change	**271**	**6.7**	**6.3**	**6.5**	**10.8**	**110**	**0.38**	**54,892**
Change (%)	**22%**	**23%**	**22%**	**22%**	**36%**	**36%**	**36%**	**51%**

Table 8.11 shows the commercial harbor craft emissions comparison for vessels associated with the Port of Corpus Christi (PCCA) or not (non-PCCA). Those that are associated with the Port are vessels that are either tenants or known to be berthed within the geographical domain, and commercial harbor craft (mainly tugboats and towboats) that called a Port berth. The non-PCCA emissions are from commercial harbor craft (mainly tugboats and towboats) that transited the area, but did not stop at a Port berth. In 2023, the non-PCCA commercial harbor craft emissions are higher due to increased time spent in the area by the tugboats/towboats that did not stop at Port berth, but were transiting the area or stopping at terminal not included in the geographic domain.

Table 8.11: 2020-2023 PCCA and non-PCCA Commercial Harbor Craft Emissions Comparison, tons, MT and %

Entity	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020								
PCCA	649	15	14	15	15	140	1	50,444
Non-PCCA	568	15	14	15	14	162	1	57,350
Total	**1,217**	**29**	**28**	**29**	**30**	**303**	**1**	**107,793**
2023								
PCCA	540	13	12	13	14	179	1	68,390
Non-PCCA	947	23	22	23	26	234	1	94,294
Total	**1,488**	**36**	**35**	**36**	**40**	**413**	**2**	**162,685**
Change between 2020 and 2023 (percent)								
PCCA	-17%	-13%	-13%	-14%	-11%	27%	36%	36%
Non-PCCA	67%	57%	57%	57%	84%	44%	64%	64%
Total	**22%**	**22%**	**22%**	**21%**	**35%**	**36%**	**51%**	**51%**

Recreational vessels for San Patricio and Nueces counties were also included in the inventory. Table 8.12 shows the comparison of emissions for recreational vessels. The vessel count is 4% lower in 2023 as compared to 2020 and emissions are lower across all pollutants.

Table 8.12: 2020-2023 Recreational Vessel Emissions Comparison, tons, metric tons and %

Year	Vessel Count	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020	12,507	477	19	17	1	1,117	7,051	0	69,785
2023	11,995	445	12	11	1	773	6,296	0	66,846
Change	**-512**	**-33**	**-6**	**-6**	**0**	**-343**	**-755**	**0**	**-2,939**
Change (%)	**-4%**	**-7%**	**-34%**	**-34%**	**-5%**	**-31%**	**-11%**	**-21%**	**-4%**

8.3 Cargo Handling Equipment

As shown in Table 8.13, for cargo handling equipment, the overall energy consumption (as measured by kilowatt hours) decreased 39% due to lower engine hours despite 33% more equipment in 2023 as compared to 2020. Table 8.14 shows the Tier distribution comparison based on equipment count.

Table 8.13: 2020-2023 CHE Energy Consumption Comparison and Equipment Count

Year	Activity (kWh)	Diesel Equipment Count
2020	3,462,623	109
2023	2,128,859	145
Change	**-1,333,764**	**36**
Change (%)	**-39%**	**33%**

Table 8.14: 2020-2023 CHE Discrete Count Tier Distribution

	2020	2023
Tier 0	13%	4%
Tier 1	6%	3%
Tier 2	6%	8%
Tier 3	16%	11%
Tier 4 interim	22%	16%
Tier 4 final	28%	36%
Unknown	10%	22%

Table 8.15 shows the cargo handling equipment emissions comparison. The 2023 emissions are lower across the board for all pollutants when compared to 2020 emissions. In 2023, there are less Tier 0 and Tier 1 equipment which lowered the emissions in addition to the lower hours of use.

Table 8.15: 2020-2023 CHE Emissions Comparison, tons, metric tons and %

Year	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
2020	20.2	3.0	2.9	3.0	2.0	6.4	0.009	2,544
2023	4.8	0.5	0.4	0.5	0.4	3.6	0.005	1,617
Change	**-15.4**	**-2.5**	**-2.5**	**-2.5**	**-1.6**	**-2.8**	**-0.004**	**-927**
Change (%)	**-76%**	**-85%**	**-85%**	**-85%**	**-79%**	**-43%**	**-41%**	**-36%**

8.4 Railroad Locomotives

Table 8.16 shows the line haul locomotive activity in million gross ton-miles (GTM) of cargo moved in 2020 and 2023 which shows a 6% increase in 2023 for line haul activity as compared to 2020.

Table 8.16: 2020-2023 Rail Locomotive Activity

Year	Million GTM
2020	3,360
2023	3,555
Change (%)	**6%**

The emission factors for line haul from EPA reflect a cleaner fleet which may partly account for the NO_x, PM and VOC emissions decrease. Activity is also a factor and there was an estimated 6% increase in freight movements measured as gross ton-miles in 2023 compared with 2020. This increase may be due to the cargo tonnage increase. The increased activity resulted in emissions increase in 2023 for CO, SO_x and CO_2 as these pollutants do not have lower engine standards as the other pollutants.

Table 8.17: 2020-2023 Locomotives Emissions Comparison, tons, metric tons and %

Year	NO_x tons	PM_{10} tons	PM_{25} tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2 tonnes
2020	385	9.3	9.3	9.3	15.4	99	0.39	34,767
2023	359	8.4	8.5	8.4	14.0	108	0.42	37,631
Change	**-26**	**-0.9**	**-0.8**	**-0.9**	**-1.4**	**8**	**0.03**	**2,864**
Change (%)	**-7%**	**-10%**	**-8%**	**-10%**	**-9%**	**8%**	**8%**	**8%**

8.5 Heavy-duty Vehicles

Table 8.18 compares the heavy-duty vehicles count and vehicle miles traveled for 2020 and 2023. In 2023, the truck count increased by 30% and vehicle miles traveled increased by 32%. The truck and VMT increase is in line with the cargo throughput increase. The 2023 truck counts for dry bulk and general cargo facilities increased by 60% as compared to 2020.

Table 8.18: 2020-2023 HDV Count and Vehicle Miles Traveled

Year	Truck Count	Truck VMT
2020	185,409	7,237,209
2023	241,117	9,528,204
Change (%)	**30%**	**32%**

The HDV emissions for 2020 were recalculated using MOVES4. Table 8.19 shows the emissions comparison for heavy-duty vehicles. The 2023 heavy-duty vehicle NO_x and PM emissions are lower compared to 2020 due to fleet turnover to newer and cleaner trucks in 2023. The other pollutant emissions are higher in 2023 as compared to 2020 due to higher truck trips and vehicle miles traveled.

Table 8.19: 2020-2023 HDV Emissions Comparison, tons, metric tons and %

Year	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2 tonnes
2020	47	1.6	1.5	1.6	2.9	19.2	0.05	14,027
2023	46	1	1	1	3	22	0.06	17,607
Change	**-1**	**-0.2**	**-0.2**	**-0.2**	**0.0**	**2.9**	**0.01**	**3,580**
Change (%)	**-2%**	**-12%**	**-11%**	**-12%**	**2%**	**15%**	**24%**	**26%**

SECTION 9 CONCLUSION AND RECOMMENDATIONS

Between 2020 and 2023, the Port of Corpus Christi continued to see significant growth. Cargo throughput increased by 27% in short tons and 27% in barrels over the period as record volumes of crude oil and LNG exports were seen in 2023. Ship arrivals grew 12% during this time. During that period several port expansion projects were completed, including additional liquid bulk export infrastructure, expanded VLCC capabilities, new LNG docks, completion of new natural gas and liquid bulk pipelines. Phases one and two of the expanded Corpus Christi Ship Channel Improvement Project have been completed and the final phase is underway.

Overall, emissions in 2023 are mostly higher than 2020, due to vessel activity increase for both the ocean-going vessels and commercial harbor craft. While emissions are higher than in 2020, overall emissions are lower than expected due in part to higher tiered engines which are cleaner and the use of alternative fuels in oceangoing vessels.

Comparison to other Ports

Compared to other major U.S. ports that also publish detailed emissions inventories and use the same methodology, the Port of Corpus Christi's CHE and truck emissions are substantially lower. This is due to the types of cargo that the Port of Corpus Christi handles, which include a significant proportion of bulk liquids. Container ports require more equipment and thus, higher activity (hp-hr) of cargo handling equipment and trucks to move the containers, while the Port of Corpus Christi's liquid bulk is mainly moved by pipeline and either terminal pumps or vessels' pumps are used to load/unload the cargo. The use of trucks and cargo handling equipment is minimal at the Port of Corpus Christi compared to other Ports.

The Port of Corpus Christi OGV emissions inventory has higher tanker emissions than other vessel types due to the significant number of tanker calls. Tankers contributed 89% of the NO_x emissions for total ocean-going vessel emissions at the Port. Other ports may have higher container vessel emissions or higher cruise ship emissions, depending on what types of cargo the port handles or which vessels call that port. But comparing total vessel emissions to the other large U.S. ports, Corpus Christi has the highest NO_x and CO_2e emissions due to more tanker activity and tankers being the main vessel type calling Corpus Christi.

The Port of Corpus Christi's towboat, tugboat and barge activity and emissions are also high compared with the other ports because of the Texas Gulf Intracoastal Waterway that runs through the Corpus Christi Bay and because liquid bulk cargo constitutes the main commodity at the Port.

Looking Ahead

Looking into the future, the Port has continued to expand and has moved up in U.S. port size rankings by tonnage and is now the number one crude oil export port in the U.S. and the second in LNG exports[18]. The Harbor Bridge project is scheduled to be completed in 2025, and the Corpus Christi Ship Channel Improvement Project is entering its last phase, both allowing larger vessels to call the Port. As cargo volumes continue to grow, we expect to continue seeing increased total emissions. Specifically, we expect NO_x and CO_2e emissions to increase in the future as compared to previous years' emissions. We also expect larger tankers to not only continue to call the Port, but potentially increase in vessel count and activity, specifically VLCCs and Suezmax tankers.

Recommendations

Emissions from tankers will continue to increase with the larger tankers calling the terminals due to the expanded channel. While the continued dredging will allow tankers to load more oil, effectively adding tonnage without increasing vessel calls, the actual number of vessel trips will likely continue to increase until the export terminals near capacity at some point in the future, depending on market conditions. There are several technologies and emission reduction strategies the Port may study to reduce vessel emissions in the future and combine with incentive programs to encourage use. These include: 1) increased use of LNG fuel for auxiliary engines and boilers; 2) the use of approved emission control technologies, such as capture and control systems or shore power, while vessels are at berth to reduce at-berth emissions; 3) the use of incentive programs to encourage cleaner fuels and cleaner engines; and 4) evaluate incentive programs that could result in improvements in Port efficiency. For example, a better understanding of vessel operations, such as if vessels are docking on arrival or waiting for terminals to be ready, or if there are delays at the berth that might be reduced with better terminal/vessel communications. While there are many reasons why delays happen that are out of the ports control (weather, daylight restrictions), a better understanding of the terminal operations and interaction with vessel owners/charterers could possibly identify some improvements.

Additionally, the Port should closely follow the progress that California ports are making with tanker shore power efforts, so the port is ready if the technology gets approved and becomes widely adopted. The Port may want to undertake a tanker study specifically geared to the tankers calling the Port of Corpus Christi to understand the tankers' engine and boiler loads in more detail, as it pertains to the at-berth emissions, especially for LNG vessels, which are relatively new to the Port.

Emissions from harbor craft, specifically towboats and tugboats, will continue to increase as the engines get older until a significant amount of turnover occurs. A program to encourage engine repower or fleet turnover would hasten this process. In California, the Carl Moyer marine diesel engine repower program has been successful in replacing old engines with newer cleaner engines by providing funds to successful applicants. In Texas, although there are incentive programs like the Texas Emissions Reduction Plan (TERP), towboats are mostly ineligible due to the TERP requirement that equipment or engines must be guaranteed to operate mainly in non-attainment areas. Other grant opportunities include the EPA Diesel Emission Reduction Act (DERA) which can only be applied through a public entity such as a port authority. In other words, a vessel owner would not be able to apply directly to EPA for a DERA grant. For this federal grant program to be of value, the Port of Corpus Christi or another public entity must be willing to manage the grant funding for the EPA and work with the vessel operators. The use of renewable diesel may also be an option to lower emissions.

[18] *https://portofcc.com/images/Strategic_Plan_2026.pdf*

The emissions from CHE and trucks are relatively low and have been reduced through equipment turnover and through increased pipeline transport, in addition to using rail over trucks as the mode of transportation. Therefore, no further recommendations for these source categories are made at this time.

Locomotive emissions may lower with fleet turnover in the future, although activity increases may overshadow any emission reductions achieved through fleet turnover. Rail can be a more environmentally efficient mode of transportation as compared to trucks and fleet turnover will continue year after year. However, the advent of very low emission trucks and the relatively slower introduction of lower-emission locomotives can diminish the edge that rail transport has traditionally held. In addition, ports typically have little to no ability or leverage to influence the locomotive fleet mix of the Class 1 railroads, which make up the majority of locomotive emissions in the port setting. Therefore, no recommendations are made for locomotives at this time.

Since the Port of Corpus Christi is still expanding, a future emissions inventory is recommended in approximately three to five years. The ocean-going vessel inventory is especially crucial to understand the changes in activity counts, vessel movements and types of tankers that call the Port. The other emission source categories are also important as operations may change, causing effects that are hard to predict.

APPENDIX A: Propulsion Engines Low Load Emission Factor Adjustments

Propulsion Engines Low Load Emission Factor Adjustments
In general terms, diesel-cycle engines are not as efficient when operated at low loads compared with higher load operation. An EPA study[19] prepared by Energy and Environmental Analysis, Inc. (EEAI) established a formula for calculating emission factors for low engine load conditions such as those encountered during harbor maneuvering and when traveling slowly at sea (e.g. in the reduced speed zone) This formula was later used and described in a study conducted for the EPA by ENVIRON.[20] While mass emissions in pounds per hour tend to go down as vessel speeds and engine loads decrease, the emission factors in g/kW-hr increase.

Equation A.1 is the equation developed by EEAI to generate emission factors for the range of load factors from 2% to 20% for each pollutant:

Equation A.1

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

Where:

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

Table A.1 presents the variables for equation A.1.

Table A.1: Low-Load Emission Factor Regression Equation Variables

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

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

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

gas turbines because the EPA study referenced above only observed an increase in emissions from diesel engines.

Table A.2: Low Load Adjustment Multipliers for Emission Factors[21]

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

The low load emission factor is calculated for each pollutant using Equation A.2.

Equation A.2

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

Where:

EF = calculated low load emission factor, expressed in terms of g/kW-hr
Adjusted EF = fuel adjusted emission factor for 2-stroke diesel propulsion engines, g/kW-hr
LLA = low load adjustment multiplier, dimensionless

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

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

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

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

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

Equation A.3

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

Where,

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

Tables A.3 and A.4 present the LAFs used across the entire engine load range.

Table A.3: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
1%	0.36	0.36	0.36	1.90	1.10	0.12	1.36	1.10	1.90	1.36
2%	0.37	0.37	0.37	1.86	1.10	0.12	1.32	1.10	1.86	1.32
3%	0.38	0.38	0.38	1.82	1.09	0.12	1.28	1.09	1.82	1.28
4%	0.38	0.38	0.38	1.78	1.09	0.12	1.24	1.09	1.78	1.24
5%	0.39	0.39	0.39	1.74	1.09	0.12	1.20	1.09	1.74	1.20
6%	0.40	0.40	0.40	1.70	1.08	0.12	1.17	1.08	1.70	1.17
7%	0.41	0.41	0.41	1.67	1.08	0.12	1.14	1.08	1.67	1.14
8%	0.41	0.41	0.41	1.63	1.08	0.12	1.11	1.08	1.63	1.11
9%	0.42	0.42	0.42	1.60	1.07	0.12	1.08	1.07	1.60	1.08
10%	0.43	0.43	0.43	1.57	1.07	0.12	1.05	1.07	1.57	1.05
11%	0.44	0.44	0.44	1.53	1.07	0.26	1.02	1.07	1.53	1.02
12%	0.45	0.45	0.45	1.50	1.07	0.39	0.99	1.07	1.50	0.99
13%	0.45	0.45	0.45	1.47	1.06	0.52	0.97	1.06	1.47	0.97
14%	0.46	0.46	0.46	1.45	1.06	0.64	0.94	1.06	1.45	0.94
15%	0.47	0.47	0.47	1.42	1.06	0.75	0.92	1.06	1.42	0.92
16%	0.48	0.48	0.48	1.39	1.06	0.85	0.90	1.06	1.39	0.90
17%	0.49	0.49	0.49	1.37	1.05	0.95	0.88	1.05	1.37	0.88
18%	0.49	0.49	0.49	1.34	1.05	1.04	0.86	1.05	1.34	0.86
19%	0.50	0.50	0.50	1.32	1.05	1.12	0.84	1.05	1.32	0.84
20%	0.51	0.51	0.51	1.30	1.05	1.20	0.82	1.05	1.30	0.82
21%	0.52	0.52	0.52	1.28	1.04	1.27	0.81	1.04	1.28	0.81
22%	0.53	0.53	0.53	1.26	1.04	1.34	0.79	1.04	1.26	0.79
23%	0.54	0.54	0.54	1.24	1.04	1.40	0.78	1.04	1.24	0.78
24%	0.54	0.54	0.54	1.22	1.04	1.46	0.76	1.04	1.22	0.76
25%	0.55	0.55	0.55	1.20	1.03	1.51	0.75	1.03	1.20	0.75

Table A.3 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
26%	0.56	0.56	0.56	1.19	1.03	1.55	0.74	1.03	1.19	0.74
27%	0.57	0.57	0.57	1.17	1.03	1.59	0.73	1.03	1.17	0.73
28%	0.58	0.58	0.58	1.16	1.03	1.63	0.72	1.03	1.16	0.72
29%	0.59	0.59	0.59	1.14	1.03	1.66	0.71	1.03	1.14	0.71
30%	0.60	0.60	0.60	1.13	1.02	1.68	0.70	1.02	1.13	0.70
31%	0.60	0.60	0.60	1.12	1.02	1.70	0.70	1.02	1.12	0.70
32%	0.61	0.61	0.61	1.10	1.02	1.72	0.69	1.02	1.10	0.69
33%	0.62	0.62	0.62	1.09	1.02	1.74	0.69	1.02	1.09	0.69
34%	0.63	0.63	0.63	1.08	1.02	1.75	0.68	1.02	1.08	0.68
35%	0.64	0.64	0.64	1.07	1.02	1.75	0.68	1.02	1.07	0.68
36%	0.65	0.65	0.65	1.06	1.01	1.75	0.68	1.01	1.06	0.68
37%	0.66	0.66	0.66	1.05	1.01	1.75	0.67	1.01	1.05	0.67
38%	0.67	0.67	0.67	1.05	1.01	1.75	0.67	1.01	1.05	0.67
39%	0.68	0.68	0.68	1.04	1.01	1.74	0.67	1.01	1.04	0.67
40%	0.69	0.69	0.69	1.03	1.01	1.73	0.67	1.01	1.03	0.67
41%	0.70	0.70	0.70	1.03	1.01	1.72	0.67	1.01	1.03	0.67
42%	0.70	0.70	0.70	1.02	1.01	1.71	0.68	1.01	1.02	0.68
43%	0.71	0.71	0.71	1.02	1.01	1.69	0.68	1.01	1.02	0.68
44%	0.72	0.72	0.72	1.01	1.00	1.67	0.68	1.00	1.01	0.68
45%	0.73	0.73	0.73	1.01	1.00	1.65	0.69	1.00	1.01	0.69
46%	0.74	0.74	0.74	1.00	1.00	1.62	0.69	1.00	1.00	0.69
47%	0.75	0.75	0.75	1.00	1.00	1.60	0.70	1.00	1.00	0.70
48%	0.76	0.76	0.76	1.00	1.00	1.57	0.70	1.00	1.00	0.70
49%	0.77	0.77	0.77	0.99	1.00	1.54	0.71	1.00	0.99	0.71
50%	0.78	0.78	0.78	0.99	1.00	1.51	0.71	1.00	0.99	0.71

Table A.3 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
51%	0.79	0.79	0.79	0.99	1.00	1.48	0.72	1.00	0.99	0.72
52%	0.80	0.80	0.80	0.99	1.00	1.45	0.73	1.00	0.99	0.73
53%	0.81	0.81	0.81	0.99	1.00	1.41	0.74	1.00	0.99	0.74
54%	0.82	0.82	0.82	0.99	1.00	1.38	0.75	1.00	0.99	0.75
55%	0.83	0.83	0.83	0.98	0.99	1.35	0.75	0.99	0.98	0.75
56%	0.84	0.84	0.84	0.98	0.99	1.31	0.76	0.99	0.98	0.76
57%	0.85	0.85	0.85	0.98	0.99	1.27	0.77	0.99	0.98	0.77
58%	0.86	0.86	0.86	0.98	0.99	1.24	0.78	0.99	0.98	0.78
59%	0.87	0.87	0.87	0.98	0.99	1.20	0.80	0.99	0.98	0.80
60%	0.88	0.88	0.88	0.98	0.99	1.16	0.81	0.99	0.98	0.81
61%	0.89	0.89	0.89	0.98	0.99	1.13	0.82	0.99	0.98	0.82
62%	0.90	0.90	0.90	0.98	0.99	1.09	0.83	0.99	0.98	0.83
63%	0.91	0.91	0.91	0.99	0.99	1.06	0.84	0.99	0.99	0.84
64%	0.92	0.92	0.92	0.99	0.99	1.02	0.85	0.99	0.99	0.85
65%	0.93	0.93	0.93	0.99	0.99	0.98	0.87	0.99	0.99	0.87
66%	0.94	0.94	0.94	0.99	0.99	0.95	0.88	0.99	0.99	0.88
67%	0.95	0.95	0.95	0.99	0.99	0.92	0.89	0.99	0.99	0.89
68%	0.97	0.97	0.97	0.99	0.99	0.88	0.91	0.99	0.99	0.91
69%	0.98	0.98	0.98	0.99	0.99	0.85	0.92	0.99	0.99	0.92
70%	0.99	0.99	0.99	0.99	0.99	0.82	0.93	0.99	0.99	0.93
71%	1.00	1.00	1.00	0.99	0.99	0.79	0.95	0.99	0.99	0.95
72%	1.01	1.01	1.01	0.99	0.99	0.76	0.96	0.99	0.99	0.96
73%	1.02	1.02	1.02	0.99	0.99	0.74	0.98	0.99	0.99	0.98
74%	1.03	1.03	1.03	0.99	0.99	0.71	0.99	0.99	0.99	0.99
75%	1.04	1.04	1.04	0.99	0.99	0.69	1.00	0.99	0.99	1.00

Table A.3 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
76%	1.05	1.05	1.05	0.99	0.99	0.66	1.02	0.99	0.99	1.02
77%	1.06	1.06	1.06	0.99	0.99	0.64	1.03	0.99	0.99	1.03
78%	1.07	1.07	1.07	0.99	0.99	0.63	1.05	0.99	0.99	1.05
79%	1.09	1.09	1.09	0.99	0.99	0.61	1.06	0.99	0.99	1.06
80%	1.10	1.10	1.10	0.99	0.99	0.60	1.08	0.99	0.99	1.08
81%	1.11	1.11	1.11	0.99	0.99	0.58	1.09	0.99	0.99	1.09
82%	1.12	1.12	1.12	0.99	0.99	0.57	1.10	0.99	0.99	1.10
83%	1.13	1.13	1.13	0.98	0.99	0.57	1.12	0.99	0.98	1.12
84%	1.14	1.14	1.14	0.98	0.99	0.56	1.13	0.99	0.98	1.13
85%	1.15	1.15	1.15	0.98	0.99	0.56	1.15	0.99	0.98	1.15
86%	1.16	1.16	1.16	0.98	0.99	0.56	1.16	0.99	0.98	1.16
87%	1.18	1.18	1.18	0.97	0.99	0.56	1.18	0.99	0.97	1.18
88%	1.19	1.19	1.19	0.97	0.99	0.57	1.19	0.99	0.97	1.19
89%	1.20	1.20	1.20	0.96	0.99	0.58	1.20	0.99	0.96	1.20
90%	1.21	1.21	1.21	0.96	0.99	0.59	1.22	0.99	0.96	1.22
91%	1.22	1.22	1.22	0.95	1.00	0.61	1.23	1.00	0.95	1.23
92%	1.23	1.23	1.23	0.95	1.00	0.63	1.24	1.00	0.95	1.24
93%	1.25	1.25	1.25	0.94	1.00	0.65	1.25	1.00	0.94	1.25
94%	1.26	1.26	1.26	0.93	1.00	0.67	1.27	1.00	0.93	1.27
95%	1.27	1.27	1.27	0.93	1.00	0.70	1.28	1.00	0.93	1.28
96%	1.28	1.28	1.28	0.92	1.00	0.73	1.29	1.00	0.92	1.29
97%	1.29	1.29	1.29	0.91	1.00	0.77	1.30	1.00	0.91	1.30
98%	1.31	1.31	1.31	0.90	1.00	0.81	1.31	1.00	0.90	1.31
99%	1.32	1.32	1.32	0.89	1.00	0.85	1.32	1.00	0.89	1.32
100%	1.33	1.33	1.33	0.88	1.00	0.90	1.34	1.00	0.88	1.34

Table A.4: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

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

Table A.4 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
26%	0.75	0.75	0.75	1.11	1.03	1.09	1.25	1.03	1.11	1.25
27%	0.75	0.75	0.75	1.09	1.03	1.08	1.22	1.03	1.09	1.22
28%	0.75	0.75	0.75	1.07	1.03	1.08	1.20	1.03	1.07	1.20
29%	0.75	0.75	0.75	1.06	1.03	1.07	1.17	1.03	1.06	1.17
30%	0.75	0.75	0.75	1.05	1.02	1.07	1.15	1.02	1.05	1.15
31%	0.75	0.75	0.75	1.03	1.02	1.06	1.13	1.02	1.03	1.13
32%	0.75	0.75	0.75	1.02	1.02	1.06	1.11	1.02	1.02	1.11
33%	0.75	0.75	0.75	1.01	1.02	1.05	1.09	1.02	1.01	1.09
34%	0.75	0.75	0.75	1.00	1.02	1.05	1.08	1.02	1.00	1.08
35%	0.76	0.76	0.76	0.99	1.02	1.04	1.06	1.02	0.99	1.06
36%	0.76	0.76	0.76	0.98	1.01	1.04	1.05	1.01	0.98	1.05
37%	0.76	0.76	0.76	0.98	1.01	1.03	1.04	1.01	0.98	1.04
38%	0.76	0.76	0.76	0.97	1.01	1.03	1.02	1.01	0.97	1.02
39%	0.76	0.76	0.76	0.96	1.01	1.02	1.01	1.01	0.96	1.01
40%	0.76	0.76	0.76	0.96	1.01	1.02	1.00	1.01	0.96	1.00
41%	0.77	0.77	0.77	0.95	1.01	1.01	0.99	1.01	0.95	0.99
42%	0.77	0.77	0.77	0.95	1.01	1.01	0.99	1.01	0.95	0.99
43%	0.77	0.77	0.77	0.94	1.01	1.01	0.98	1.01	0.94	0.98
44%	0.78	0.78	0.78	0.94	1.00	1.00	0.97	1.00	0.94	0.97
45%	0.78	0.78	0.78	0.94	1.00	1.00	0.97	1.00	0.94	0.97
46%	0.78	0.78	0.78	0.94	1.00	0.99	0.96	1.00	0.94	0.96
47%	0.79	0.79	0.79	0.94	1.00	0.99	0.96	1.00	0.94	0.96
48%	0.79	0.79	0.79	0.93	1.00	0.98	0.96	1.00	0.93	0.96
49%	0.79	0.79	0.79	0.93	1.00	0.98	0.96	1.00	0.93	0.96
50%	0.80	0.80	0.80	0.93	1.00	0.98	0.96	1.00	0.93	0.96

Table A.4 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
51%	0.80	0.80	0.80	0.94	1.00	0.97	0.95	1.00	0.94	0.95
52%	0.81	0.81	0.81	0.94	1.00	0.97	0.95	1.00	0.94	0.95
53%	0.81	0.81	0.81	0.94	1.00	0.96	0.95	1.00	0.94	0.95
54%	0.82	0.82	0.82	0.94	1.00	0.96	0.95	1.00	0.94	0.95
55%	0.82	0.82	0.82	0.94	0.99	0.96	0.96	0.99	0.94	0.96
56%	0.83	0.83	0.83	0.94	0.99	0.95	0.96	0.99	0.94	0.96
57%	0.84	0.84	0.84	0.95	0.99	0.95	0.96	0.99	0.95	0.96
58%	0.84	0.84	0.84	0.95	0.99	0.95	0.96	0.99	0.95	0.96
59%	0.85	0.85	0.85	0.95	0.99	0.94	0.96	0.99	0.95	0.96
60%	0.86	0.86	0.86	0.95	0.99	0.94	0.97	0.99	0.95	0.97
61%	0.86	0.86	0.86	0.96	0.99	0.93	0.97	0.99	0.96	0.97
62%	0.87	0.87	0.87	0.96	0.99	0.93	0.97	0.99	0.96	0.97
63%	0.88	0.88	0.88	0.96	0.99	0.93	0.98	0.99	0.96	0.98
64%	0.89	0.89	0.89	0.97	0.99	0.93	0.98	0.99	0.97	0.98
65%	0.89	0.89	0.89	0.97	0.99	0.92	0.98	0.99	0.97	0.98
66%	0.90	0.90	0.90	0.98	0.99	0.92	0.99	0.99	0.98	0.99
67%	0.91	0.91	0.91	0.98	0.99	0.92	0.99	0.99	0.98	0.99
68%	0.92	0.92	0.92	0.98	0.99	0.91	0.99	0.99	0.98	0.99
69%	0.93	0.93	0.93	0.99	0.99	0.91	1.00	0.99	0.99	1.00
70%	0.94	0.94	0.94	0.99	0.99	0.91	1.00	0.99	0.99	1.00
71%	0.94	0.94	0.94	0.99	0.99	0.91	1.00	0.99	0.99	1.00
72%	0.95	0.95	0.95	1.00	0.99	0.91	1.01	0.99	1.00	1.01
73%	0.96	0.96	0.96	1.00	0.99	0.91	1.01	0.99	1.00	1.01
74%	0.97	0.97	0.97	1.00	0.99	0.91	1.01	0.99	1.00	1.01
75%	0.98	0.98	0.98	1.01	0.99	0.90	1.01	0.99	1.01	1.01

Table A.4 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
76%	0.99	0.99	0.99	1.01	0.99	0.90	1.01	0.99	1.01	1.01
77%	1.00	1.00	1.00	1.01	0.99	0.90	1.01	0.99	1.01	1.01
78%	1.01	1.01	1.01	1.01	0.99	0.91	1.01	0.99	1.01	1.01
79%	1.03	1.03	1.03	1.02	0.99	0.91	1.01	0.99	1.02	1.01
80%	1.04	1.04	1.04	1.02	0.99	0.91	1.01	0.99	1.02	1.01
81%	1.05	1.05	1.05	1.02	0.99	0.91	1.01	0.99	1.02	1.01
82%	1.06	1.06	1.06	1.02	0.99	0.91	1.01	0.99	1.02	1.01
83%	1.07	1.07	1.07	1.02	0.99	0.92	1.01	0.99	1.02	1.01
84%	1.08	1.08	1.08	1.02	0.99	0.92	1.00	0.99	1.02	1.00
85%	1.10	1.10	1.10	1.02	0.99	0.92	1.00	0.99	1.02	1.00
86%	1.11	1.11	1.11	1.02	0.99	0.93	0.99	0.99	1.02	0.99
87%	1.12	1.12	1.12	1.02	0.99	0.93	0.99	0.99	1.02	0.99
88%	1.13	1.13	1.13	1.02	0.99	0.94	0.98	0.99	1.02	0.98
89%	1.15	1.15	1.15	1.01	0.99	0.95	0.97	0.99	1.01	0.97
90%	1.16	1.16	1.16	1.01	0.99	0.95	0.97	0.99	1.01	0.97
91%	1.17	1.17	1.17	1.01	1.00	0.96	0.96	1.00	1.01	0.96
92%	1.19	1.19	1.19	1.00	1.00	0.97	0.94	1.00	1.00	0.94
93%	1.20	1.20	1.20	1.00	1.00	0.98	0.93	1.00	1.00	0.93
94%	1.22	1.22	1.22	0.99	1.00	0.99	0.92	1.00	0.99	0.92
95%	1.23	1.23	1.23	0.99	1.00	1.01	0.91	1.00	0.99	0.91
96%	1.24	1.24	1.24	0.98	1.00	1.02	0.89	1.00	0.98	0.89
97%	1.26	1.26	1.26	0.97	1.00	1.03	0.87	1.00	0.97	0.87
98%	1.28	1.28	1.28	0.97	1.00	1.05	0.86	1.00	0.97	0.86
99%	1.29	1.29	1.29	0.96	1.00	1.07	0.84	1.00	0.96	0.84
100%	1.31	1.31	1.31	0.95	1.00	1.08	0.82	1.00	0.95	0.82