# 2020 AIR EMISSIONS INVENTORY

PORT CORPUS CHRISTI®

October 2021

*Prepared by:*

STARCREST CONSULTING GROUP, LLC

ENVIRONMENTAL MANAGEMENT • AIR QUALITY • CLIMATE • SUSTAINABILITY

# Port of Corpus Christi Authority
# 2020 Air Emissions Inventory

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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ACKNOWLEDGEMENTS

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| | |
|---|---|
| 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 |
| NR | not reported |
| 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 |
| SFC | specific fuel consumption |
| $SO_x$ | 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 |
| ZMR | zero mile rate |

# SECTION 1 INTRODUCTION

This section describes the rationale behind the 2020 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 update study to estimate Port-related mobile source emissions that occurred in 2020, and to compare those emissions to the previous inventory and to the total 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 2017. The comparison of 2020 emissions with the 2017 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 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.).

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.

## 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, 2.5-micron)
  - 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 weight 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
- $CH_4$ – 25
- $N_2O$ - 298

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*

The activity year for this study is calendar year 2020. To the extent practicable, the emission estimates are based on activities that occurred during this period. If information specific to 2020 was not available, reasonable estimates of operational characteristics were developed. These cases are identified 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: 1990-2019*, April 2021.

### 1.3 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.

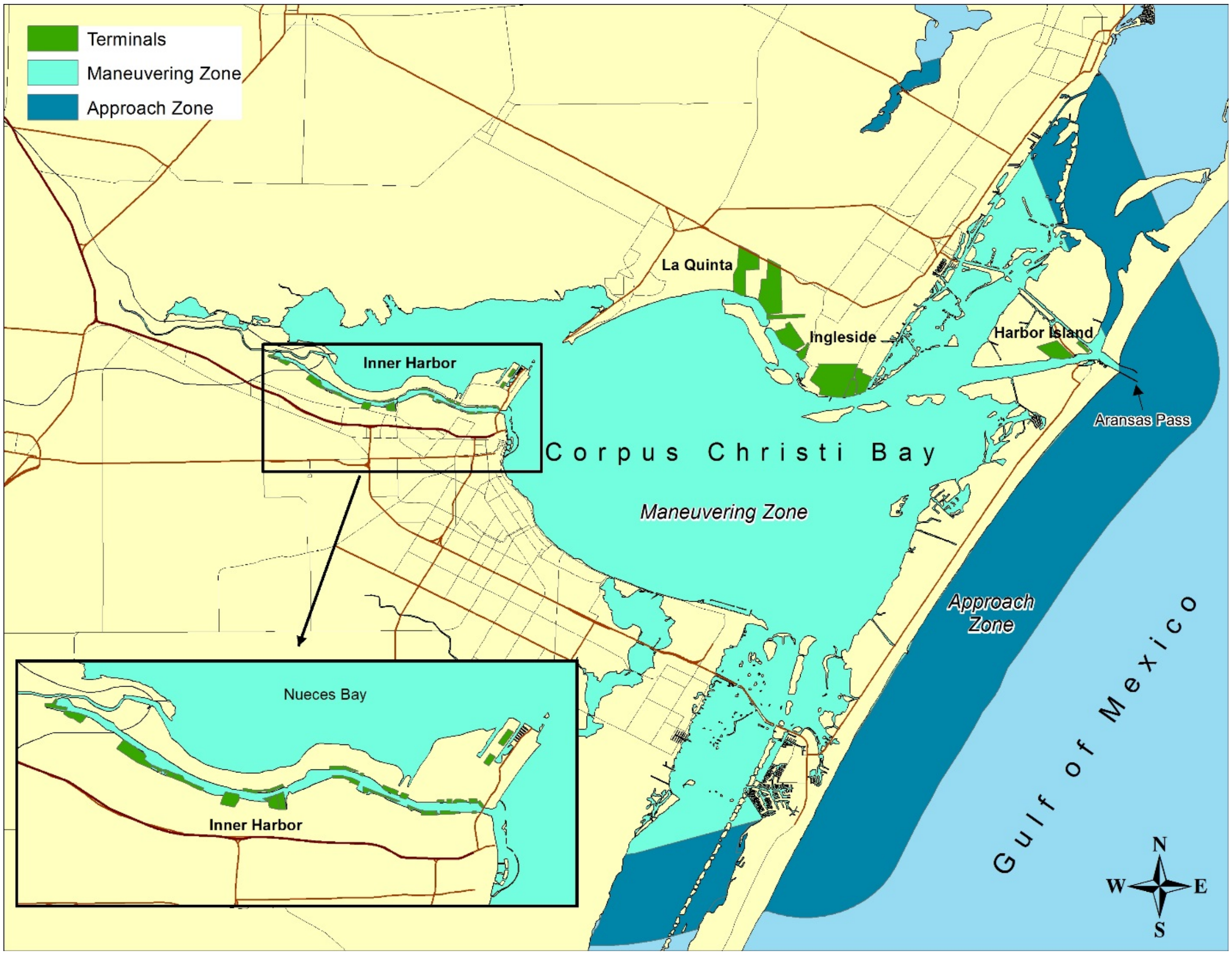
**Table 1.1: List of Terminals**

| Name | Location | Type | Name | Location | Type |
|---|---|---|---|---|---|
| ADM/Growmark | Inner Harbor | Bulk Materials | PCCA Oil Docks | Inner Harbor | Bulk Liquid |
| Cemex USA | 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 | Flint Ingleside | Ingleside | Bulk Liquid |
| Heldenfels | Inner Harbor | Dry Cargo | Oxychem | Ingleside | Bulk Liquid |
| Texas Leigh Cement | Inner Harbor | Dry Cargo | MODA | Ingleside | Bulk Liquid |
| J. Bludworth | Inner Harbor | Dry Dock | South Texas Gateway | Ingleside | Bulk Liquid |
| Buckeye | Inner Harbor | Bulk Liquid | Voestalpine | La Quinta | Bulk Liquid |
| Citgo Docks | Inner Harbor | Bulk Liquid | Cheniere | La Quinta | Bulk Liquid |
| Eagle Ford | Inner Harbor | Bulk Liquid | Oxychem | La Quinta | Bulk Liquid |
| Equistar | Inner Harbor | Bulk Liquid | Sherwin Alumina Co. | La Quinta | Bulk Materials |
| Epic | Inner Harbor | Bulk Liquid | Helix Energy Solutions | La Quinta | Dry Cargo |
| Flint Hills Docks | Inner Harbor | Bulk Liquid | Kiewit Offshore Services | La Quinta | Dry Cargo |
| Kirby Marine | Inner Harbor | Bulk Liquid | Signet Maritime | La Quinta | Mooring |
| Martin Partners | Inner Harbor | Bulk Liquid | Rincon A | Rincon | Dry Cargo |
| Nu Star Logistics | Inner Harbor | Bulk Liquid | Tor Minerals | Rincon | Dry Cargo |

*1.3.1 Marine-side Geographical Domain*

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.

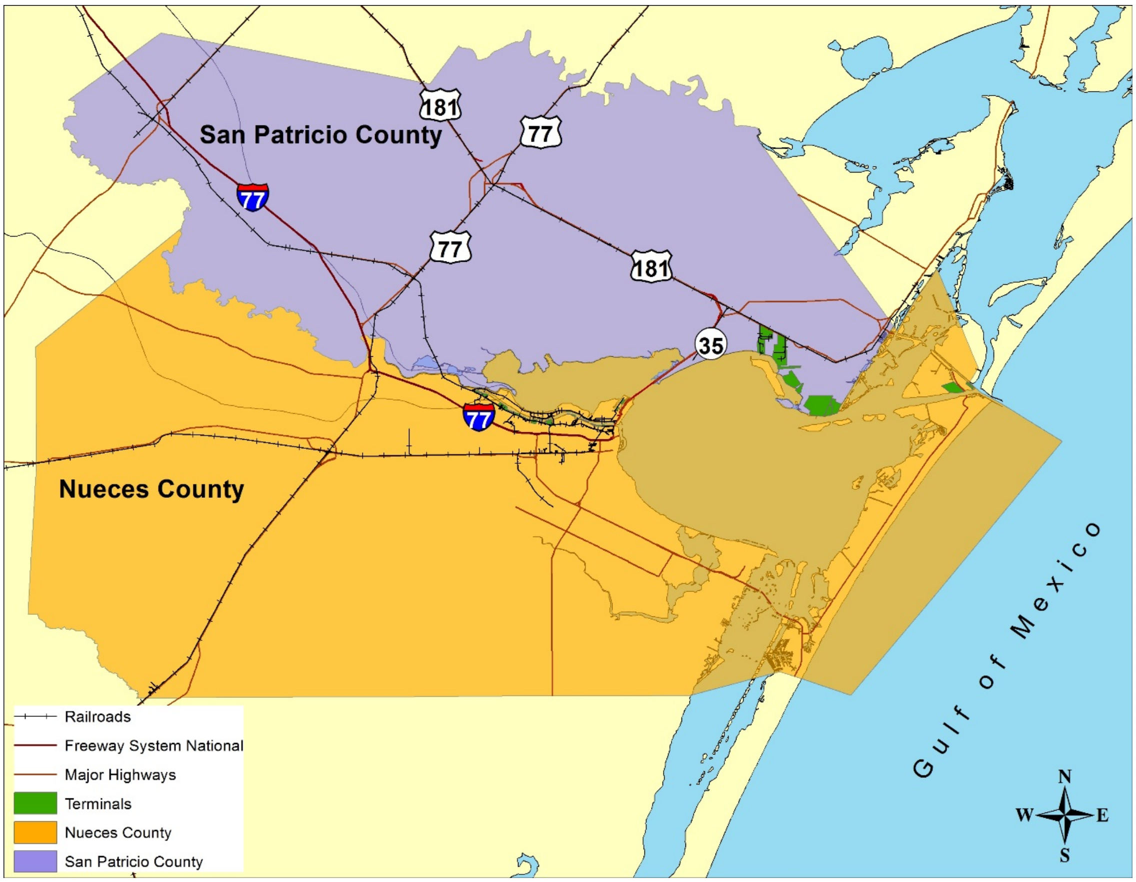
**Figure 1.1: Marine-side Geographical Domain**



*1.3.2 Land-side Geographical Domain*

Figure 1.2 illustrates the land-side geographical domain. The shaded areas indicate the county boundaries and the terminals included in this inventory.

**Figure 1.2: Land-side Geographical Domain**




*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.

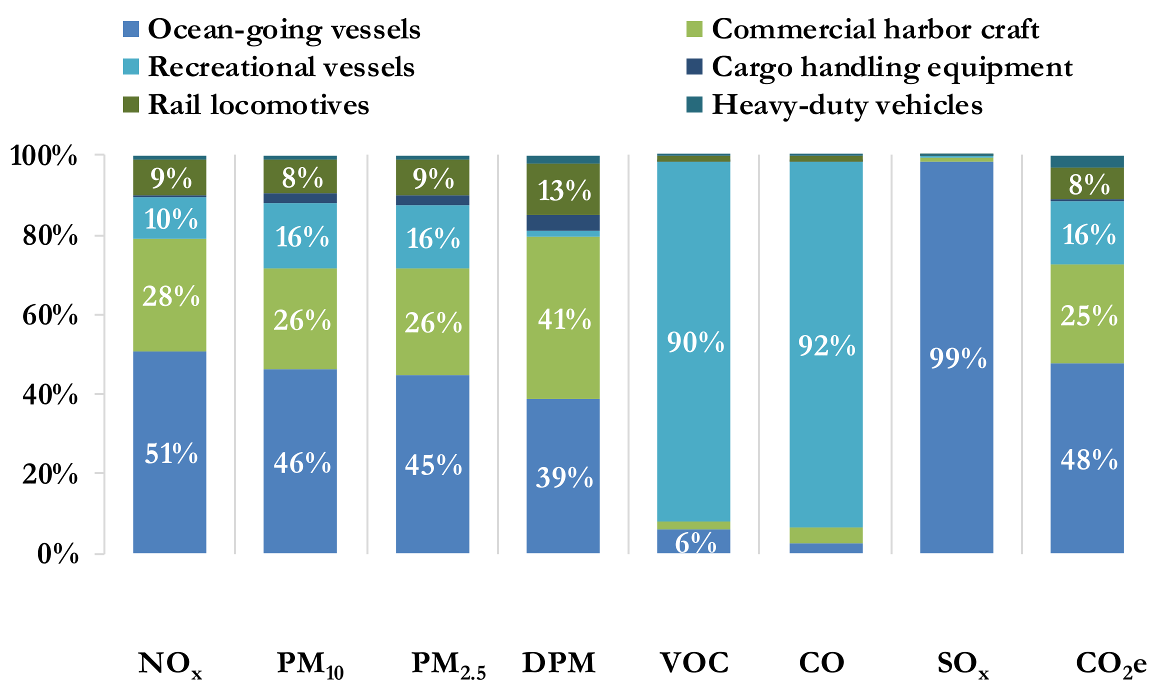
## SECTION 2 SUMMARY RESULTS

The total emissions from 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. Figure 2.1 shows the emissions distribution for 2020. Ocean-going vessels and commercial harbor craft contribute the majority of the maritime-related emissions, followed by recreational vessels.

**Table 2.1: 2020 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 | 2,187 | 53 | 48 | 28 | 73 | 201 | 137.5 | 208,491 |
| Commercial harbor craft | 1,217 | 29 | 28 | 29 | 30 | 303 | 1.1 | 107,964 |
| Recreational vessels | 450 | 19 | 17 | 1 | 1,117 | 7,051 | 0.5 | 70,010 |
| Cargo handling equipment | 20 | 3 | 3 | 3 | 2 | 6 | 0.0 | 2,544 |
| Rail locomotives | 387 | 9 | 9 | 9 | 15 | 100 | 0.4 | 34,903 |
| Heavy-duty vehicles | 45 | 1 | 1 | 1 | 2 | 20 | 0.1 | 13,491 |
| **Total** | **4,306** | **114** | **107** | **72** | **1,239** | **7,680** | **139.5** | **437,403** |

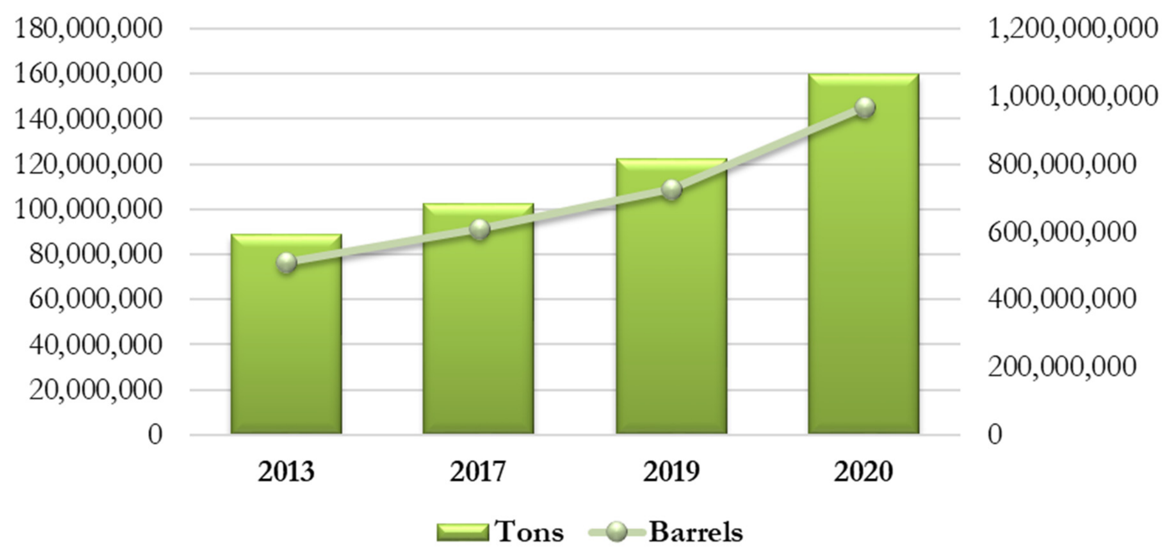
**Figure 2.1: 2020 Maritime-related Emissions Distribution**



***Comparison of 2020 Emissions to 2017***

Comparing 2020 to 2017, the Port of Corpus Christi saw both port expansion and significant cargo growth and moved up in port size rankings.[3] Expansion projects continued at the Port with additional terminals added in 2020. At the end of 2015, a 40-year ban on exporting oil was lifted allowing the export of U.S. oil to be exported to foreign destinations and increasing liquid bulk activity in the U.S. Gulf Coast. Figure 2.2 illustrates the upward cargo trend for the Port of Corpus Christi which has become one of the largest crude oil exporters in the United States since the ban.[4]

**Figure 2.2: Port of Corpus Christi Cargo Trend for Short Tons and Barrels**




As illustrated in Table 2.2, cargo throughput increased 56% in tons of cargo and 59% in barrels since 2017. Ocean-going vessel arrivals increased 15% and larger tankers are visiting the Port and staying longer at berth.

**Table 2.2: 2017-2020 Cargo Volume Vessel Arrivals Comparison**

| Year | Cargo (short tons) | Cargo (barrels) | OGV Arrivals |
|---|---|---|---|
| 2017 | 102,391,848 | 608,524,933 | 1,863 |
| 2020 | 159,713,040 | 968,280,326 | 2,143 |
| **Change (%)** | **56%** | **59%** | **15%** |

[3] *www.portofcc.com/port-of-corpus-christi-finishes-2020-with-record-tonnage/*
[4] *www.portofcc.com/port-corpus-christi-the-1-u-s-crude-oil-export-port-video/*

The 2017 vs 2020 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 the consistency between the years, the 2017 emissions were recalculated using the latest methodology. Overall emissions are higher in 2020 as compared to 2017. The increase in emissions is mainly due to more tanker activity, increased harbor craft and cargo handling equipment activity. Locomotive and truck emissions are lower in 2020 as compared to 2017 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.

Despite the significant 56%-59% increase in cargo, emissions are 8% and 20% higher across all pollutants. The $CO_2e$ emissions usually follow the activity trends more closely than other pollutants due to lack of emissions standards for $CO_2$ and emissions are 16% higher in 2020.

**Table 2.3: 2017-2020 Maritime-related Emissions Comparison**

| | NOx tons | PM10 tons | PM2.5 tons | DPM tons | VOC tons | CO tons | SOx tons | CO2e MT |
|---|---|---|---|---|---|---|---|---|
| **2017** | | | | | | | | |
| Ocean-going vessels | 1,744 | 43 | 40 | 20 | 56 | 153 | 114.5 | 173,619 |
| Commercial harbor craft | 1,199 | 28 | 28 | 28 | 29 | 229 | 0.9 | 84,877 |
| Cargo handling equipment | 18 | 2 | 2 | 2 | 3 | 8 | 0.0 | 1,689 |
| Locomotives | 443 | 11 | 11 | 11 | 19 | 105 | 0.4 | 36,638 |
| Heavy-duty vehicles | 77 | 3 | 3 | 3 | 4 | 30 | 0.1 | 19,258 |
| **Total** | **3,480** | **88** | **83** | **65** | **112** | **524** | **116** | **316,080** |
| **2020** | | | | | | | | |
| Ocean-going vessels | 2,187 | 53 | 48 | 28 | 73 | 201 | 137.5 | 208,491 |
| Commercial harbor craft | 1,217 | 29 | 28 | 29 | 30 | 303 | 1.1 | 107,964 |
| Cargo handling equipment | 20 | 3 | 3 | 3 | 2 | 6 | 0.0 | 2,544 |
| Locomotives | 387 | 9 | 9 | 9 | 15 | 100 | 0.4 | 34,903 |
| Heavy-duty vehicles | 45 | 1 | 1 | 1 | 2 | 20 | 0.1 | 13,491 |
| **Total** | **3,856** | **96** | **90** | **71** | **122** | **629** | **139** | **367,393** |
| **Change between 2017 and 2020 (percent)** | | | | | | | | |
| Ocean-going vessels | 25% | 22% | 21% | 38% | 29% | 31% | 20% | 20% |
| Commercial harbor craft | 2% | 3% | 3% | 4% | 0% | 32% | 27% | 27% |
| Cargo handling equipment | 14% | 39% | 39% | 39% | -21% | -17% | 38% | 51% |
| Locomotives | -13% | -17% | -17% | -17% | -20% | -5% | -5% | -5% |
| Heavy-duty vehicles | -42% | -48% | -48% | -48% | -39% | -34% | -31% | -30% |
| **Total** | **11%** | **9%** | **8%** | **10%** | **9%** | **20%** | **20%** | **16%** |

Note: Table excludes recreational vessel emissions

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

***General Highlights***

- The Port has become a major oil exporter since the ban on exporting oil was lifted at the end of 2015.
- Cargo throughput increased 56% in tons of cargo and 59% in barrels since 2017.
- Many terminal and expansion projects have been completed since 2017.

***Ocean-going vessels***

- OGV emissions increased in 2020 compared to 2017. This was primarily due to more vessels visiting the Port and more time spent at berth for the larger tankers.
- Tanker loading activity increased to 80% of at-berth tanker activity in 2020 compared to 50% in 2017. Increased tanker loading means less vessel energy consumption needed since the land-based pumps are used for loading.
- There were vessels with newer engines. The percent of vessels with Tier II engines was higher in 2020 than in 2017. And 6% of vessels had Tier III engines in 2020. Tier III engines have 75% lower $NO_x$ emission standards.

***Commercial Harbor Craft***

- The overall energy consumption increased by 27% for commercial harbor craft showing increased activity in 2020 as compared to 2017.
- In 2020, there are harbor craft with newer vessels than in 2017. This contributed to the $NO_x$ and PM emissions only increasing by 2%-4% in 2020 despite the 27% increase in activity.
- The 27% increase in $CO_2e$ emissions is due to the higher activity in 2020.
- The increase in CO emissions increased is related to an increase in Tier 2 and Tier 3 engines that have higher CO emission rates compared to pre-Tier 2 engines and the increase in activity.

***Cargo Handling Equipment***

- The overall energy consumption (as measured by horsepower hours) increased 54% due to increased hours of engine use and 31% more equipment in 2020 as compared to 2017.
- Emissions increased in 2020 for most pollutants due to increased activity, but the total emissions remain relatively low since liquid bulk cargo does not require the use of CHE.

***Railroad Locomotives***

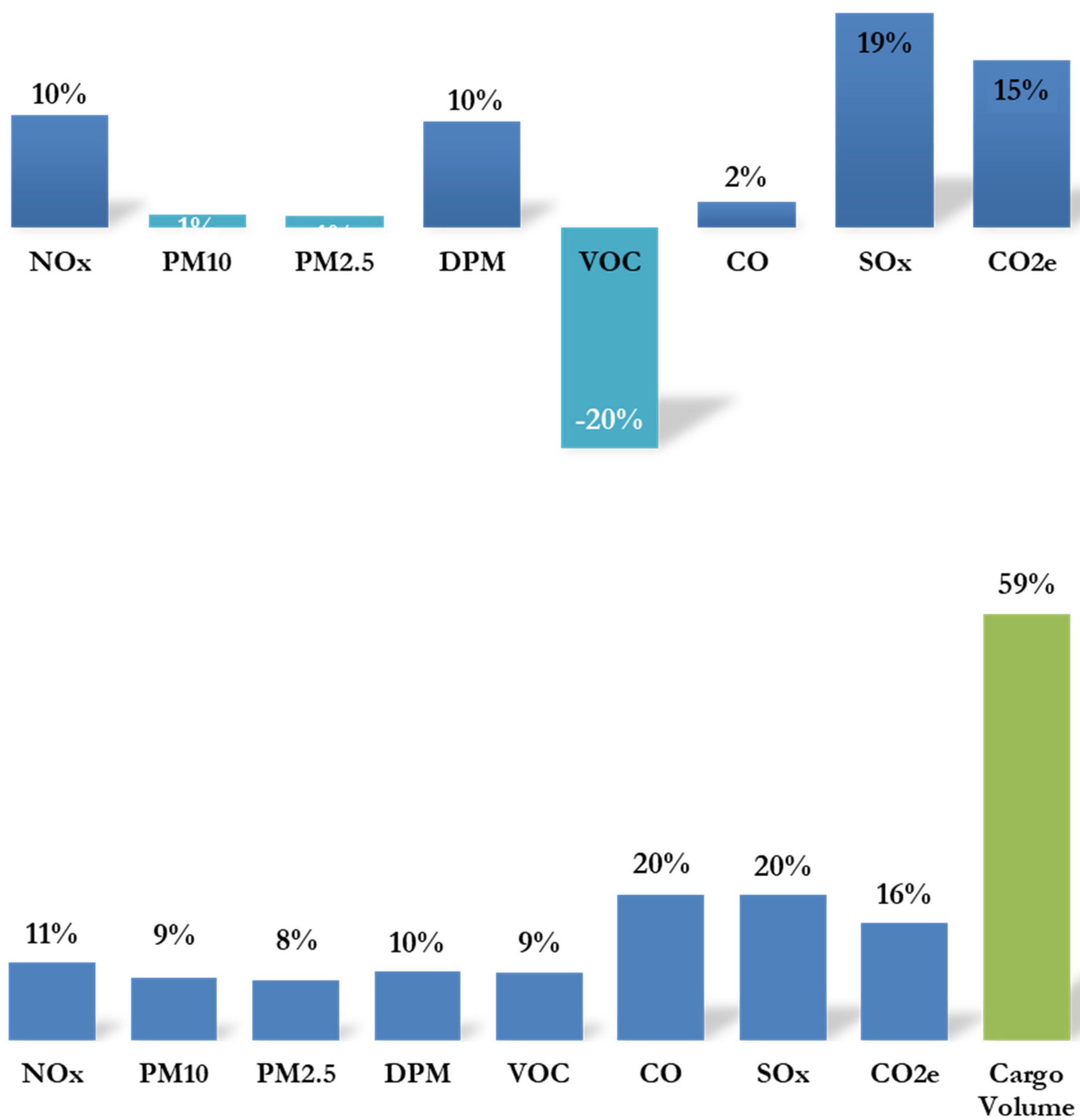
- Locomotive line-haul activity was 4% lower in 2020, therefore overall emissions are lower.
- Locomotive switching emissions increased, but the overall locomotive emissions are lower is due to the line haul emissions being lower in 2020.
- Rail efficiency improvements and fleet turnover are also factors in the emission reductions.

***Trucks***

- The truck count and vehicle miles traveled are 27-28% lower in 2020.
- Truck emissions are lower in 2020 as compared to 2017 due to lower activity and fleet turnover. The $NO_x$ and PM emissions are 42-48% lower than the 2017 emissions.
- There are less trucks in 2020 as compared to 2017 due to less tanker trucks due to new pipeline and the closing of a grain terminal which eliminated grain truck trips.

Figure 2.3 illustrates the emissions change comparing 2020 to 2017. The top figure includes recreational vessels for sake of completeness. While the figure below only includes the commercial emissions (i.e., without recreational vessels) and has a column for the cargo volume in barrels. It illustrates that despite the significant increase in cargo volume in barrels, emissions increased 8% - 20% in 2020 as compared to 2017.

**Figure 2.3: Emissions Comparison**



***2020 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. At the time of this report publication, the 2020 TCEQ emissions were not finalized yet and TCEQ provided the latest 2020 emission estimates.

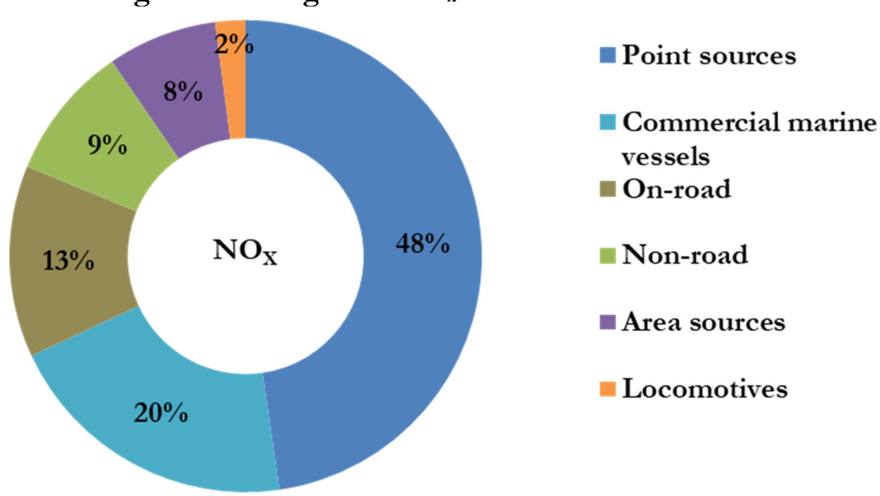
Table 2.4 lists the emission source category, the latest inventory year, and the estimated emissions for Nueces and San Patricio Counties. Please note that the 2020 commercial marine vessel and locomotive emissions from this inventory were used in place of the 2020 TCEQ emissions because they represent all emissions from these categories in the two counties and are the most current. The commercial marine vessels include both the ocean-going vessels and commercial harbor craft emissions.

**Table 2.4: 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 | 2020 | TCEQ | 7,978 | 1,869 | 1,378 | 4,399 | 9,494 | 590 |
| On-road | 2020 | TCEQ | 2,196 | 251 | 86 | 1,237 | 17,954 | 14 |
| Non-road | 2020 | TCEQ | 1,546 | 142 | 135 | 1,558 | 16,373 | 43 |
| Area sources | 2020 | TCEQ | 1,253 | 16,073 | 2,617 | 9,552 | 1,437 | 80 |
| Commercial marine vessels | 2020 | Starcrest | 3,404 | 82 | 77 | 102 | 503 | 139 |
| Locomotives | 2020 | Starcrest | 387 | 9 | 9 | 2 | 20 | 0 |
| **Total** | | | **16,763** | **18,427** | **4,303** | **16,851** | **45,782** | **865** |

The pie charts in Figures 2.4 through 2.8 summarize the distribution of regional emissions for each of the pollutants in 2020. 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 2.4: Regional $NO_x$ Emissions Distribution**



For Figures 2.5 to 2.7, emissions for commercial marine vessels and locomotives were combined as they only account for 1% of the PM, VOC and CO emissions in the region.

**Figure 2.5: Regional $PM_{10}$ Emissions Distribution**

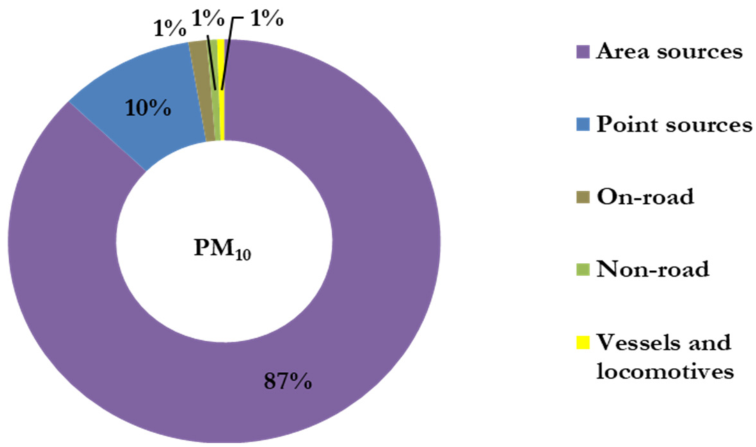



**Figure 2.6: Regional VOC Emissions Distribution**

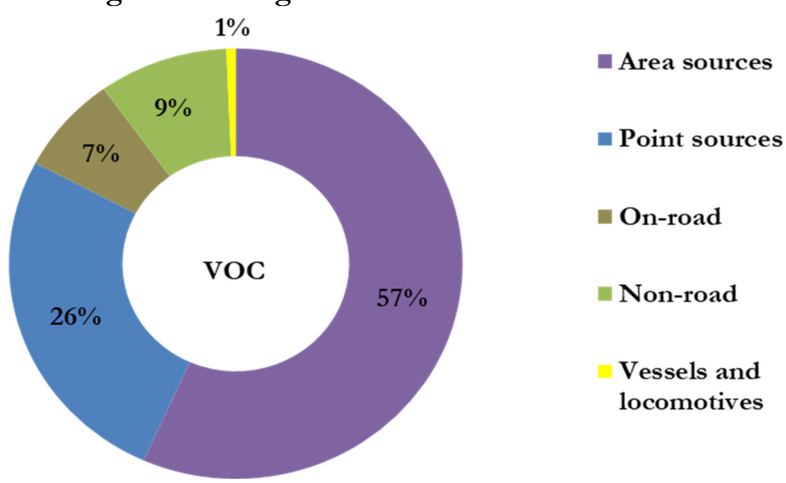



**Figure 2.7: Regional CO Emissions Distribution**

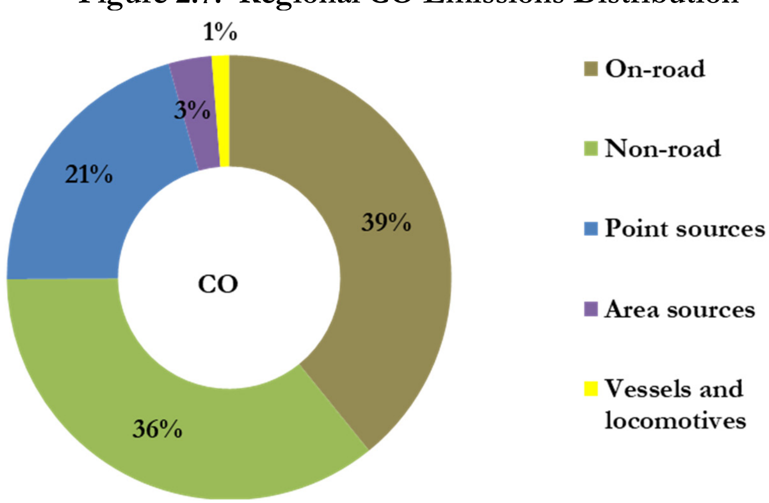
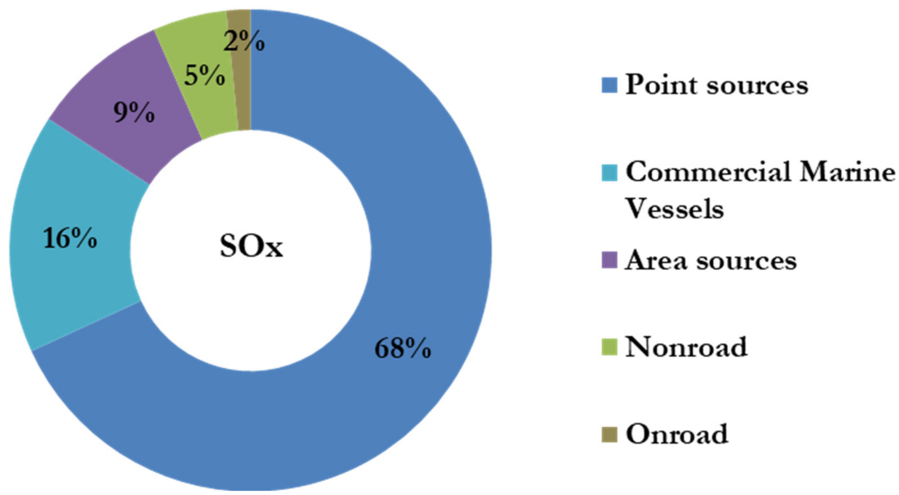


Figure 2.8 illustrates that the commercial marine vessels account for 16% of the $SO_x$ emissions in the region.

**Figure 2.8: Regional $SO_x$ Emissions Distribution**




***Comparison of 2020 Regional Emissions to 2017***

Table 2.5 summarizes the emissions comparison for the regional emissions. In 2020, the overall Nueces and San Patricio County regional emissions are lower than in 2017, except for CO.

**Table 2.5: Nueces and San Patricio County Regional Emissions Comparison**

| Source | $NO_x$ tons | $PM_{10}$ tons | $PM_{2.5}$ tons | VOC tons | CO tons | $SO_2$ tons |
|---|---|---|---|---|---|---|
| 2017 | 17,204 | 29,066 | 5,587 | 17,810 | 39,906 | 1,333 |
| 2020 | 16,763 | 18,427 | 4,303 | 16,851 | 45,782 | 866 |
| **Change** | **-3%** | **-37%** | **-23%** | **-5%** | **15%** | **-35%** |

It should be noted that the 2017 emissions provided by TCEQ are not using the latest emissions methodology but are included for sake of general comparison for the regional emissions. The 2017 regional emissions do not match what was included in the previous 2017 Air Emissions Inventory because the locomotives and commercial vessels estimated by Starcrest were updated.

## SECTION 3 OCEAN-GOING VESSELS

This section presenting emissions estimates for the ocean-going vessels (OGV or vessels) source category 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 2,143 vessel calls to the Port in 2020. A vessel call is counted as a first arrival to a berth, excluding shifts. 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

The following vessel types called the Port in 2020:

- **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 molasses or asphalt. Oil tankers are classified based on their size.

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 towboats or pushboats that tow or push the barge(s).

Figure 3.1 shows the percentage of calls by vessel type. Tankers (81%) made up the majority of the calls, followed by bulk carriers (10%); ATB/ITB (5%); general cargo (4%); and auto carriers (0.3%).

**Figure 3.1: 2020 Distribution of Calls by Vessel Type**

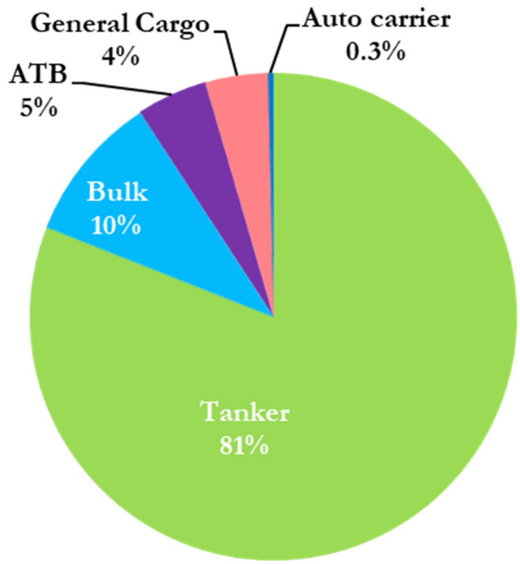



Table 3.1 presents the number of arrivals, departures, and shifts associated with the vessel types that called the Port in 2020. Larger tankers, such as Aframax, Suezmax and VLCC, and tankers with LNG cargo called the Port in 2020 more than in 2017 when the last inventory was conducted.

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

| Vessel Type | Arrivals | Departures | Shifts | Total |
|---|---|---|---|---|
| Auto Carrier | 7 | 7 | 0 | 14 |
| Bulk | 179 | 163 | 74 | 416 |
| Bulk - Heavy Load | 12 | 9 | 7 | 28 |
| Bulk - Self Discharging | 19 | 19 | 1 | 39 |
| General Cargo | 89 | 83 | 7 | 179 |
| ATB/ITB | 101 | 98 | 35 | 234 |
| Tanker - Chemical | 467 | 455 | 114 | 1,036 |
| Tanker - Asphalt | 30 | 29 | 4 | 63 |
| Tanker - LNG | 115 | 115 | 5 | 235 |
| Tanker - LPG | 150 | 148 | 35 | 333 |
| Tanker - Handysize | 55 | 54 | 9 | 118 |
| Tanker - Panamax | 43 | 40 | 12 | 95 |
| Tanker - Aframax | 649 | 626 | 111 | 1,386 |
| Tanker - Suezmax | 161 | 159 | 24 | 344 |
| Tanker - VLCC | 66 | 65 | 3 | 134 |
| **Total** | **2,143** | **2,070** | **441** | **4,654** |

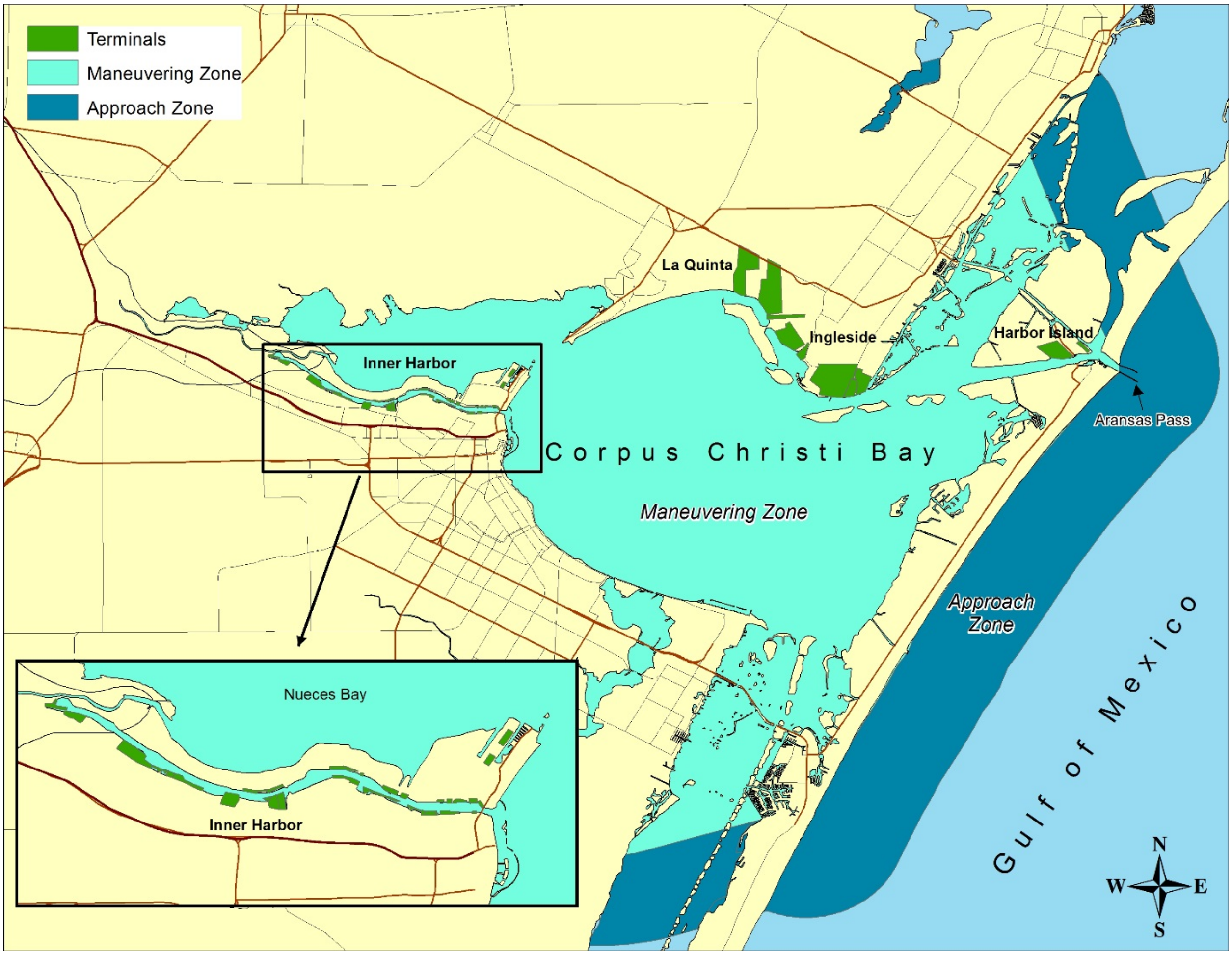
Table 3.2 presents the hoteling times at berth in 2020. The average time spent at berth are slightly higher in 2020 than in previous years, especially for the larger tankers. The average stay is 2 days with a maximum of 10 days for a tanker in 2020.

**Table 3.2: Hotelling Times at Berth, hours**

| Vessel Type | Min Hrs | Max Hrs | Avg Hrs | Vessel Count |
|---|---|---|---|---|
| Auto Carrier | 14.5 | 45.4 | 29.6 | 7 |
| Bulk | 2.0 | 528.5 | 81.8 | 153 |
| Bulk - Heavy Load | 22.4 | 271.0 | 85.4 | 6 |
| Bulk - Self Discharg | 17.6 | 50.8 | 24.0 | 5 |
| General Cargo | 6.2 | 205.0 | 54.7 | 76 |
| ATB/ITB | 0.9 | 7,762.4 | 86.7 | 19 |
| Tanker - Chemical | 1.7 | 184.6 | 39.9 | 233 |
| Tanker - Asphalt | 9.8 | 67.5 | 27.1 | 7 |
| Tanker - LNG | 18.8 | 120.3 | 33.4 | 67 |
| Tanker - LPG | 8.4 | 99.6 | 31.7 | 28 |
| Tanker - Handysize | 6.9 | 97.9 | 45.1 | 33 |
| Tanker - Panamax | 16.2 | 188.0 | 51.9 | 37 |
| Tanker - Aframax | 1.3 | 251.2 | 43.6 | 276 |
| Tanker - Suezmax | 4.3 | 142.9 | 42.3 | 65 |
| Tanker - VLCC | 26.8 | 74.4 | 45.8 | 57 |

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 from Starcrest Vessel Boarding Program (VBP) which includes data collected from ships engineers at various ports to determine auxiliary engine and boiler loads, by the various operational modes. If VBP data for the vessel(s) that visited the Port was not available, appropriate defaults were calculated as call-weighted averages for vessel types that had 10% or greater calls from specific vessels in the VBP. For vessel types with too little VBP data to calculate a default, an average of defaults used for other ports' EIs were used. The vessel specific parameter data is obtained under license from IHS Markit and includes vessel type, engine type, propulsion engine horsepower, keel laid date, and other parameters. This data is commonly known as "Lloyd's data" for historical reasons.

### 3.3 Operational Profiles

Emission estimates have been developed for the three combustion emission source types associated with marine vessels: 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 before the vessel departs the EI geographical boundary. Additional power is typically brought online since the vessel is preparing to or traveling in restricted waters.
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 2020 emission estimates are calculated based on the assumption that 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).

### 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

$$E_i = Energy_i \times EF \times FCF \times CF$$

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
CF = control factor(s) for emission reduction technologies, dimensionless

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

$$Energy_i = Load \times Act$$

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 to 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 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

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

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.[5] $NO_x$ 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

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)[6]. Table 3.3 list 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[7] and classification societies[8] 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.

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

Table 3.4 shows the 2020 vessel Tier count for diesel propulsion engines. It shows that 48% percent of the vessels calling the Port in 2020 are Tier II and newer. Table 3.5 list the emission factors for auxiliary engines using 0.1% sulfur.

**Table 3.4: Vessel Tier Count and Percent**

| | Tier 0 | Tier I | Tier II | Tier III |
|---|---|---|---|---|
| Count | 33 | 522 | 452 | 64 |
| Percent | 3% | 49% | 42% | 6% |

**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 |

*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.

*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 information on use by mode, because neither the IMO nor the classification societies require vessel owners to provide this information.

Under VBP, vessels are boarded during their visits to ports and information is collected for the vessel and sister vessels. Specifically, during VBP, interviews with the vessel engineer is conducted to obtain data 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, call weighted 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 is not available, an average of the latest published defaults for the Port of Los Angeles[9] and Port of Long Beach[10] by vessel type and mode is used. Table 3.7 summarizes the auxiliary engine load defaults by mode used for this study by vessel subtype.

**Table 3.7: Average Auxiliary Engine Load Defaults, kW**

| Vessel Type | Sea | Maneuvering | Berth Hotelling |
|---|---|---|---|
| Auto Carrier | 570 | 1,193 | 962 |
| Bulk | 255 | 283 | 523 |
| Bulk - Heavy Load | 359 | 949 | 211 |
| Bulk - Self Discharging | 305 | 807 | 179 |
| General Cargo | 462 | 1,616 | 754 |
| ATB/ITB | 78 | 205 | 101 |
| Tanker - Chemical | 461 | 569 | 1,363 |
| Tanker - Asphalt | 500 | 750 | 500 |
| Tanker - LNG | 2,913 | 3,204 | 3,826 |
| Tanker - LPG | 500 | 750 | 500 |
| Tanker - Handysize | 661 | 682 | 1,053 |
| Tanker - Panamax | 476 | 499 | 784 |
| Tanker - Aframax | 477 | 590 | 910 |
| Tanker - Suezmax | 667 | 568 | 689 |
| Tanker - VLCC | 630 | 741 | 1,011 |

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

### *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, call weighted average auxiliary boiler engine load defaults derived from VBP data or an average of defaults for other ports by vessel type is used.[11]

Tankers have much higher auxiliary boiler usage rates 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 about 80% of the tanker calls were loading and the other 20% were unloading or discharging cargo.

Articulated tug barges (ATBs) do not use boilers for pumping cargo; therefore, their boiler energy default is zero. 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. The auxiliary boiler load defaults in kilowatts used for each vessel type are presented in Table 3.8 for most vessels and Table 3.9 for diesel-electric vessels.

**Table 3.8: Auxiliary Boiler Load Defaults, kW**

| Vessel Type | Sea | Maneuvering | Berth Hotelling |
|---|---|---|---|
| Auto Carrier | 84 | 173 | 296 |
| Bulk | 58 | 138 | 170 |
| Bulk - Heavy Load | 35 | 94 | 125 |
| Bulk - Self Discharging | 44 | 103 | 132 |
| General Cargo | 49 | 113 | 145 |
| ATB/ITB | 0 | 0 | 0 |
| Tanker - Chemical | 98 | 141 | 367 |
| Tanker - Asphalt | 690 | 690 | 875 |
| Tanker - LNG | 0 | 145 | 548 |
| Tanker - LPG | 100 | 200 | 1,000 |
| Tanker - Handysize | 144 | 286 | 3,077 |
| Tanker - Panamax | 536 | 444 | 3,152 |
| Tanker - Aframax | 188 | 202 | 5,601 |
| Tanker - Suezmax | 144 | 99 | 8,170 |
| Tanker - VLCC | 240 | 116 | 8,262 |

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

**Table 3.9: 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 |

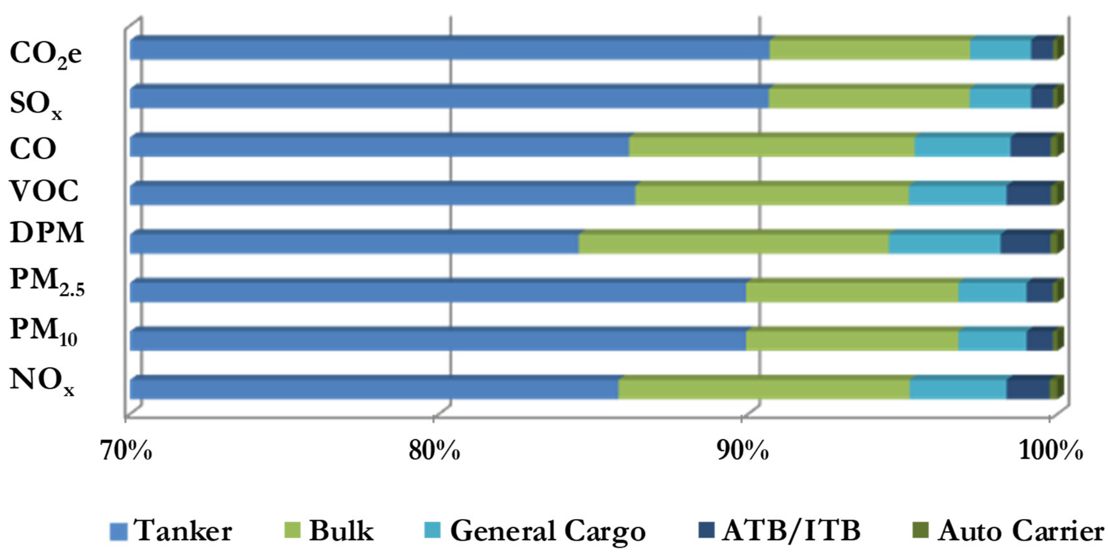
### 3.5 OGV Emission Estimates

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 3.10 shows that tankers have the highest emissions at the Port.

**Table 3.10: 2020 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 | 6 | 0.08 | 0.07 | 0.06 | 0.15 | 0.44 | 0.2 | 291 |
| Bulk | 206 | 3.61 | 3.32 | 2.78 | 6.42 | 18.54 | 8.9 | 13,519 |
| General Cargo | 69 | 1.16 | 1.07 | 1.00 | 2.30 | 6.23 | 2.7 | 4,123 |
| ATB/ITB | 30 | 0.44 | 0.41 | 0.44 | 1.04 | 2.60 | 1.0 | 1,481 |
| Tanker | 1,876 | 47.26 | 43.48 | 23.43 | 62.65 | 172.95 | 124.7 | 189,077 |
| **Total** | **2,187** | **52.55** | **48.35** | **27.72** | **72.56** | **200.78** | **137.5** | **208,491** |

**Figure 3.3: 2020 Distribution of Emissions by Vessel Type**



The emissions are presented by engine type in Table 3.11 and by operating mode in Table 3.12. Auxiliary engines have the highest criteria pollutant emissions, while boilers have the highest GHG emissions.

**Table 3.11: 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 | 583 | 4 | 4 | 4 | 11 | 40 | 13 | 19,787 |
| Auxiliary Engines | 1,361 | 23 | 21 | 23 | 49 | 136 | 52 | 79,008 |
| Boilers | 242 | 25 | 23 | 0 | 12 | 25 | 72 | 109,696 |
| **Total** | **2,187** | **53** | **48** | **28** | **73** | **201** | **138** | **208,491** |

Based on the geographical scope of the study which is mainly within the port complex extending to 3 nm out, 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 3.12: 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 | 1,504 | 46 | 43 | 22 | 58 | 150 | 120 | 182,435 |
| Maneuvering | 683 | 6 | 6 | 6 | 15 | 50 | 17 | 26,056 |
| **Total** | **2,187** | **53** | **48** | **28** | **73** | **201** | **138** | **208,491** |

# 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.
- **Crew and supply vessels** – These supply vessels make numerous trips back and forth from a terminal or home berth to anchorage and offshore platforms.
- **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.
- **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 2020. Averages of the model year, horsepower, or operating hours are used as default values when vessel specific data is not available. In 2020, there were approximately 565 discrete vessels included.

**Table 4.1: 2020 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 |
| Crew and supply vessels | 1980 | 2006 | 2006 | 0 | 4,023 | 1,378 | 0 | 69 | 2 |
| Excursion | 1966 | 2002 | 1983 | 240 | 800 | | 50 | 50 | 50 |
| Ferry | 2010 | 2020 | 2018 | 350 | 755 | 594 | 2,096 | 4,875 | 3,387 |
| Government | 1987 | 2008 | 1999 | 225 | 750 | 505 | 500 | 2,500 | 1,300 |
| Miscellaneous | 1963 | 2013 | 2001 | 280 | 1,408 | 884 | 0 | 77 | 1 |
| Tugboat | 1979 | 2008 | 1997 | 1950 | 3,150 | 2,265 | 2,681 | 2,681 | 2,681 |
| Towboats | 1963 | 2014 | 1996 | 280 | 5,445 | 1,365 | 0 | 1,528 | 76 |

**Table 4.2: 2020 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 |
| Crew and supply vessels | 1980 | 2019 | 2006 | na | na | na | 0 | 2,870 | 85 |
| Excursion | na | na | na | na | na | na | 0 | 5,496 | 53 |
| Ferry | 2007 | 2017 | 2010 | 98 | 113 | 107 | 1,532 | 2,438 | 1,899 |
| Government | na | na | na | na | na | na | na | na | na |
| Miscellaneous | 1963 | 2013 | 2001 | na | na | na | 0 | 5,496 | 53 |
| Tugboat | 1989 | 2008 | 2000 | 100 | 201 | 140 | 2,681 | 2,681 | 2,681 |
| Towboats | 1963 | 2014 | 1996 | 89 | 89 | 89 | 0 | 8,188 | 750 |

The data for excursion vessels, ferries, government vessels, and tugboats 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. 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 towboats, crew and supply vessels, miscellaneous vessels, and some 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.
- Transit - Hours in this zone were assumed for one auxiliary engine and two main engines.

IMO and MMSI numbers were joined with IHS 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 tow boat operators' websites and IHS indicated that the majority of the vessels have two main engines. Therefore, as a default, it was assumed that on average tow boats have two propulsion engines so total propulsion horsepower was divided by two and assigned to each propulsion engine. The auxiliary engine horsepower was not available. This information was obtained for several vessels via various towboat operator's websites and the average horsepower based on the collected data was used.

### 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 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."[12]

[12] *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 |
| Crew and supply | 0.45 | 0.43 |
| Ferry and excursion | 0.42 | 0.43 |
| Government | 0.45 | 0.43 |
| Miscellaneous (C1/C2) | 0.52 | 0.43 |
| Pilot boat | 0.51 | 0.43 |
| Tugboat | 0.50 | 0.43 |
| Towboat and pushboat | 0.68 | 0.43 |
| Work boat | 0.45 | 0.43 |

## 4.4 Commercial Harbor Craft Emission Estimates

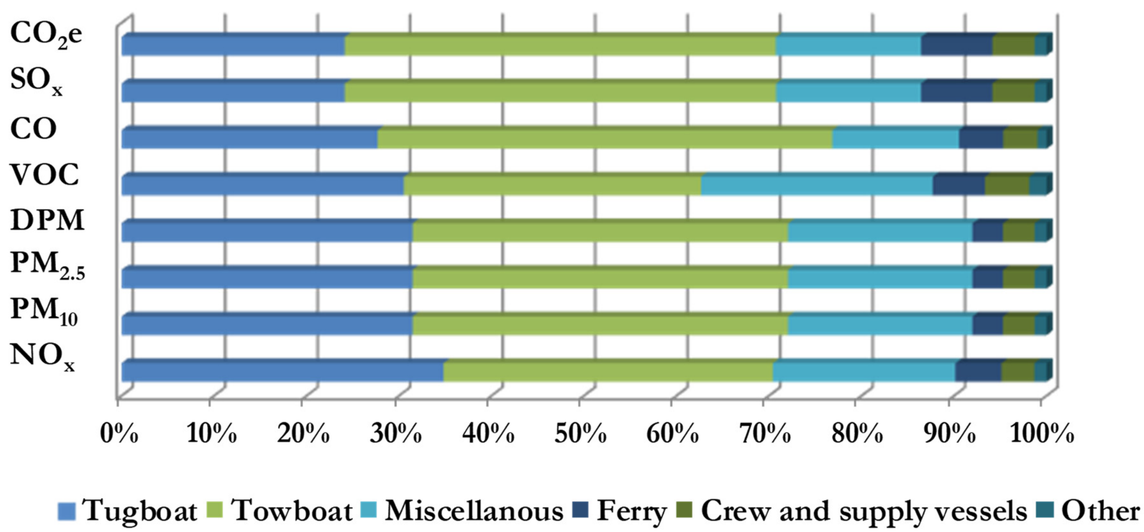
Table 4.6 presents the emissions for commercial harbor craft by vessel type, not including recreational vessels. Tugboats have the highest emissions compared to all commercial harbor craft, followed by towboats and miscellaneous vessels. If the vessel type could not be determined from IHS data, they were characterized as miscellaneous vessels. Tugboats and towboats have the highest emissions 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 |
| Crew and supply vessels | 43 | 1.0 | 1.0 | 1.0 | 1.4 | 11 | 0.0 | 4,923 |
| Excursion | 2 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0.0 | 143 |
| Ferry | 61 | 1.0 | 0.9 | 1.0 | 1.7 | 14 | 0.1 | 8,299 |
| Government | 10 | 0.2 | 0.2 | 0.2 | 0.4 | 2 | 0.0 | 986 |
| Miscellanous | 240 | 5.8 | 5.7 | 5.8 | 7.4 | 41 | 0.2 | 16,951 |
| Tugboat | 424 | 9.2 | 8.9 | 9.2 | 9.0 | 84 | 0.3 | 26,048 |
| Towboat | 433 | 11.9 | 11.5 | 11.9 | 9.5 | 149 | 0.5 | 50,328 |
| **Total** | **1,217** | **29.3** | **28.4** | **29.3** | **29.6** | **303** | **1.1** | **107,964** |

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**




### 4.5 Recreational Vessel Emission Estimates

The recreational vessel population by vessel type for Nueces and San Patricio counties was obtained from the Texas Parks and Wildlife's Boat Registration Records. Fleet average emission factors in grams per hour for exhaust and running loss and in grams per vehicle for evaporative emissions by vessel types and fuel types were obtained from MOVES3 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 2020 recreational vessel emissions are presented in Table 4.7.

**Table 4.7: 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 | 8,949 | 232 | 14.9 | 13.7 | 0.0 | 942 | 4,173 | 0.2 | 38,100 |
| Inboard/Sterndrive | Gasoline | 1,989 | 134 | 1.8 | 1.7 | 0.0 | 96 | 1,933 | 0.1 | 20,720 |
| Personal Water Craft | Gasoline | 1,210 | 48 | 1.0 | 0.9 | 0.0 | 76 | 937 | 0.0 | 7,251 |
| Inboard/Sterndrive | Diesel | 348 | 36 | 0.9 | 0.9 | 0.9 | 2 | 8 | 0.0 | 3,921 |
| Outboard | Diesel | 11 | 0 | 0.0 | 0.0 | 0.0 | 0 | 0 | 0.0 | 18 |
| **Total** | | **12,507** | **450** | **18.5** | **17.1** | **0.9** | **1,117** | **7,051** | **0.5** | **70,010** |

## SECTION 5 CARGO HANDLING EQUIPMENT

This section presents emissions estimates for the cargo handling equipment source category and is organized into following 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).

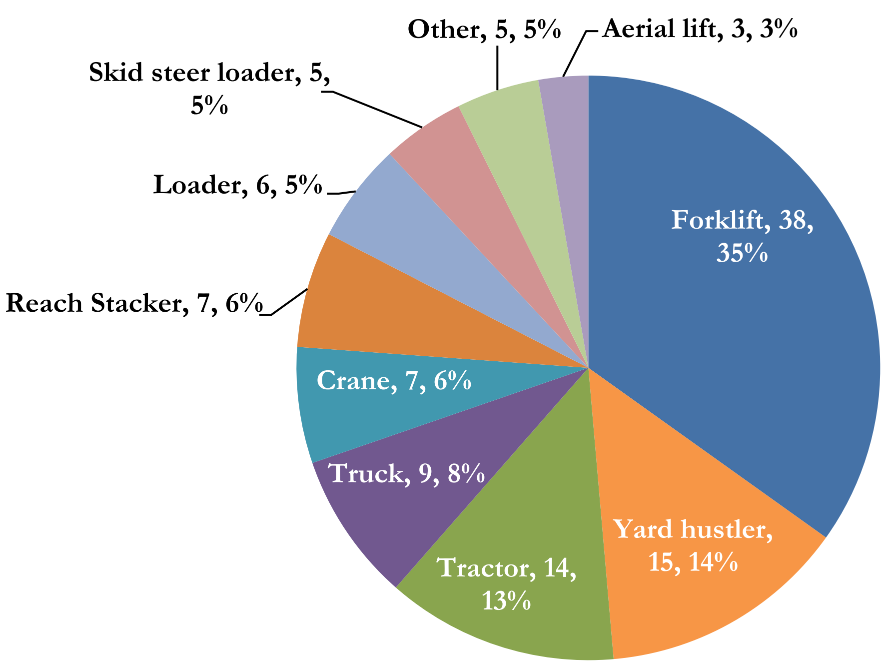
### 5.1 Source Description

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

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

Figure 5.1 presents the distribution of the 109 pieces of cargo handling equipment inventoried for the Port in 2020. The "other" category in the figure includes three sweepers and two backhoes.

**Figure 5.1: 2020 Distribution of Cargo Handling Equipment**



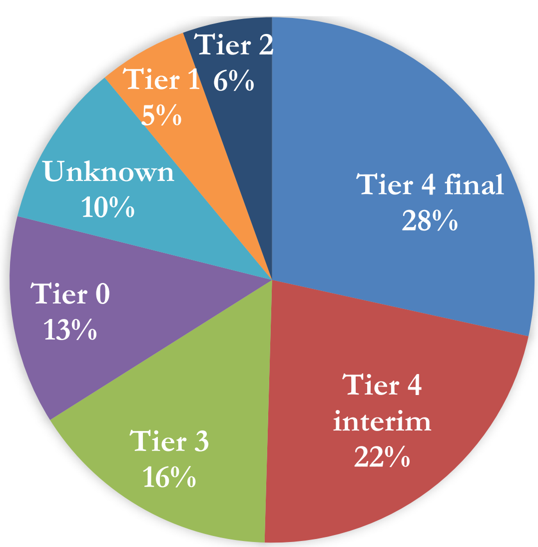
## 5.2 Data and Information Acquisition

Table 5.1 summarizes the characteristics of the CHE operating at the Port in 2020. 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[13] (Tier 0, 1, 2, 3, 4 interim, and 4 final) based on model year and horsepower range. Unknown in the figure represents percent of the equipment where MY and/or HP information was not available to determine engine tier.

**Table 5.1: 2020 Equipment Characteristics**

| Equipment | Count | Model Year Average | Horsepower Average | Annual Hours Average |
|---|---|---|---|---|
| Backhoe | 2 | 2015 | 78 | 100 |
| Aerial lift (Manlift) | 3 | 2011 | 147 | 43 |
| Crane | 7 | 1976 | 383 | 575 |
| Forklift | 38 | 2009 | 111 | 621 |
| Loader | 6 | 2010 | 128 | 472 |
| Reach Stacker | 7 | 2012 | 377 | 996 |
| Skid steer loader | 5 | 2012 | 83 | 65 |
| Sweeper | 3 | 2012 | 74 | 472 |
| Tractor | 14 | 2013 | 50 | 57 |
| Truck | 9 | 2010 | 356 | 162 |
| Yard hustler | 15 | 2013 | 175 | 489 |
| **Total** | **109** | | | |

**Figure 5.2: 2020 CHE Diesel Tier Count Distribution**




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

### 5.3 Emission Estimation Methodology

Emissions were estimated using EPA's MOVES3 model[14] 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 MOVES3 equipment type. Table 5.2 presents equipment types by Source Classification Code (SCC), load factor, and MOVES3/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 | 0.59 | Terminal tractor |
| Truck | 2270002051 | 0.59 | Off-highway trucks |
| Yard hustler | 2270003070 | 0.39 | Terminal tractor |

Except for yard hustlers, load factors for all other equipment were obtained from MOVES3. For yard hustlers (also known as yard tractors), a load factor of 0.39 is used based on a 2008 study[15] prepared for the Port of Los Angeles and Port of Long Beach by Starcrest Consulting Group., LLC. This load factor is the most current and appropriate load factor representing diesel yard hustlers in port. MOVES3 use a load factor of 0.59 for yard hustlers based on a 1997 study prepared for the EPA[16].

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 MOVES3 model has option to output emissions factors in grams/hp-hr by calendar year for each of the MOVES3 equipment types by horsepower groups and model year. The model year groups are aligned with EPA's nonroad equipment emissions standards. MOVES3 emission factors reflect the actual ULSD fuel used in 2020. 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.

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

[15] Ports of Los Angeles and Long Beach, *San Pedro Bay Ports Yard Tractor Load Factor Study*, December 2008.

[16] EPA, Evaluation of Power Systems Research (PSR) Nonroad Population Data Base, 1997.

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.

MOVES3 was run for calendar year 2020 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 MOVES3 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.

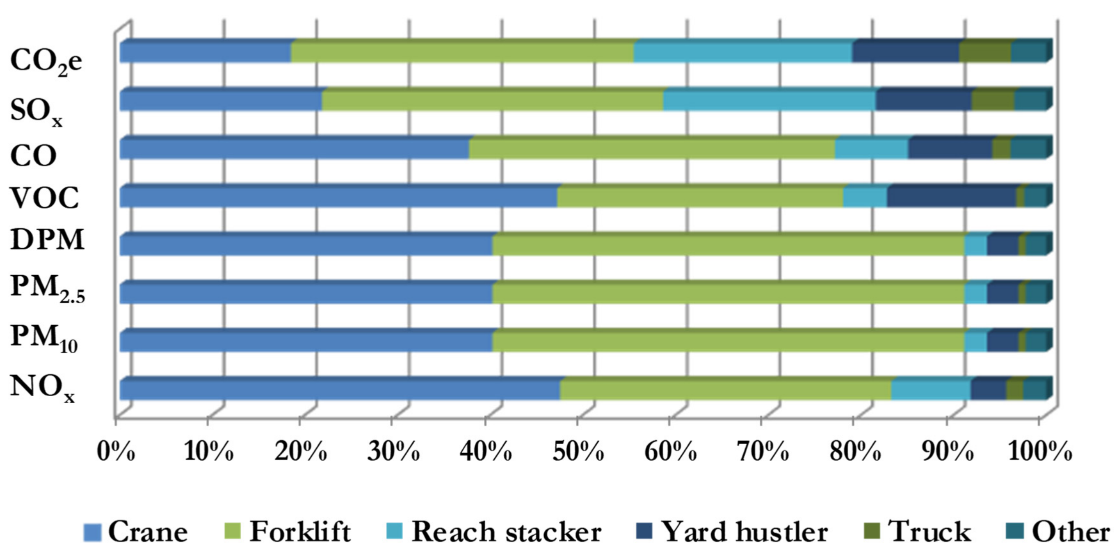
## 5.4 Cargo Handling Equipment Emission Estimates

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

**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 | 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2 |
| Crane | 7 | 9.61 | 1.20 | 1.17 | 1.20 | 0.97 | 2.42 | 0.00 | 470 |
| Forklift | 38 | 7.23 | 1.52 | 1.48 | 1.52 | 0.63 | 2.53 | 0.00 | 942 |
| Loader | 6 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.14 | 0.00 | 48 |
| Manlift | 3 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 3 |
| Reach stacker | 7 | 1.73 | 0.07 | 0.07 | 0.07 | 0.10 | 0.51 | 0.00 | 599 |
| 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 | 14 | 0.08 | 0.02 | 0.02 | 0.02 | 0.00 | 0.01 | 0.00 | 13 |
| Truck | 9 | 0.37 | 0.02 | 0.02 | 0.02 | 0.02 | 0.13 | 0.00 | 142 |
| Yard hustler | 15 | 0.78 | 0.10 | 0.10 | 0.10 | 0.29 | 0.58 | 0.00 | 294 |
| **Total** | **109** | **20.22** | **2.99** | **2.90** | **2.99** | **2.05** | **6.41** | **0.01** | **2,544** |

**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: emission 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.

Locomotive operations included in this inventory are switching and rail yard activities of the Corpus Christi Terminal Railroad (CCTR), Union Pacific (UP), and line haul activities of 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.

## 6.2 Data and Information Acquisition

CCTR provided information on their six CCTR switching locomotives. The information includes the model, year of manufacture, horsepower, and annual fuel consumption of each locomotive. Similar information was provided by UP for the 2017 emissions inventory for switching locomotives they operate in Nueces County, which was scaled for 2020 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. UP also provided revised information for 2017 because they discovered that the information they provided for the 2017 inventory was inaccurate and reported much higher activity than actually occurred in 2017. 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 Emission 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 such as 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.[17] 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.

[17] 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[18] 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 2020 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.

[18] 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 two tier levels account for the switchers operated by CCTR and by UP, although stricter standards will apply when these locomotives are rebuilt.

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

| | $NO_x$ | $PM_{10}$ | $PM_{25}$ | VOC | CO<br>g/hphr | $SO_x$ | $CO_2$ | $N_2O$ | $CH_4$ |
|---|---|---|---|---|---|---|---|---|---|
| **Line haul** | | | | | | | | | |
| 2020 composite | 4.76 | 0.11 | 0.11 | 0.17 | 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 |

## 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 | $PM_{25}$ tons | DPM tons | VOC tons | CO tons | $SO_x$ tons | $CO_2$ tonnes |
|---|---|---|---|---|---|---|---|---|
| Line Haul | 353 | 8.2 | 8.2 | 8.2 | 12.6 | 95.0 | 0.37 | 33,286 |
| Switching | 34 | 1.2 | 1.1 | 1.2 | 2.8 | 4.8 | 0.02 | 1,617 |
| **Total** | **387** | **9.3** | **9.3** | **9.3** | **15.4** | **99.8** | **0.39** | **34,903** |

# 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 2020. 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 74,061truck visits related to liquid bulk terminals and 111,348 truck visits associated with dry cargo facilities, for a total of 185,409 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"[19] 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 in 2020 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 6.33 million highway miles and 0.91 million non-highway miles have been estimated for 2020. A sensitivity analysis on the effect of exclusively using the longer route to estimate VMT indicates a maximum overestimate of 9% 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 9%.

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 185,409 hours in 2017. 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,[20] and on a study published by the Oak Ridge National Laboratory[21] that reported the most common range of idling times for heavy-duty trucks, excluding overnight idling, is in the 15- to 60-minute range.

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

[20] 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/*

[21] 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

$$E = EF \times A$$

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 MOVES3, which estimates emissions and emission factors for on-road vehicles of all types, including HDVs.

The MOVES3 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 MOVES3 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 | $NO_x$ | $PM_{10}$ | $PM_{25}$ | VOC | CO | $SO_x$ | $CO_2$ | $N_2O$ | $CH_4$ |
|---|---|---|---|---|---|---|---|---|---|
| Rural Restricted Access (g/mi) | 3.988 | 0.106 | 0.098 | 0.147 | 1.859 | 0.006 | 1,656 | 0.001 | 0.016 |
| Rural Unrestricted Access (g/mi) | 4.253 | 0.119 | 0.109 | 0.164 | 2.050 | 0.006 | 1,672 | 0.002 | 0.018 |
| Short-Term Idle (g/hr) | 62.885 | 3.003 | 2.763 | 5.905 | 22.400 | 0.068 | 7,966 | 0.083 | 0.340 |

## 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 | $PM_{25}$ tons | DPM tons | VOC tons | CO tons | $SO_x$ tons | $CO_2$ tonnes |
|---|---|---|---|---|---|---|---|---|
| On-road driving | 32 | 0.9 | 0.8 | 0.9 | 1.2 | 15.0 | 0.04 | 12,008 |
| On-site idling | 13 | 0.6 | 0.6 | 0.6 | 1.2 | 4.6 | 0.01 | 1,483 |
| **Total** | **45** | **1.5** | **1.4** | **1.5** | **2.4** | **19.6** | **0.06** | **13,491** |

## SECTION 8 COMPARISON OF 2020 AND 2017 EMISSION ESTIMATES

This section provides a comparison of the emission estimates for 2020 and 2017 by source category. Emissions estimation methodology changed for all emission source categories between 2017 and 2020 inventories due to methodology advances. Therefore, 2017 emissions have been recalculated to incorporate the latest 2020 methodology to provide a valid basis for comparison. The 2017 emissions included in this report will not match the emissions in the 2017 EI report because of the recalculation. The methodology changes include EPA's MOVES3, which is used for several of the source categories, and Port EI Guidance Document[22] which provided emission factors and load factors for OGV and commercial harbor craft. 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 2020 compared to 2017, including recreational vessels. Overall emissions are higher in 2020 as compared to 2017 for most pollutants, except particulate matter and VOC. VOC emissions are lower in 2020 due the recreational vessel emissions change.

**Table 8.1: 2017-2020 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 |
|---|---|---|---|---|---|---|---|---|
| 2017 | 3,913 | 113 | 106 | 65 | 1,544 | 7,506 | 117 | 380,289 |
| 2020 | 4,306 | 114 | 107 | 72 | 1,239 | 7,680 | 140 | 437,403 |
| **Change** | **393** | **1** | **1** | **6** | **-305** | **174** | **23** | **57,114** |
| **Change (%)** | **10%** | **1%** | **1%** | **10%** | **-20%** | **2%** | **19%** | **15%** |

Table 8.2 provides a comparison of cargo volumes in short tons and barrels between 2017 and 2020. Compared to 2017, cargo in short tons was up by 56% and cargo in barrels was up 59% due to the significant growth seen at the Port between 2017 and 2020.

**Table 8.2: 2017-2020 Cargo Volumes Comparison**

| Year | Cargo (short tons) | Cargo (barrels) |
|---|---|---|
| 2017 | 102,391,848 | 608,524,933 |
| 2020 | 159,713,040 | 968,280,326 |
| **Change (%)** | **56%** | **59%** |

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

Table 8.3 provides the emissions comparison for the sources tied to cargo volume, without including recreational vessels. When not including the recreational vessels, the overall emissions are higher in 2020 as compared to 2017. The increase in emissions is mainly due to more tanker activity, increased harbor craft and cargo handling equipment activity. Locomotive and truck emissions are lower in 2020 as compared to 2017 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 despite the significant 56%-59% increase in cargo, emissions are 8% and 20% higher across the board.

**Table 8.3: 2017-2020 Emissions Comparison by Source Category, tons, metric tons and %**

| | NOx tons | PM10 tons | PM2.5 tons | DPM tons | VOC tons | CO tons | SOx tons | CO2e MT |
|---|---|---|---|---|---|---|---|---|
| **2017** | | | | | | | | |
| Ocean-going vessels | 1,744 | 43 | 40 | 20 | 56 | 153 | 114.5 | 173,619 |
| Commercial harbor craft | 1,199 | 28 | 28 | 28 | 29 | 229 | 0.9 | 84,877 |
| Cargo handling equipment | 18 | 2 | 2 | 2 | 3 | 8 | 0.0 | 1,689 |
| Locomotives | 443 | 11 | 11 | 11 | 19 | 105 | 0.4 | 36,638 |
| Heavy-duty vehicles | 77 | 3 | 3 | 3 | 4 | 30 | 0.1 | 19,258 |
| **Total** | **3,480** | **88** | **83** | **65** | **112** | **524** | **116** | **316,080** |
| **2020** | | | | | | | | |
| Ocean-going vessels | 2,187 | 53 | 48 | 28 | 73 | 201 | 137.5 | 208,491 |
| Commercial harbor craft | 1,217 | 29 | 28 | 29 | 30 | 303 | 1.1 | 107,964 |
| Cargo handling equipment | 20 | 3 | 3 | 3 | 2 | 6 | 0.0 | 2,544 |
| Locomotives | 387 | 9 | 9 | 9 | 15 | 100 | 0.4 | 34,903 |
| Heavy-duty vehicles | 45 | 1 | 1 | 1 | 2 | 20 | 0.1 | 13,491 |
| **Total** | **3,856** | **96** | **90** | **71** | **122** | **629** | **139** | **367,393** |
| **Change between 2017 and 2020 (percent)** | | | | | | | | |
| Ocean-going vessels | 25% | 22% | 21% | 38% | 29% | 31% | 20% | 20% |
| Commercial harbor craft | 2% | 3% | 3% | 4% | 0% | 32% | 27% | 27% |
| Cargo handling equipment | 14% | 39% | 39% | 39% | -21% | -17% | 38% | 51% |
| Locomotives | -13% | -17% | -17% | -17% | -20% | -5% | -5% | -5% |
| Heavy-duty vehicles | -42% | -48% | -48% | -48% | -39% | -34% | -31% | -30% |
| **Total** | **11%** | **9%** | **8%** | **10%** | **9%** | **20%** | **20%** | **16%** |

The following subsections explain the various fleet and activity changes by source category that impacted the emissions for 2020 as compared to 2017.

## 8.1 Ocean-going Vessels

Total energy consumption (in terms of kW-hr) by OGV emission sources for 2017 and 2020 are shown in Table 8.4. There was a 23% increase in total OGV energy consumption in 2020 as compared to 2017. The main engine and auxiliary boiler energy consumption increased by 7%, while the auxiliary engine energy consumption increased by 51%. The significant auxiliary engine energy consumption increase is due to larger tankers spending more time at berth.

**Table 8.4: 2017-2020 OGV Energy Consumption Comparison by Emissions Source, kW-hr**

| Year | All Emission Sources | Main Engine | Auxiliary Engine | Boiler |
|---|---|---|---|---|
| 2017 | 207,645,380 | 29,497,833 | 74,332,340 | 103,815,207 |
| 2020 | 254,949,067 | 31,435,571 | 112,085,968 | 111,427,528 |
| **Change (%)** | **23%** | **7%** | **51%** | **7%** |

In 2020, the number of shifts was 54% lower, while the arrivals are 15% higher as compared to 2017.

**Table 8.5: 2013-2017 OGV Movements**

| Year | Arrivals | Departures | Shifts | Total |
|---|---|---|---|---|
| 2017 | 1,863 | 1,715 | 951 | 4,529 |
| 2020 | 2,143 | 2,070 | 441 | 4,654 |
| **Change** | **280** | **355** | **-510** | **125** |
| **Change (%)** | **15%** | **21%** | **-54%** | **3%** |

Table 8.6 provides a comparison of the engine tier distribution for OGV. In 2020, there were vessels with Tier III engines and the percent of Tier II vessels increased. The newer engines have lower $NO_x$ emission standards.

**Table 8.6: 2017-2020 OGV Propulsion Engine Tier Comparison**

| Year | Tier 0 | Tier I | Tier II | Tier III |
|---|---|---|---|---|
| 2017 | 8% | 57% | 26% | 0% |
| 2020 | 3% | 49% | 42% | 6% |

The OGV emissions for 2017 were recalculated in 2020 due to methodology changes occurred since the publication of the 2017 EI report. The latest methodology described in the OGV section follows the EPA Ports Emissions Inventory Guidance published in 2020.

Table 8.7 provides the OGV emissions comparison by engine type. Hotelling times increased in 2020 which is reflected in the increased activity and emissions for auxiliary engines which are used at berth. In 2020, there were more VLCCs, and these very large tankers spent more time at berth in 2020 than in 2017.

**Table 8.7: 2017-2020 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 |
|---|---|---|---|---|---|---|---|---|
| **2017** | | | | | | | | |
| Main Engines | 535 | 5 | 4 | 5 | 12 | 39 | 12 | 18,644 |
| Auxiliary Engines | 983 | 16 | 14 | 16 | 33 | 91 | 35 | 52,664 |
| Boilers | 226 | 23 | 21 | 0 | 11 | 23 | 67 | 102,311 |
| **Total** | **1,744** | **43** | **40** | **20** | **56** | **153** | **114** | **173,619** |
| **2020** | | | | | | | | |
| Main Engines | 583 | 4 | 4 | 4 | 11 | 40 | 13 | 19,787 |
| Auxiliary Engines | 1,361 | 23 | 21 | 23 | 49 | 136 | 52 | 79,008 |
| Boilers | 242 | 25 | 23 | 0 | 12 | 25 | 72 | 109,696 |
| **Total** | **2,187** | **53** | **48** | **28** | **73** | **201** | **138** | **208,491** |
| **Change between 2017 and 2020 (percent)** | | | | | | | | |
| Main Engines | 9% | -3% | -3% | -4% | -8% | 2% | 6% | 6% |
| Auxiliary Engines | 38% | 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| Boilers | 7% | 7% | 7% | 0% | 7% | 7% | 7% | 7% |
| **Total** | **25%** | **21%** | **21%** | **38%** | **29%** | **31%** | **20%** | **20%** |

## 8.2 Commercial Harbor Craft

As shown in Table 8.8, the harbor craft overall energy consumption (as measured by kilowatt hours) increased by 27% from 2017 to 2020, resulting in the emissions increase. The average vessel maneuvering time used to calculate the tugboat activity decreased by 10% in 2020 as compared to 2017.

**Table 8.8: 2017-2020 Commercial Harbor Craft Energy Consumption Comparison and Vessel Maneuvering Time**

| Year | Activity (kW-hr) | Maneuvering Time |
|---|---|---|
| 2017 | 123,018,870 | 2.63 |
| 2020 | 156,592,985 | 2.37 |
| **Change** | **33,574,114** | **-0.26** |
| **Change (%)** | **27%** | **-10%** |

The harbor craft emissions for 2017 were recalculated using the 2020 methodology due to methodology updates that occurred since the publication of the 2017 EI report. The methodology described in the harbor craft section of this report was used for both the 2017 and 2020 emissions calculations. The emission factors and load factors changed due to using the latest factors included in the EPA Ports EI Guidance document.

Table 8.9 shows the Tier distribution comparison based on vessel activity. It shows that in 2020, vessels with cleaner engines are being used more than in 2017. This contributed to the emissions being lower in 2020 than in 2017 despite the increase in activity as shown in Table 8.10.

**Table 8.9: 2017-2020 Commercial Harbor Craft Activity Tier Distribution, %**

| Tier | 2017 | 2020 |
|---|---|---|
| Tier 0 | 58% | 43% |
| Tier 1 | 4% | 7% |
| Tier 2 | 32% | 22% |
| Tier 3 | 6% | 10% |
| Tier 4 | 0% | 18% |

Table 8.10 shows the harbor craft emissions comparison. The commercial harbor craft emissions were higher in 2020 as compared to 2017. The increase in emissions is due to the higher activity in 2020 and lack of emission control standards for $CO_2$. The increase in CO emissions is related to an increase in Tier 2 and Tier 3 engine usage that have higher CO emission rates compared to pre-Tier 2 engines. Due to newer fleet mix and usage in 2020, the $NO_x$ and PM emissions did not increase as much for the other pollutants. The $SO_x$ and $CO_2e$ emissions increased at same rate as the activity increase.

**Table 8.10: 2017-2020 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 |
|---|---|---|---|---|---|---|---|---|
| 2017 | 1,199 | 28.5 | 27.6 | 28.3 | 29.5 | 229 | 0.85 | 84,877 |
| 2020 | 1,217 | 29.3 | 28.4 | 29.3 | 29.6 | 303 | 1.08 | 107,964 |
| **Change** | **18** | **0.8** | **0.8** | **1.0** | **0.1** | **74** | **0.23** | **23,087** |
| **Change (%)** | **2%** | **3%** | **3%** | **4%** | **0.4%** | **32%** | **27%** | **27%** |

Recreational vessels for San Patricio and Nueces counties were also included in the inventory. Table 8.11 shows the comparison of emissions for recreational vessels. The vessel count increased in 2020 by 9% as compared to 2017.

**Table 8.11: 2017-2020 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 |
|---|---|---|---|---|---|---|---|---|---|
| 2017 | 11,427 | 432 | 25 | 23 | 0.8 | 1,432 | 6,982 | 1.2 | 64,209 |
| 2020 | 12,507 | 450 | 19 | 17 | 0.9 | 1,117 | 7,051 | 0.5 | 70,010 |
| **Change** | **1,080** | **18** | **-6** | **-6** | **0.1** | **-315** | **69** | **-0.7** | **5,801** |
| **Change (%)** | **9%** | **4%** | **-25%** | **-25%** | **7%** | **-22%** | **1%** | **-61%** | **9%** |

## 8.3 Cargo Handling Equipment

As shown in Table 8.12, for cargo handling equipment, the overall energy consumption (as measured by horsepower hours) increased 54% due to increased hours of engine use and 31% more equipment in 2020 as compared to 2017. Table 8.13 shows the Tier distribution comparison based on equipment count.

**Table 8.12: 2017-2020 CHE Energy Consumption Comparison and Equipment Count**

| Year | Activity (hp-hr) | Diesel Equipment Count |
|---|---|---|
| 2017 | 2,254,343 | 83 |
| 2020 | 3,462,623 | 109 |
| **Change** | **1,208,280** | **26** |
| **Change (%)** | **54%** | **31%** |

**Table 8.13: 2017-2020 CHE Discrete Count Tier Distribution**

| | 2017 | 2020 |
|---|---|---|
| Tier 0 | 12% | 13% |
| Tier 1 | 10% | 6% |
| Tier 2 | 18% | 6% |
| Tier 3 | 14% | 16% |
| Tier 4 interim | 22% | 22% |
| Tier 4 final | 20% | 28% |
| Unknown | 4% | 10% |

CHE emissions for 2017 were re-calculated using the latest model, MOVES3. Table 8.14 shows the cargo handling equipment emissions comparison. Except for VOC and CO, the 2020 emissions are higher than in 2017 due to more equipment and increased activity. Due to increased use of cleaner equipment, the increase in all criteria pollutant is less than the overall increase in usage expressed in hp-hr.

**Table 8.14: 2017-2020 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 |
|---|---|---|---|---|---|---|---|---|
| 2017 | 17.5 | 2.2 | 2.1 | 2.2 | 2.6 | 7.7 | 0.006 | 1,689 |
| 2020 | 20.2 | 3.0 | 2.9 | 3.0 | 2.0 | 6.4 | 0.009 | 2,544 |
| **Change** | **2.7** | **0.8** | **0.8** | **0.8** | **-0.6** | **-1.3** | **0.002** | **855** |
| **Change (%)** | **15%** | **39%** | **39%** | **39%** | **-21%** | **-17%** | **38%** | **51%** |

### 8.4 Railroad Locomotives

Table 8.15 shows the line haul locomotive activity in million gross ton-miles (GTM) of cargo moved in 2017 and 2020 which shows a 4% reduction in 2020 for line haul activity as compared to 2017.

**Table 8.15: 2017-2020 Rail Locomotive Activity**

| Year | Million GTM |
|---|---|
| 2017 | 3,487 |
| 2020 | 3,360 |
| **Change (%)** | **-4%** |

The locomotive emissions for 2017 were recalculated because UP found they had over-reported their tonnage figures when providing information for the 2017 emissions inventory, and to account for a different data source for the line haul fuel consumption rate. This recalculation lowered the estimated 2017 emissions but there was still a decrease in 2020 for line haul emissions. However, switching emissions increased because of more local activity. The overall decrease in locomotive emissions is due to the line haul emissions decrease in 2020. The emission factors for line haul from EPA reflect a cleaner fleet which may partly account for the line haul emissions decrease. Activity is also a factor and there was an estimated 4% decrease in freight movements measured as gross ton-miles in 2020 compared with 2017. This decrease may have partly resulted from the completion of pipeline projects which reduced the need for tanker railcars to move bulk liquids, and partly from increased rail efficiency. The combined decreased activity, continued efficiency improvements and fleet turnover to newer, cleaner line haul locomotives serving the area led to the significant emissions decrease in 2020.

**Table 8.16: 2017-2020 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 |
|---|---|---|---|---|---|---|---|---|
| 2017 | 443 | 11.3 | 11.3 | 11.3 | 19.3 | 105 | 0.41 | 36,638 |
| 2020 | 387 | 9.3 | 9.3 | 9.3 | 15.4 | 100 | 0.39 | 34,903 |
| **Change** | **-56** | **-2.0** | **-2.0** | **-2.0** | **-3.9** | **-5** | **-0.02** | **-1,735** |
| **Change (%)** | **-13%** | **-18%** | **-17%** | **-18%** | **-20%** | **-5%** | **-5%** | **-5%** |

It should be noted that switching activity and emissions were higher in 2020 but overall emissions were lower for the locomotives category due to the line haul activity and emissions being lower in 2020.

## 8.5 Heavy-duty Vehicles

Table 8.17 compares the heavy-duty vehicles count and vehicle miles traveled for 2017 and 2020. In 2020, the truck count decreased by 28% and vehicle miles traveled decreased by 27%. This decrease is mainly due to the completion of pipeline projects that reduced the need for tanker trucks and the closing of a grain terminal that eliminated grain truck trips. The 2017 truck counts and VMT are different in this report from what was published in the 2017 EI report due to improved truck call data on two bulk terminals. The default used in 2017 was changed to a better estimate provided by the terminal in 2020 in order to compare the two years.

**Table 8.17: 2017-2020 HDV Count and Vehicle Miles Traveled**

| Year | Truck Count | Truck VMT |
|---|---|---|
| 2017 | 256,363 | 9,971,182 |
| 2020 | 185,409 | 7,237,209 |
| **Change (%)** | **-28%** | **-27%** |

The HDV emissions for 2017 were recalculated using MOVES3. Table 8.18 shows the emissions comparison for heavy-duty vehicles. The 2020 heavy-duty vehicle emissions decreased compared to 2017 due to fewer truck trips and vehicle miles traveled. In addition, emissions of criteria pollutants decreased more than the decrease in VMT due to fleet turnover to newer, cleaner trucks.

**Table 8.18: 2017-2020 HDV 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 |
|---|---|---|---|---|---|---|---|---|
| 2017 | 77 | 2.8 | 2.6 | 2.8 | 3.9 | 29.7 | 0.08 | 19,258 |
| 2020 | 45 | 2 | 1 | 2 | 2 | 20 | 0.06 | 13,491 |
| **Change** | **-32** | **-1.3** | **-1.2** | **-1.3** | **-1.5** | **-10.1** | **-0.03** | **-5,767** |
| **Change (%)** | **-42%** | **-47%** | **-46%** | **-47%** | **-39%** | **-34%** | **-31%** | **-30%** |

## SECTION 9 CONCLUSION AND RECOMMENDATIONS

Between 2017 and 2020, the Port of Corpus Christi continued to see significant growth. Cargo throughput increased by 56% in short tons and 59% in barrels over the period. During that period several port expansion projects were completed, including additional liquid bulk export infrastructure, VLCC capable facilities, new LNG docks, completion of new natural gas and liquid bulk pipelines, the expanded the Corpus Christi Ship Channel, and starting construction for the Harbor Bridge.

Despite the significant increase in throughput since 2017, the 2020 emissions increased 5% for $NO_x$ emissions and 10% for $CO_2e$ (GHG) emissions as compared to 2017 for all pollutants. The emission increase in 2020 are mainly due to the larger tankers calling the Port in larger numbers. But the overall emissions remained relatively lower than expected with lower particulate matter emissions due to lower locomotive and truck activity, in addition to cleaner fleet for the commercial harbor craft, locomotives and trucks.

### 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 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 86% of the $NO_x$ emissions for total ocean-going vessel emissions at the Port in 2020. 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, pushboat, 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 Christ 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. Based on the first half of 2021 which set a new tonnage record and increased 5% from the same period in 2020, we expect to continue seeing increased total emissions in the near future. Specifically, we expect $NO_x$ and $CO_2e$ emissions to increase in the future as compared to previous year emissions. We also expect larger tankers to continue to call the Port, 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 and new terminal operations. While the dredging will allow tankers to load more oil, effectively adding tonnage without increasing vessel calls, the actual number of vessel trips may still increase until the export terminals near capacity at some point in the future, depending on market conditions. Some technologies and emission reduction strategies the Port may study to reduce vessel emissions in the future include: 1) the use of LNG fuel for propulsion and auxiliary engines, 2) the use of capture and control system while vessels are at berth to reduce at-berth emissions, and 3) automated mooring technology which improves operation efficiency and lowers maneuvering and hoteling time at berth. Additionally, the Port may want to do 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, especially as it pertains to the at-berth emissions, especially for LNG vessels, which are relatively new to the Port. Other ports conduct vessel programs to better understand the specific vessel fleet that call their berths. The study would entail interviews with tanker companies through phone and email correspondence and not necessarily include in-person or on-board interviews.

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 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 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[23] 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.[24] 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

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

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

[23] EPA, *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data,* February 2000
[24] 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[25]**

| 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

[25] 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

$$\boldsymbol{Ei = Energy \times EF \times EFA \times LAFi \times FCF \times CF}$$

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 |