2017 AIR EMISSIONS INVENTORY

PORT CORPUS CHRISTI®

Prepared by:

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

September 2019

Port of Corpus Christi Authority
2017 Air Emissions Inventory

Prepared for:

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ACRONYMS AND ABBREVIATIONS

AIS	automatic information system
ATB	articulated tug and barge
BNSF	Burlington Northern Santa Fe Railway
BSFC	brake specific fuel consumption
CF	control factor
CHE	cargo handling equipment
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CCTR	Corpus Christi Terminal Railroad
D	distance
DF	deterioration factor
DPM	diesel particulate matter
DR	deterioration rate
DWT	deadweight tonnage
E	emissions
ECA	Emission control area (as designated by the International Maritime Organization)
EEAI	Energy and Environmental Analysis, Inc.
EF	emission factor
EI	emissions inventory
EPA	U.S. Environmental Protection Agency
FCF	fuel correction factor
g/bhp-hr	grams per brake horsepower-hour
g/hr	grams per hour
g/kW-hr	grams per kilowatt-hour
g/mi	grams per mile
GIS	geographic information system
GHG	greenhouse gas
GWP	global warming potential
HC	hydrocarbons
HDV	heavy-duty vehicle
HFO	heavy fuel oil
hp	horsepower
hrs	hours
IFO	intermediate fuel oil
IMO	International Maritime Organization
ITB	integrated tug and barge

KCS	Kansas City Southern (rail company)
kW	kilowatt
kW-hr	kilowatt hour
lbs/day	pounds per day
LF	load factor
LLA	low load adjustment
Lloyd's	Historical name for marine vessel data licensed from IHS Markit
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MCR	maximum continuous rating
MDO	marine diesel oil
MGO	marine gas oil
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
RO	residual oil
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 2017 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 2017, and to compare those emissions to both the baseline 2013 Emissions Inventory that was completed in 2015 and to total emissions within the two-county area. The emissions inventory is the foundation or baseline for other activities such as air quality analysis and strategy development; this 2017 calendar year update study is the first comparison to the 2013 calendar year baseline. The Port of Corpus Christi underwent significant expansion and growth between 2013 and 2017, a process that continues to date. The comparison of 2017 emissions with emissions in 2013 and in the two-county area in 2017 will assist the Port staff in understanding how the 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 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 below described 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)
    - Carbon dioxide equivalent (CO_2e)

Emission factors for most of the source categories in this study are available for total hydrocarbons rather than VOCs. In these instances where only hydrocarbon emission factors are available, a conversion factor of 1.053 was used to convert the hydrocarbon emission estimates to VOCs.[2] The major exception is heavy-duty vehicle emission factors which were obtained for VOCs from the EPA emission estimating model MOVES2014b.

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[3] 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 2017. To the extent practicable, the emission estimates are based on activities that occurred during this period. If information specific to 2017 was not available, reasonable estimates of operational characteristics were developed. These cases are identified in the text for each 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. See: *www.epa.gov/otaq/toxics.htm*
[2]U.S. EPA, Conversion Factors for Hydrocarbon Emission Components. EPA-420-R-10-015. July 2010
[3]U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017*, April 2015.

1.3 Geographical Domain

An overview of the geographical extent for each of the source categories is provided below. Table 1.1 lists the terminals that are included in this inventory. Each terminal may have one or more of the source categories associated with emissions. Both public and private terminals were included in this inventory.

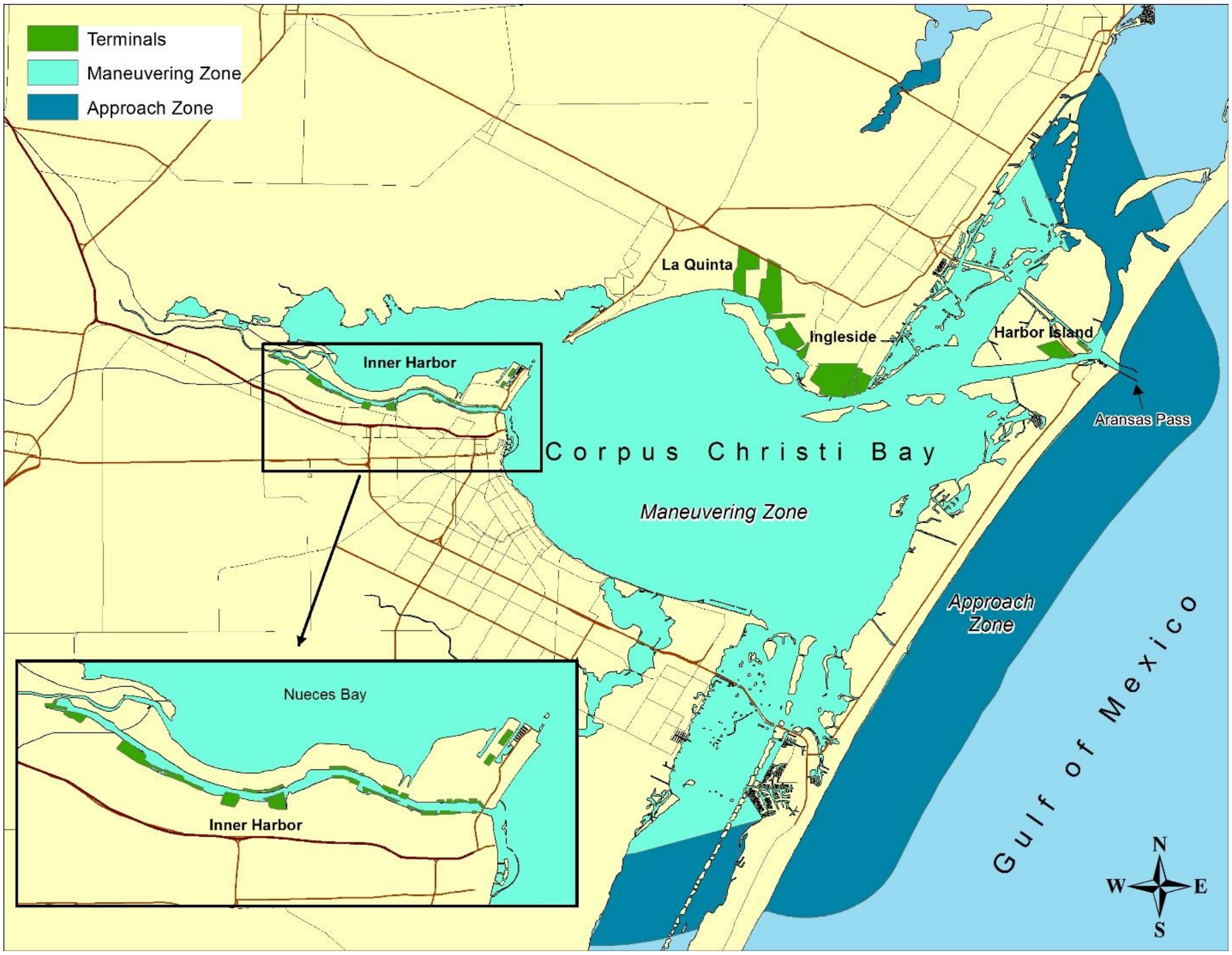
Table 1.1: List of Terminals

Name	Location	Type	Name	Location	Type
Gulf Copper	Harbor Island	Bulk Materials	Public Oil Docks (1-12, 14, 15)	Inner Harbor	Bulk Liquid
Martin Partners	Harbor Island	Bulk Liquid	POCCA Bulk Docks (1,2)	Inner Harbor	Bulk Materials
ADM/Growmark	Inner Harbor	Bulk Materials	POCCA Cargo Docks (8,9)	Inner Harbor	Bulk Materials
Bulk Terminal Docks (1,2)	Inner Harbor	Bulk Materials	Fordyce Co.	Inner Harbor	Mooring
Cemex USA	Inner Harbor	Bulk Materials	G&H Towing	Inner Harbor	Mooring
Interstate Grain	Inner Harbor	Bulk Materials	US Coast Guard	Inner Harbor	Mooring
Vulcan Materials	Inner Harbor	Bulk Materials	J. Bludworth	Inner Harbor	Dry Dock
Bay Inc	Inner Harbor	Dry Cargo	Gulf Marine Fab.	Ingleside	Dry Cargo
Heldenfels	Inner Harbor	Dry Cargo	Flint Ingleside (4,5)	Ingleside	Bulk Liquid
Public Cargo Dock 9	Inner Harbor	Dry Cargo	Oxychem	Ingleside	Bulk Liquid
Public Cargo Docks (8,14,15)	Inner Harbor	Dry Cargo	Voestalpine	La Quinta	Bulk Liquid
Texas Leigh Cement	Inner Harbor	Dry Cargo	Cheniere	La Quinta	Bulk Liquid
Trafigura Texas Dock and Rail	Inner Harbor	Dry Cargo	Oxychem	Ingleside	Bulk Liquid
Buckeye (1-5)	Inner Harbor	Bulk Liquid	Oxychem	La Quinta	Bulk Liquid
Citgo Docks (1-3, 6-8)	Inner Harbor	Bulk Liquid	Sherwin Alumina Co.	La Quinta	Bulk Materials
Equistar/Lyondell Basell	Inner Harbor	Bulk Liquid	Helix Energy Solutions	La Quinta	Dry Cargo
Flint Hills Docks (1-3)	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

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. 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.

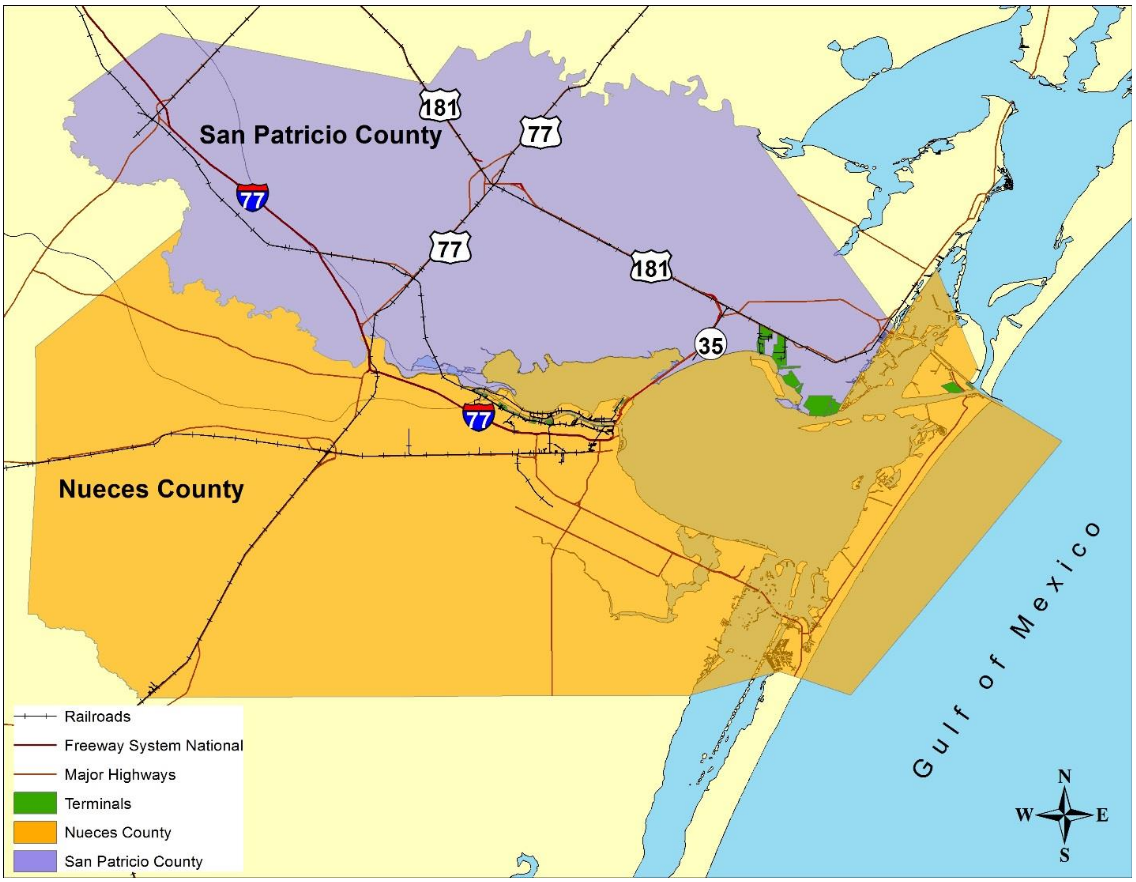
Figure 1.1: Marine-side Geographical Domain



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 for maritime-related mobile sources in the 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. The commercial harbor craft and recreational vessel emissions are listed separately. As discussed in Section 1, the CO_2e emissions are presented in tonnes rather than short tons and have been calculated using the GWP values listed in Section 1.

Table 2.1: 2017 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	1,817	47	44	27	59	160	125	179,058
Commerical harbor craft	1,211	40	37	40	37	351	3	75,853
Recreational vessels	461	25	25	1	1,419	6,982	0	64,130
Cargo handling equipment	15	1	1	1	2	6	0	2,381
Rail locomotives	628	16	16	16	28	145	1	50,618
Heavy-duty vehicles	94	5	4	5	5	24	0	24,575
Total	**4,226**	**134**	**127**	**90**	**1,550**	**7,668**	**129**	**396,615**

Between 2013 and 2017, the Port of Corpus Christi saw significant growth in cargo volume and moved up in port size rankings. During that period several expansion projects were completed, and new terminals commenced operations. In addition, cargo throughput increased by 15% in short tons and 19% in barrels over the period, as illustrated in Table 2.2.

Table 2.2: Cargo Volume Comparison

Year	Cargo (short tons)	Cargo (barrels)
2013	88,699,848	511,703,921
2017	102,391,848	608,524,933
Change (%)	**15%**	**19%**

The 2013 vs 2017 comparison of maritime-related emissions is summarized in Table 2.3. Despite the double digit increase in cargo volume (15%-19%), emissions were reduced significantly for most pollutants, except for NO_x and GHG emissions (as CO_2e). The PM, DPM and SO_x emissions are lower in 2017 primarily due to the use of lower sulfur content fuel by ocean-going vessels in compliance with the North American Emission Control Area (ECA). The use of lower sulfur fuel by ocean going vessels does not reduce NO_x emissions at the same level as the PM, DPM and SO_x emissions. The NO_x emissions are higher in 2017 due to a different vessel fleet as compared to vessels calling 2013, different assist tug mix and increase in rail locomotive activity. There was no significant change in CO_2e emissions despite the increased activity.

Table 2.3: Maritime-related Emissions Comparison, 2013 vs 2017 Calendar Years

Year	NO_x	PM_{10}	$PM_{2.5}$	DPM	VOC	CO	SO_x	CO_2e
	tons	tons	tons	tons	tons	tons	tons	tonnes
2013	3,684	287	243	145	2,143	7,827	1,347	391,663
2017	4,226	134	127	90	1,550	7,668	129	396,615
Change	**542**	**-154**	**-116**	**-56**	**-594**	**-159**	**-1,218**	**4,952**
Change (%)	**15%**	**-54%**	**-48%**	**-38%**	**-28%**	**-2%**	**-90%**	**1%**

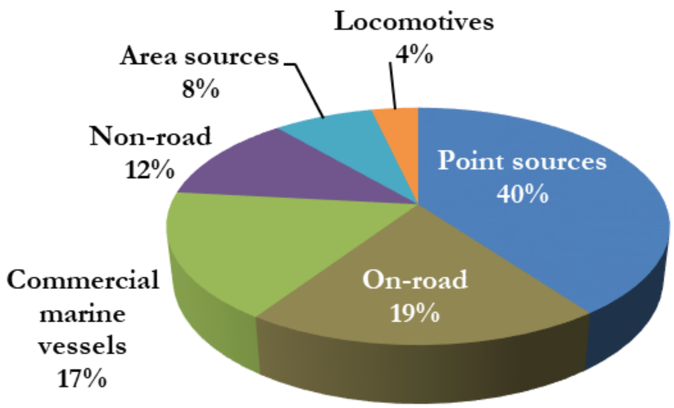
Part of the scope of this study was to obtain and summarize the TCEQ emissions inventory categories for air quality planning purposes. The TCEQ emission estimates for Nueces and San Patricio counties compiled from TCEQ public records are summarized in Table 2.4, which lists the emission source category, the latest inventory year, and the estimated emissions. Please note that the 2017 commercial marine vessel and locomotive emissions from this inventory were used in place of the 2017 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	PM_{10}	$PM_{2.5}$	VOC	CO	SO_2
			tons	tons	tons	tons	tons	tons
Point sources	2017	TCEQ	6,982	1,901	1,410	5,214	7,752	716.9
On-road	2017	TCEQ	3,394	258	109	1,545	19,746	24.8
Non-road	2017	TCEQ	2,103	167	159	1,181	10,839	41.8
Area sources	2017	TCEQ	1,340	26,658	3,829	9,811	1,464	63.2
Commercial marine vessels	2017	Starcrest	3,028	87	81	96	511	128
Locomotives	2017	Starcrest	628	16	16	28	145	0.6
Total			**17,475**	**29,086**	**5,605**	**17,873**	**40,457**	**975**

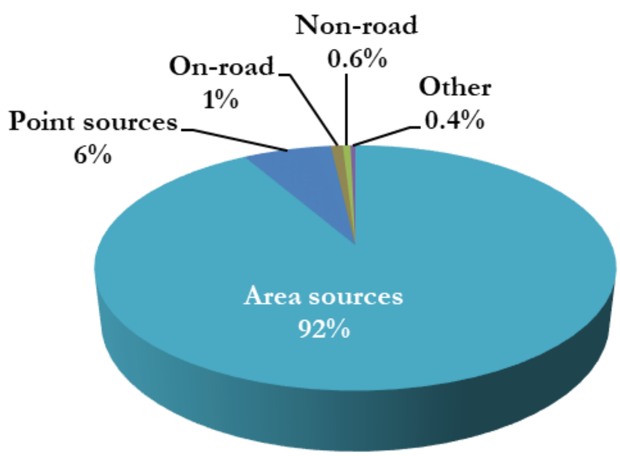
The pie charts in Figures 2.1 through 2.5 summarize the distribution of regional emissions for each of the pollutants in 2017. The percentage distribution of each source category varies by pollutant. Due to rounding, the percent values may not add up to 100%.

Figure 2.1: Regional NO_x Emissions Distribution



For Figure 2.2, "Other" includes commercial marine vessels and locomotives.

Figure 2.2: Regional PM_{10} Emissions Distribution



For Figures 2.3 and 2.4, "Other" includes commercial marine vessels and locomotives.

Figure 2.3: Regional VOC Emissions Distribution

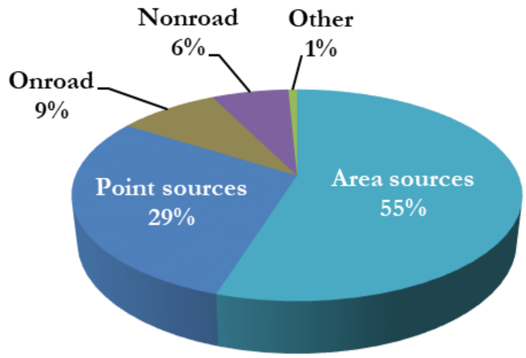


Figure 2.4: Regional CO Emissions Distribution

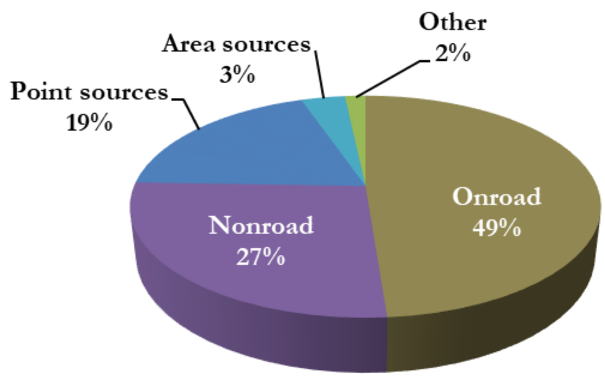
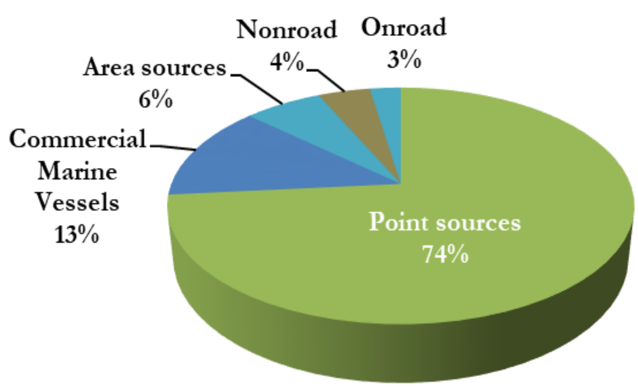


Figure 2.5: Regional SO_x Emissions Distribution



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 1,863 vessel calls to the Port in 2017. 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 2017:

- **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.
- **Roll-on roll-off vessel (RoRo)** – commonly known as RoRos, these vessels can accommodate vehicles and large wheeled equipment.
- **Tanker** –vessels that transport liquids in bulk, such as oil, chemicals, or other specialty goods such as molasses or asphalt. Tankers are classified based on their size.
- **Miscellaneous vessel** – includes various vessels that cannot be categorized under any of the other vessel type categories.

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 (70%) made up the majority of the calls, followed by bulk carriers (13%); ATB/ITB (12%); general cargo (5%); and other vessels (0.4%). In 2017, there were more tankers and less ATB/ITB as compared to 2013.

Figure 3.1: 2017 Distribution of Calls by Vessel Type

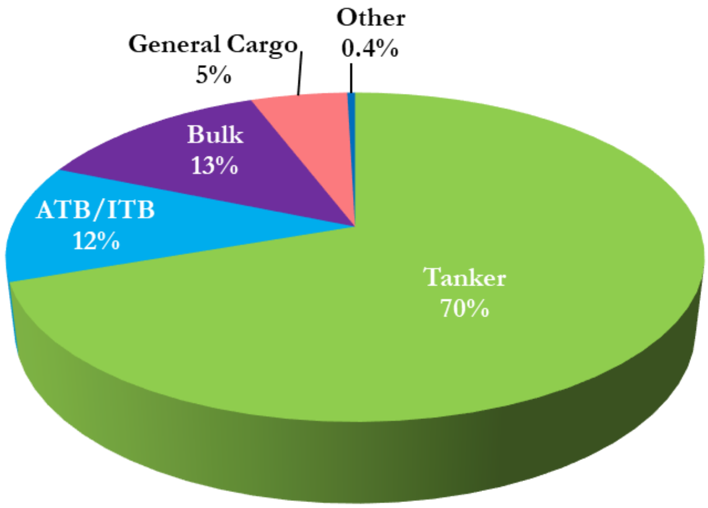


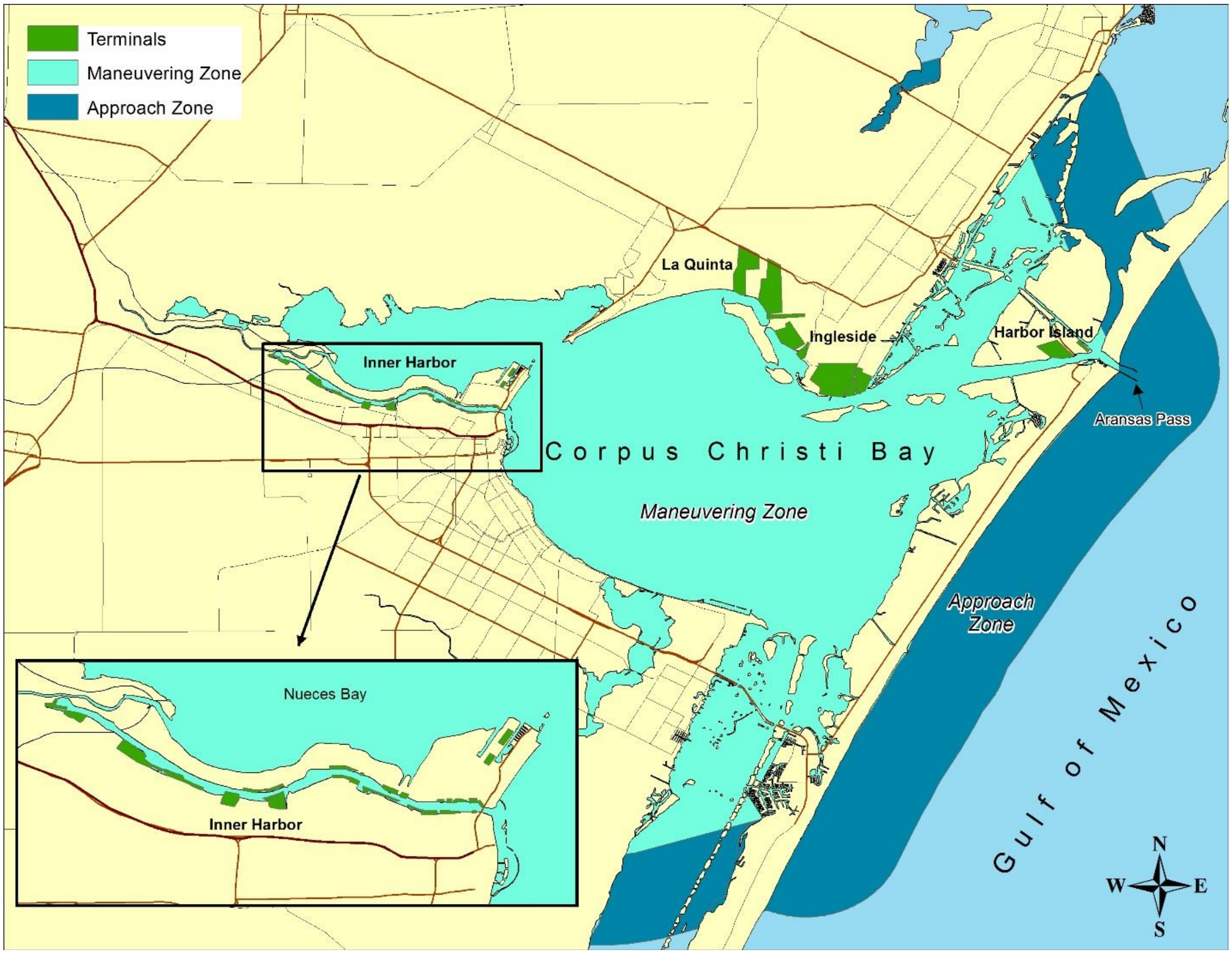
Table 3.1 presents the number of arrivals, departures, and shifts associated with the vessel types that called the Port in 2017. Other vessels in Figure 3.1 include auto carrier and RoRo.

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

Vessel Type	Arrivals	Departures	Shifts	Total
Auto Carrier	7	7	0	14
Bulk	221	212	98	531
Bulk - Heavy Load	6	5	2	13
Bulk - Self Discharging	14	14	0	28
General Cargo	100	97	13	210
ATB/ITB	216	205	486	907
RoRo	1	1	0	2
Tanker - Chemical	610	533	162	1305
Tanker - Asphalt	38	38	1	77
Tanker - LPG	1	1	0	2
Tanker - Handysize	189	183	49	421
Tanker - Aframax	287	268	86	641
Tanker - Panamax	73	61	24	158
Tanker - Suezmax	99	89	30	218
Tanker - VLCC	1	1	0	2
Total	**1,863**	**1,715**	**951**	**4,529**

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



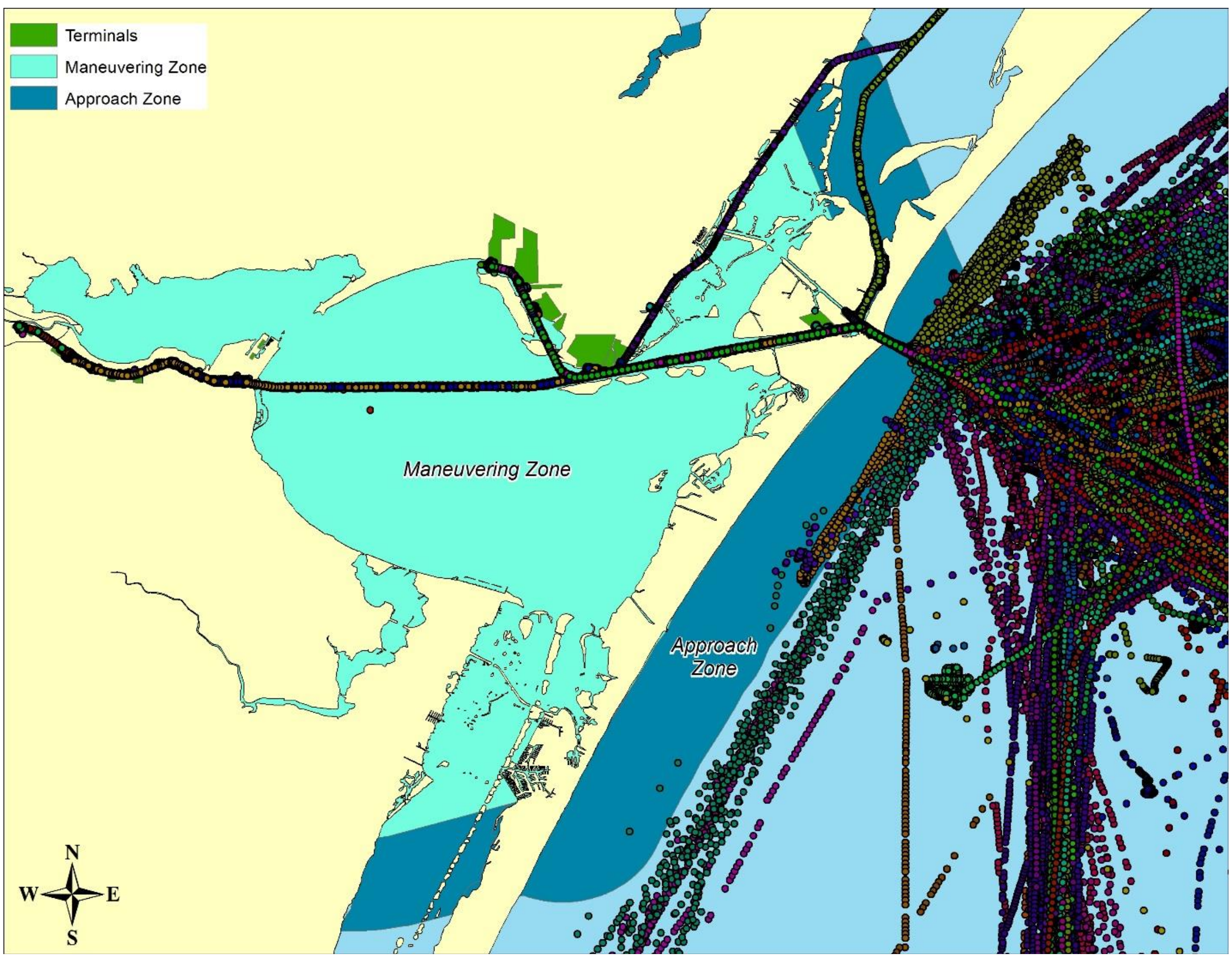
The OGV geographic domain is classified into operating zones for approaching and maneuvering activity. The approach zone extends three nautical miles from the shoreline into the Gulf of Mexico. Ships traveling in the approach zone are considered to be traveling in restricted waters as they are near the 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 processed to determine discrete vessel activity parameters including speed over water. 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. The Port also provided wharfinger data detailing vessel calls to terminals, which was used as a secondary data source to check the vessel activity resulting from AIS data processing.

AIS data points contain vessel specific geographical and temporal information including, but not limited to: IMO number, MMSI number, geographic coordinates, speed over water, heading, date, and time. Figure 3.3 shows a spatial representation of the AIS data collected for this inventory.

Figure 3.3: AIS Dataset



The AIS data was processed into vessel call activity through a combination of database processing and Geographic Information System (GIS) analysis. The processed AIS data provides vessel specific speed profiles and time spent operating in the approach and maneuvering zones, as well as hotelling time at a berth. Vessel activities listed in the wharfinger data were matched to activities generated from AIS data. When the AIS activity does not contain a trip listed in the wharfinger data, either due to a temporal AIS data gap or lack of AIS data for entire vessel activity, the wharfinger data was manually added to the AIS activity to complete a trip. Approximately 4% of the total vessel calls were gap-filled using the wharfinger data.

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 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. In addition to auxiliary engine and boiler loads VBP database includes, when available, data from the vessel specific International Maritime Organization (IMO) Engine International Air Pollution Prevention Certificate (EIAPP). For vessels with a valid propulsion engine EIAPP, the engine's actual NO_x emissions value (g/kW-hr) is used in place of the default NO_x emission factor, which is the same as the applicable engine's IMO Tier NO_x requirement.

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 provided by the Aransas Corpus Christi Pilots (the Pilots), 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 2017 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). For 2013 vessel emissions since, the assumption was that vessels' engines used heavy fuel oil with an average sulfur content of 1.0% per the ECA regulation applicable in 2013.

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 3.4.6, for auxiliary engines can be found in subsections 3.4.7 and 3.4.8, and for auxiliary boilers can be found in subsection 3.4.9. 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

Load factor for propulsion engines is estimated using the ratio of actual speed compared to the ship's maximum rated speed. Propulsion engine load factor is estimated using the Propeller Law, which shows that propulsion engine load, varies with the cube of vessel speed. Therefore, propulsion engine load at a given speed is estimated by taking the cube of that speed divided by the vessel's maximum speed, as illustrated by the following equation.

Equation 3.3

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

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, OGVs traveling in the maneuvering zone experience the phenomenon of "squat" in which the ships traveling in confined channels experience additional resistance moving through the channels in the zone. 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

$$\boldsymbol{LFx = LF + 10\%}$$

Where:

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

3.4.3 Propulsion Engine Activity

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

Equation 3.5

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

Where:

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

Distance and actual speeds are derived from AIS data point locations and associated over the water speed (discussed in Section 3.2).

3.4.4 Propulsion Engine Emission Factors

The main engine emission factors used in this study were reported in the ENTEC 2002 study,[4] except for PM, CO and greenhouse gas emission factors. An IVL Swedish Environmental Research Institute 2004 study[5] was the source for the PM emission factors for gas turbine and steamship vessels, as well as the CO and greenhouse gas emission factors for CO_2, and N_2O. Per IVL 2004 study data, CH_4 were assumed to be 0.2% of HC emission factors.

The main and auxiliary engine particulate matter (PM_{10}) and SO_x emission factors are based on the following equations[6] for heavy fuel oil (HFO) with 2.7% sulfur content:

Equation 3.6

$$\boldsymbol{PM_{10}\ EF\ \left(\frac{g}{kW} - hr\right) for\ HFO = 1.35 + BSFC\ x\ 7\ x\ 0.02247\ x\ (Fuel\ Sulfur\ Fraction - 0.0246)}$$

Where:

BSFC = brake specific fuel consumption in g/kW-hr

Equation 3.7

$$\boldsymbol{SO_2\ EF\ (g/kW - hr) = BSFC\ x\ 2\ x\ 0.97753\ x\ (Fuel\ Sulfur\ Fraction)}$$

Where:

0.97753 is the fraction of fuel sulfur converted to SO_2 and 2 is the ratio of molecular weights of SO_2 and S.

The base emission factors are based on HFO with average sulfur content of 2.7%. IMO has established NO_x emission standards for marine diesel engines.[7] 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

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.

All vessels calling the Port in 2017 were assumed to be compliant with the IMO North American ECA requirement to use 0.1% MDO/MGO sulfur content fuel. The emission factors were corrected using fuel correction factors (FCFs) from the baseline HFO 2.7% S to fuel using 0.1% sulfur content. The FCFs that were used are presented in Table 3.2. The lower sulfur content fuel used in 2017 compared to the 1% sulfur used in the 2013 inventory resulted in lower PM, NO_x and SO_x emissions in 2017.

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[4]ENTEC, *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report*, July 2002

[5]IVL, *Methodology for Calculating Emissions from Ships: Update on Emission Factors,* 2004. (IVL 2004)

[6]Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, Final Report, April 2009

[7]See: *www.dieselnet.com/standards/inter/imo.php*

Table 3.2: OGV Fuel Correction Factors

Actual Fuel Used Content	Sulfur Content by weight %	NO_x	PM	VOC	CO	SO_x	CO_2	N_2O	CH_4
MGO	0.1%	0.940	0.170	1.000	1.000	0.037	0.950	0.940	1.000

Table 3.3 list the baseline and adjusted emission factors for propulsion engines using 2.7% S and 0.1% sulfur, respectively.

Table 3.3: OGV Emission Factors for Diesel Propulsion, Steam (Boiler) Propulsion and Gas Turbine Engines, 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
2.7% S Fuel										
Slow Speed Main	1999 and older	18.1	1.42	1.14	0.60	1.40	10.29	620	0.031	0.012
Slow Speed Main	2000 to 2011	17.0	1.42	1.14	0.60	1.40	10.29	620	0.031	0.012
Slow Speed Main	2011 to 2016	15.3	1.42	1.14	0.60	1.40	10.29	620	0.031	0.012
Slow Speed Main	2016 and newer	3.6	1.42	1.14	0.60	1.40	10.29	620	0.031	0.012
Medium Speed Main	1999 and older	14.0	1.43	1.14	0.50	1.10	11.35	683	0.031	0.012
Medium Speed Main	2000 to 2011	13.0	1.43	1.14	0.50	1.10	11.35	683	0.031	0.012
Medium Speed Main	2011 to 2016	11.2	1.43	1.14	0.50	1.10	11.35	683	0.031	0.012
Medium Speed Main	2016 and newer	2.8	1.43	1.14	0.50	1.10	11.35	683	0.031	0.012
Gas Turbine	All	6.1	0.06	0.05	0.10	0.20	16.10	970	0.08	0.002
Steam Main and Boiler	All	2.1	0.93	0.74	0.10	0.20	16.10	970	0.080	0.002
0.1% S Fuel										
Slow Speed Main	1999 and older	17.0	0.24	0.19	0.60	1.40	0.38	589	0.029	0.012
Slow Speed Main	2000 to 2011	16.0	0.24	0.19	0.60	1.40	0.38	589	0.029	0.012
Slow Speed Main	2011 to 2016	14.4	0.24	0.19	0.60	1.40	0.38	589	0.029	0.012
Slow Speed Main	2016 and newer	3.4	0.24	0.19	0.60	1.40	0.38	589	0.029	0.012
Medium Speed Main	1999 and older	13.2	0.24	0.19	0.50	1.10	0.42	649	0.029	0.012
Medium Speed Main	2000 to 2011	12.2	0.24	0.19	0.50	1.10	0.42	649	0.029	0.012
Medium Speed Main	2011 to 2016	10.5	0.24	0.19	0.50	1.10	0.42	649	0.029	0.012
Medium Speed Main	2016 and newer	2.6	0.24	0.19	0.50	1.10	0.42	649	0.029	0.012
Gas Turbine	All	5.7	0.01	0.01	0.10	0.20	0.60	922	0.075	0.002
Steam Main and Boiler	All	2.0	0.16	0.13	0.10	0.20	0.60	922	0.075	0.002

3.4.5 Propulsion Engines Low Load Emission Factors

In general, diesel-cycle engines are less efficient when operated at low loads than at higher loads. An EPA study[8] 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 at slow speeds at sea (e.g. in the reduced speed zone.) While mass emissions, g/hr, tend to go down as vessel speeds and engine loads decrease, the emission factors, g/kW-hr increase.

The following equations describe the low-load effect where emission rates can increase, based on a limited set of data from Lloyd's Maritime Program and the USCG. The low load effect was also described in a study conducted for the EPA by ENVIRON.[9] Equation 3.8 is the equation developed by EEAI to generate emission factors for the range of load factors from 2% to <20% for each pollutant:

Equation 3.8

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

Where:

y = emissions, g/kW-hr
a = coefficient
b = intercept
x = exponent (negative)
fractional load = propulsion engine load factor (2% - <20%), derived by the Propeller Law, percent (see equation 3.3)

Table 3.4 presents the variables for equation 3.8.

Table 3.4: 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 3.5. In keeping with the 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

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

loads less than 20%. Low load emission factor adjustments do not apply to steamships or ships having gas turbines because the EPA study referenced above only observed an increase in emissions from diesel engines.

Table 3.5: Low Load Adjustment Multipliers for Emission Factors

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

Emission factors between engine loads 2% and 20% are calculated for each pollutant using Equation 3.9.

Equation 3.9

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

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

Emission factors for MAN 2-stroke propulsion (main) engines were adjusted at all engine loads range using test data from the San Pedro Bay Ports' (SPBP) *MAN Slide Valve Low-Load Emissions Test Final Report* (Slide Valve Test)[10] completed under the SPBP Technology Advancement Program (TAP) in conjunction with MAN and Mitsui. The following enhancements are incorporated when estimating emissions for vessels equipped with MAN 2 -stroke propulsion engines.

- 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 emissions test data collected at various engine loads 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%) instead of LLA described above. The LAF is pollutant based and varies based on engine valve (SV or C3). The equation for estimating emissions from MAN propulsion engine is:

Equation 3.10

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

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

[10]As referenced in the Emission Estimating Methodology and Enhancements Section.

Tables 3.6 and 3.7 present the LAFs used across the entire engine load range.

Table 3.6: 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 3.6 (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 3.6 (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 3.6 (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 3.7: 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 3.7 (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 3.7 (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 3.7 (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

3.4.6 Propulsion Engine Defaults

OGVs calling the Port were matched using the most current Lloyd's data and VBP information to determine main engine power ratings.

3.4.7 Auxiliary Engine Emission Factors

The ENTEC 2002 and IVL 2004 auxiliary engine emission factors used in this study are presented in Table 3.8. Similar to the propulsion engine emission factors, the 2.7% sulfur HFO base emission factors are multiplied by the appropriate pollutant FCF to calculate the 0.1% sulfur emission factors (see 3.4.4). PM_{10} and SO_x emission factors are based on equations 3.5 and 3.6 described in earlier sections. In 2017, per the IMO North American ECA requirement, it was assumed that auxiliary engines used 0.1% sulfur fuel.

Table 3.8: Emission Factors for Auxiliary Engines using 2.7% S and 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
2.7% S Fuel										
Medium Auxiliary	1999 and older	14.7	1.44	1.15	0.40	1.10	11.98	722	0.031	0.008
Medium Auxiliary	2000 to 2011	13.0	1.44	1.15	0.40	1.10	11.98	722	0.031	0.008
Medium Auxiliary	2011 to 2016	11.2	1.44	1.15	0.40	1.10	11.98	722	0.031	0.008
Medium Speed Main	2016 and newer	2.8	1.44	1.15	0.40	1.10	11.98	722	0.031	0.008
High Auxiliary	1999 and older	11.6	1.44	1.15	0.40	0.90	11.98	690	0.031	0.008
High Auxiliary	2000 to 2011	10.4	1.44	1.15	0.40	0.90	11.98	690	0.031	0.008
High Auxiliary	2011 to 2016	8.2	1.44	1.15	0.40	0.90	11.98	690	0.031	0.008
High Auxiliary	2016 and newer	2.1	1.44	1.15	0.40	0.90	11.98	690	0.031	0.008
0.1% S Fuel										
Medium Auxiliary	1999 and older	13.8	0.24	0.20	0.40	1.10	0.44	686	0.029	0.008
Medium Auxiliary	2000 to 2011	12.2	0.24	0.20	0.40	1.10	0.44	686	0.029	0.008
Medium Auxiliary	2011 to 2016	10.5	0.24	0.20	0.40	1.10	0.44	686	0.029	0.008
Medium Speed Main	2016 and newer	2.6	0.24	0.20	0.40	1.10	0.44	686	0.029	0.008
High Auxiliary	1999 and older	10.9	0.24	0.20	0.40	0.90	0.44	656	0.029	0.008
High Auxiliary	2000 to 2011	9.8	0.24	0.20	0.40	0.90	0.44	656	0.029	0.008
High Auxiliary	2011 to 2016	7.7	0.24	0.20	0.40	0.90	0.44	656	0.029	0.008
High Auxiliary	2016 and newer	2.0	0.24	0.20	0.40	0.90	0.44	656	0.029	0.008

3.4.8 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 visited and their sister ships. The Lloyd's database contains limited auxiliary engine's installed power information and information on use by mode, because neither the IMO nor the classification societies require vessel owners to provide this information. VBP data relating to auxiliary engine use is acquired by vessel type, by emission source, and by mode. When estimating auxiliary engine emissions, the following hierarchy is followed: VBP data if the vessel has been boarded, VBP data if the vessel is a sister to a boarded vessel, and average auxiliary engine load defaults derived from VBP data for other ports. Table 3.9 summarizes the auxiliary engine load defaults by mode used for this study by vessel subtype.

Table 3.9: Average Auxiliary Engine Load Defaults, kW

Vessel Type	Sea	Maneuvering	Berth Hotelling
Auto Carrier	503	1508	838
Bulk	255	675	150
Bulk - Heavy Load	255	675	150
Bulk - Self Discharging	305	807	179
General Cargo	516	1,439	722
ATB/ITB	79	208	102
RoRo	132	396	229
Tanker - Chemical	658	890	816
Tanker - Asphalt	500	750	500
Tanker - LPG	500	750	500
Tanker - Handysize	537	601	820
Tanker - Panamax	561	763	623
Tanker - Aframax	576	719	724
Tanker - Suezmax	860	1,288	2,509
Tanker - VLCC	1,080	1,486	1,171

3.4.9 Auxiliary Boiler Emission Factors and Load Defaults

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 3.10 shows the emission factors used for the auxiliary boilers based on ENTEC 2002 and IVL 2004 studies. Similar to the propulsion and auxiliary engine emission factors, the 2.7% sulfur HFO base emission factors are multiplied by the appropriate pollutant FCF to calculate the 1.0% sulfur HFO emission factors (see 3.4.4). In 2017, per IMO's North American ECA requirement, auxiliary boilers were assumed to use the 0.1% sulfur fuel.

Table 3.10: Emission Factors for OGV Auxiliary Boilers using 2.7% S and 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
2.7% S Fuel										
Steam Main and Boiler	All	2.1	0.93	0.74	0.10	0.20	16.10	970	0.080	0.002
0.1% S Fuel										
Steam Main and Boiler	All	2.0	0.16	0.13	0.10	0.20	0.60	922	0.075	0.002

The boiler fuel consumption data collected from vessels during the VBP was converted to equivalent kilowatts using specific fuel consumption (SFC) factors found in the ENTEC 2002 study. The average SFC value based on residual fuel is 305 grams of fuel per kW-hour. The average kW for auxiliary boilers was calculated using the following equation.

Equation 3.9

$$\boldsymbol{Average\ kW = ((daily\ fuel/24) \times 1{,}000{,}000)/305}$$

Where:

Average kW = average energy output of boilers, kW
daily fuel = boiler fuel consumption, tonnes per day

As with auxiliary engines, the primary source of load data is from the VBP, and direct values for vessels boarded are used on an individual basis for vessels boarded and their sister ships. For vessels not boarded nor have had any sister vessels boarded through the VBP, average loads are developed by class from the data available from the VBP program. The Lloyd's data does not include information on engine loads.

Auxiliary boiler energy defaults in kilowatts used for each vessel type are presented in Table 3.11. 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 to heat fuel for pumping. 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, while the higher boiler load listed in the table was used as a default for the tanker calls that were discharging cargo. The data showed that about 50% of the tanker calls were loading and the other 50% were unloading or discharging cargo.

Ocean-going tugboats do not have boilers; 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 shown in the table are used. These defaults are similar to the hotelling defaults, except for the tankers for the reason discussed above.

Table 3.11: Auxiliary Boiler Load Defaults, kW

Vessel Type	Sea	Maneuvering	Berth Hotelling
Auto Carrier	87	184	314
Bulk	35	94	125
Bulk - Heavy Load	35	94	125
Bulk - Self Discharging	132	132	132
General Cargo	56	124	160
ATB/ITB	0	0	0
RoRo	67	148	259
Tanker - Chemical	59	136	568
Tanker - Asphalt	100	200	1,000
Tanker - LPG	100	200	1,000
Tanker - Handysize	144	144	2,586
Tanker - Panamax	167	351	3,421
Tanker - Aframax	179	438	5,030
Tanker - Suezmax	144	191	5,843
Tanker - VLCC	240	720	6,000

3.4.10 Control Factors for Emission Reduction Technologies

Control factors are used to account for the emissions benefits associated with emission reduction technologies installed on vessels/engines. Besides the emission reduction due to IMO's North American ECA for lower sulfur fuel, there were no other emission reduction technologies identified with the OGVs calling the Port in 2017.

3.5 OGV Emission Estimates

The emission estimates presented in this document are listed in various ways to provide as much information to the reader as possible. The emissions are presented by vessel type, engine type, and operating mode. Due to rounding, not all totals in the tables may match the sum of the listed individual values. Table 3.12 through 3.14 show that tankers have the highest emissions and that the majority of the emissions occur during hoteling.

Table 3.12: 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	9	0.15	0.14	0.13	0.30	0.70	0.3	456
Bulk	137	2.48	2.34	1.99	3.80	11.50	5.7	8,191
General Cargo	89	1.80	1.69	1.64	2.90	8.10	3.6	5,092
ATB/ITB	74	1.40	1.31	1.40	2.60	6.30	2.5	3,505
RoRo	1	0.01	0.01	0.01	0.02	0.10	0.0	32
Tanker	1,507	40.90	38.37	21.92	49.40	133.20	113.0	161,782
Total	**1,817**	**46.74**	**43.86**	**27.09**	**59.02**	**159.90**	**125.1**	**179,058**

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

Emission Source	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Main Engines	558	6	6	6	13	42	14	19,301
Auxiliary Engines	1,013	21	20	21	34	93	38	53,525
Boilers	245	20	18	0	12	25	74	106,232
Total	**1,817**	**47**	**44**	**27**	**59**	**160**	**125**	**179,058**

Table 3.14: OGV Emissions of Criteria Pollutants by Operating Mode

Operating Mode	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Hotelling	1,136	38	36	18	42	107	107	152,947
Maneuvering	606	8	7	8	15	47	16	23,189
Transit	74	1	1	1	2	6	2	2,922
Total	**1,817**	**47**	**44**	**27**	**59**	**160**	**125**	**179,058**

SECTION 4 HARBOR VESSELS

This section presents emission estimates for the harbor vessels source category 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

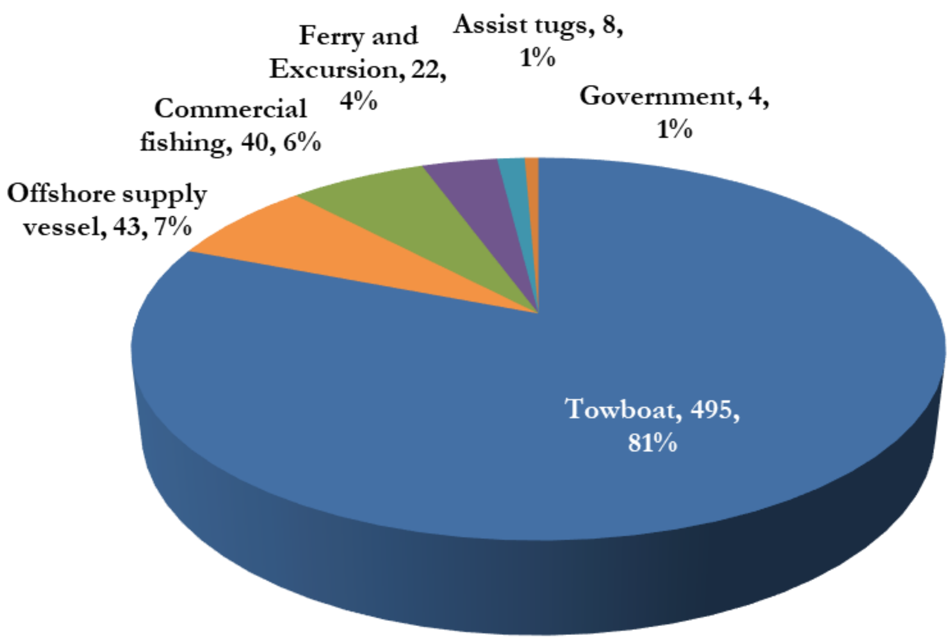
Emissions from the following types of diesel-fueled commercial harbor craft were quantified:

- **Commercial fishing vessels** – Commercial fishing vessels are vessels primarily engaged in commercial fishing.
- **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.
- **Offshore supply vessels** – These supply vessels make numerous trips back and forth from a terminal or home berth to the offshore platforms.
- **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 count and emissions are included in section 4.5.

Figure 4.1 presents the distribution of the 612 diesel fueled commercial harbor craft inventoried for the two counties in 2017. Recreational vessels are not included in this count since they are not considered commercial harbor craft and are reported separately. Towboats make up 81% of the commercial harbor craft inventoried.

Figure 4.1: 2017 Distribution of Commercial Harbor Craft



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 2017. Averages of the model year, horsepower, or operating hours are used as default values when vessel specific data is not available.

Table 4.1: 2017 Main Engine Characteristics by Commercial Harbor Craft Type

Propulsion Engines									
Harbor	Model year			Horsepower			Annual Operating Hours		
Craft Type	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Commercial fishing	na	na	na	500	500	500	50	50	50
Excursion	1977	2002	1989	240	800	660	50	50	50
Ferry	2010	2014	2012	350	600	413	468	6,895	4,308
Government	1999	2008	2005	225	750	505	500	2,000	1,500
Offshore supply vessels	1974	2014	2001	1,479	28,600	2,538	0	740	4
Tugboat	1989	2008	1999	1950	3,150	2,265	na	na	na
Towboats	1963	2014	1996	280	5,445	1,365	0	1,528	76

Table 4.2: 2017 Auxiliary Engine Characteristics by Commercial Harbor Craft Type

Auxiliary Engines									
Harbor	Model year			Horsepower			Annual Operating Hours		
Craft Type	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Commercial fishing	na	na	na	40	40	40	50	50	50
Excursion	na	na	na	na	na	na	na	na	na
Ferry	2000	2009	2006	98	113	109	234	3,448	2,154
Government	na	na	na	na	na	na	na	na	na
Offshore supply vessels	1974	2014	2001	266	5,351	1,480	0	740	4
Tugboat	1989	2008	2000	100	201	143	na	na	na
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. It was assumed that all commercial fishing vessels have Tier 0 engines.

For offshore supply vessels, AIS data was used and the emissions were estimated using the OGV methodology since these vessels are larger than the typical commercial harbor craft. It should be noted that all commercial harbor craft in this inventory use ULSD, with the exception of offshore supply vessels which were assumed to use 0.1% sulfur fuel.

For towboats, 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 and U.S. Waterways data to determine number of propulsion engines, model year and horsepower. The horsepower provided by U.S. Waterways is total propulsion horsepower for the vessel. Information on several vessels via various tow boat operators' websites 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 through U.S. Waterways data. 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. The emission factors used for harbor craft with Category 1 engines are listed in Table 4.3 for diesel-fueled main propulsion and auxiliary engines. The emission factors units are in grams per kilowatt-hour.

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.

Table 4.3: Harbor Craft Emission Factors for Category 1 Diesel Engines, g/kW-hr

kW Range	Year Range	NO_x	PM	VOC	CO	SO_x	CO_2	N_2O	CH_4
Category 1, Tier 0 Engines									
37 to 76	≤2000	10.0	0.40	0.27	1.7	1.3	690	0.031	0.01
76 to 131	≤2000	10.0	0.40	0.27	1.5	1.3	690	0.031	0.01
131 to 226	≤2000	10.0	0.80	0.27	1.5	1.3	690	0.031	0.01
226 to 561	≤2000	10.0	0.30	0.27	1.5	1.3	690	0.031	0.01
561 to 1,001	≤2000	10.0	0.30	0.27	1.5	1.3	690	0.031	0.01
1,001 to 1,400	≤2000	13.0	0.30	0.27	2.5	1.3	690	0.031	0.01
1,400 to 2,000	≤2000	13.0	0.30	0.27	2.5	1.3	690	0.031	0.01
2,000 to 3, 701	≤2000	13.0	0.30	0.27	2.5	1.3	690	0.031	0.01
3, 701+	≤2000	13.0	0.30	0.27	2.5	1.3	690	0.031	0.01
Category 1, Tier 1 Engines									
37 to 76	2000-2004	9.8	0.40	0.27	1.7	1.3	690	0.031	0.01
76 to 131	2000-2004	9.8	0.40	0.27	1.5	1.3	690	0.031	0.01
131 to 226	2000-2004	9.8	0.30	0.27	1.5	1.3	690	0.031	0.01
226 to 561	2000-2004	9.8	0.30	0.27	1.5	1.3	690	0.031	0.01
561 to 1,001	2000-2004	9.8	0.30	0.27	1.5	1.3	690	0.031	0.01
1,001 to 1,400	2000-2007	9.8	0.30	0.27	2.5	1.3	690	0.031	0.01
1,400 to 2,000	2000-2007	9.8	0.30	0.27	2.5	1.3	690	0.031	0.01
2,000 to 3,701	2000-2007	9.8	0.30	0.27	2.5	1.3	690	0.031	0.01
3,701+	2000-2007	9.8	0.30	0.27	2.5	1.3	690	0.031	0.01
Category 1, Tier 2 Engines									
37 to 76	2004-2009	7.3	0.40	0.20	5.0	1.3	690	0.031	0.01
76 to 131	2004-2013	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
131 to 226	2004-2013	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
226 to 561	2004-2013	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
561 to 1,001	2004-2013	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
1,001 to 1,400	2007-2013	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
1,400 to 2,000	2007-2013	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
2,000 to 3,701	2007-2016	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
3,701+	2007-2016	7.0	0.20	0.20	5.0	1.3	690	0.031	0.01
Category 1, Tier 3 Engines									
37 to 76	2009-2014	7.3	0.30	0.20	5.0	0.0065	690	0.031	0.01
76 to 131	2013+	5.2	0.12	0.20	5.0	0.0065	690	0.031	0.01
131 to 226	2013+	5.2	0.12	0.20	5.0	0.0065	690	0.031	0.01
226 to 561	2013+	5.2	0.12	0.20	5.0	0.0065	690	0.031	0.01
561 to 1,001	2013+	5.2	0.12	0.20	5.0	0.0065	690	0.031	0.01
1,001 to 1,400	2007-2013	5.2	0.12	0.20	5.0	0.0065	690	0.031	0.01
1,400 to 2,000	2007-2013	5.2	0.12	0.20	5.0	0.0065	690	0.031	0.01

The emission factors used for commercial harbor craft with Category 2 engines are listed in Table 4.4 for diesel-fueled main propulsion and auxiliary engines. The emission factors units are in grams per kilowatt-hour.

Table 4.4: Harbor Craft Emission Factors for Category 2 Diesel Engines, g/kW-hr

kW Range	Year Range	NO_x	PM	VOC	CO	SO_x	CO_2	N_2O	CH_4
Category 2, Tier 0 Engines									
≤600	≤2000	13.2	0.72	0.5	1.1	1.3	690	0.031	0.01
600 to 1,400	≤2000	13.2	0.72	0.5	1.1	1.3	690	0.031	0.01
1,400 to 2,000	≤2000	13.2	0.72	0.5	1.1	1.3	690	0.031	0.01
2,000 to 3,701	≤2000	13.2	0.72	0.5	1.1	1.3	690	0.031	0.01
3,701+	≤2000	13.2	0.72	0.5	1.1	1.3	690	0.031	0.01
Category 2, Tier 1 Engines									
≤600	2000-2007	9.8	0.72	0.5	1.1	1.3	690	0.031	0.01
600 to 1,400	2000-2007	9.8	0.72	0.5	1.1	1.3	690	0.031	0.01
1,400 to 2,000	2000-2007	9.8	0.72	0.5	1.1	1.3	690	0.031	0.01
2,000 to 3,701	2000-2007	9.8	0.72	0.5	1.1	1.3	690	0.031	0.01
3,701+	2000-2007	9.8	0.72	0.5	1.1	1.3	690	0.031	0.01
Category 2, Tier 2 Engines									
≤600	2007-2014	8.2	0.50	0.5	5.0	1.3	690	0.031	0.01
600 to 1,400	2007-2014	8.2	0.50	0.5	5.0	1.3	690	0.031	0.01
1,400 to 2,000	2007-2014	8.2	0.50	0.5	5.0	1.3	690	0.031	0.01
2,000 to 3,701	2007-2014	8.2	0.50	0.5	5.0	1.3	690	0.031	0.01
3,701+	2007-2014	8.2	0.50	0.5	5.0	1.3	690	0.031	0.01
Category 2, Tier 3 Engines									
≤600	2014+	6.5	0.34	0.5	5.0	0.0065	690	0.031	0.01
600 to 1,400	2014-2017	6.5	0.34	0.5	5.0	0.0065	690	0.031	0.01
1,400 to 2,000	2014-2016	6.5	0.34	0.5	5.0	0.0065	690	0.031	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 that were used in this inventory for the harbor craft vessel types for their propulsion and auxiliary engines.

Table 4.5: Commercial Harbor Craft Load Factors

Harbor Craft Type	Propulsion Engine	Auxiliary Engine
Commercial fishing	0.30	0.30
Ferry and excursion	0.34	0.43
Government	0.51	0.43
Tugboat	0.31	0.43
Towboat	0.68	0.43

Fuel correction factors are applied to reflect the effect of fuel on emissions when the actual fuel used is different than the fuel used to develop the emission factors. Table 4.6 summarizes the fuel correction factors used for Tier 0, Tier 1 and Tier 2 engines. For Tier 3 engines, fuel correction factors are not required as the emission factors already reflect the use of ULSD fuel.

Table 4.6: Fuel Correction Factors for Tiers 0, 1, and 2 Commercial Harbor Craft Engines

Fuel	NO_x	PM	VOC	CO	SO_x	CO_2	N_2O	CH_4
ULSD	1.0	0.86	1.0	1.0	0.005	1.0	1.0	1.0

4.4 Commercial Harbor Craft Emission Estimates

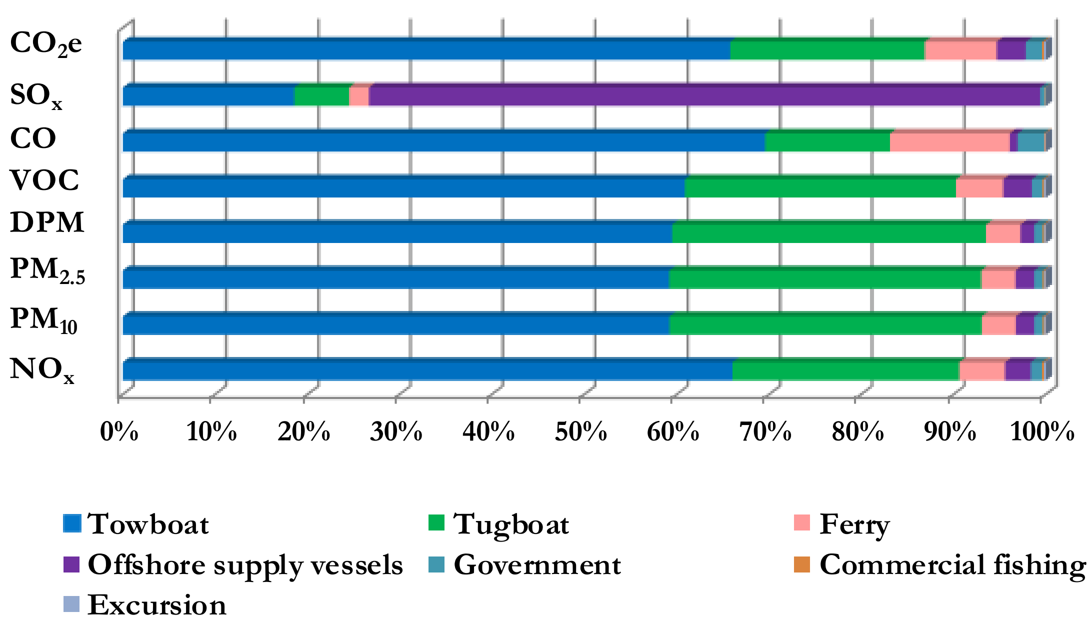
Table 4.7 presents the emissions for commercial harbor craft by vessel type, not including recreational vessels. Towboats have the highest emissions compared to all commercial harbor craft, followed by tugboats, which have the second highest emissions, both due to the high hours of use for these vessel types.

Table 4.7: 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	3	0.07	0.06	0.07	0.07	0.4	0.0	169
Excursion	3	0.07	0.06	0.07	0.07	0.4	0.0	164
Ferry	60	1.47	1.36	1.47	1.88	45.5	0.1	5,903
Government	15	0.37	0.34	0.37	0.42	10.0	0.0	1,320
Offshore supply vessels	33	0.80	0.75	0.59	1.14	2.9	1.8	2,397
Tugboat	298	13.50	12.42	13.50	10.81	47.6	0.2	16,012
Towboat	799	23.63	21.74	23.57	22.43	244.4	0.5	49,889
Total	**1,211**	**39.90**	**36.72**	**39.63**	**36.83**	**351.3**	**2.5**	**75,853**

Figure 4.2 presents the distribution of emissions by harbor craft type. The SO_x emissions are the highest for offshore supply vessels as compared to the other harbor craft due to its use of 0.1% sulfur fuel. This may be a conservative estimate as some of the offshore supply vessels may use a lower sulfur fuel, but we did not have the data to determine which ones.

Figure 4.2: 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. Emission factors in grams per hour by vessel types and fuel types were obtained from MOVES2014b 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 2017 recreational vessel emissions are presented in Table 4.8.

Table 4.8: Recreational Vessel Emissions

Vessel Type	Engine Type	Vessel Count	NO_x tpy	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	VOC tpy	CO tpy	SO_x tpy	CO_2e tonnes
Outboard	Gasoline	8,182	224.40	20.48	20.48	0.00	1189.27	4027.38	0.22	34,919
Inboard/Sterndrive	Gasoline	1,819	154.90	1.67	1.67	0.00	108.73	2071.56	0.13	19,260
Personal Water Craft	Gasoline	1,106	44.23	1.84	1.84	0.00	119.45	875.79	0.04	6,638
Inboard/Sterndrive	Diesel	311	37.35	0.81	0.75	0.81	1.85	7.52	0.04	3,507
Outboard	Diesel	10	0.12	0.01	0.01	0.01	0.02	0.07	0.00	16
Total		**11,427**	**461.00**	**24.81**	**24.75**	**0.82**	**1419.32**	**6982.32**	**0.43**	**64,130**

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).

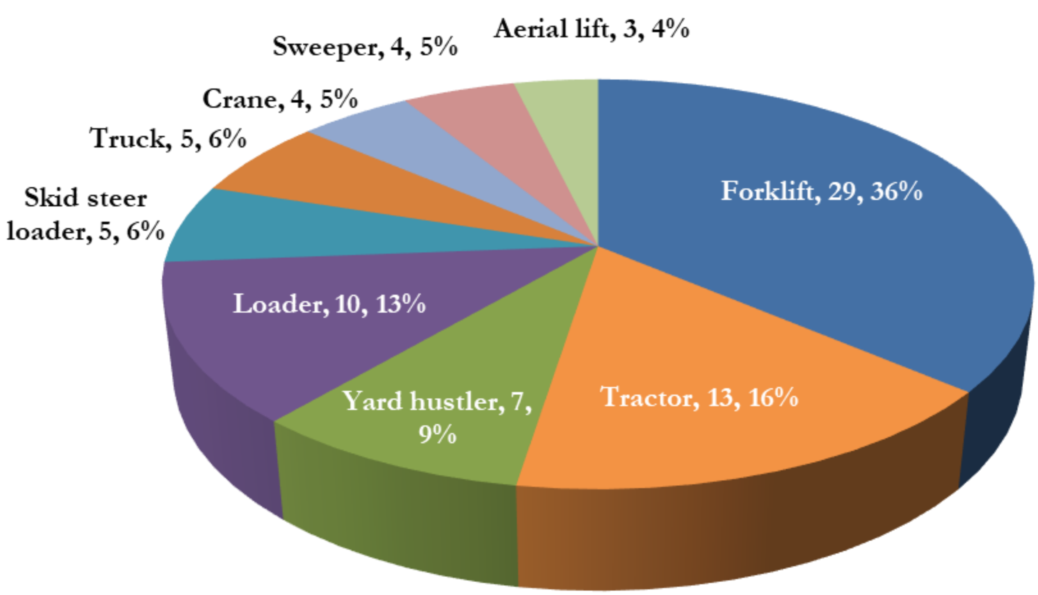
5.1 Source Description

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
- Light plants

Figure 5.1 presents the distribution of the 83 pieces of cargo handling equipment inventoried for the Port in 2017. The "other" category in the figure includes a backhoe and two light plants. The loaders and top loaders are added together for purpose of the figure.

Figure 5.1: 2017 Distribution of Cargo Handling Equipment



5.2 Data and Information Acquisition

Table 5.1 summarizes the characteristics of the cargo handling equipment operating at the Port in 2017. Averages of the model year, horsepower, or operating hours are used as default values when equipment specific data is not available. The "na" in the tables means that data was not available at time of data collection and therefore a default from MOVES2014b was used for that equipment type.

Table 5.1: 2017 Equipment Characteristics

Equipment	Count	Model Year Average	Horsepower Average	Annual Hours Average
Aerial lift	3	2011	147	43
Backhoe	1	2012	78	na
Crane	4	na	287	593
Forklift	29	2005	95	614
Light plants	2	2004	50	100
Loader	6	2010	na	na
Skid steer loader	5	2016	83	67
Sweeper	4	2010	74	na
Top loader	4	2009	343	500
Tractor	13	2013	50	57
Truck	5	2013	410	9
Yard hustler	7	2006	182	1,114
Total	**83**			

5.3 Emission Estimation Methodology

Emissions were estimated using the MOVES2014b emission estimating model[11] 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 matched with equipment types recognized by the model. For example, a "sweeper" corresponds directly to a single line item for the model, but top loader was categorized under the modeling category "other material equipment" because the model does not include a more specific category for these equipment types.

[11]See: EPA MOVES, *www.epa.gov/otaq/models/moves/*

The equipment identified by survey was categorized into the most closely corresponding MOVES2014b equipment type, as illustrated in Table 5.2, which presents equipment types by Source Classification Code (SCC), load factor, and MOVES2014b/NONROAD category common name.

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. For 2017, no fuel adjustment was necessary as the MOVES2014b EFs are based on ULSD fuel which was the actual fuel used in 2017.

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 MOVES2014b model has option to output emissions factors in grams/hp-hr by calendar year for each of the MOVES2014b equipment types by horsepower groups and model year. The model year groups are aligned with EPA's nonroad equipment emissions standards. MOVES2014b EFs reflect the actual Ultra Low Sulfur Diesel (ULSD) fuel used in 2017. The estimates of CHE emissions from each piece of equipment is based on its model year, horsepower rating, annual hours of operation, and equipment-specific load factor assumptions.

The load factors by NONROAD category as used by MOVES2014b are listed in Table 5.2. Except for yard hustlers, load factors for all other equipment were obtained from MOVES2014b. For yard hustlers (also known as yard tractors), a load factor of 0.39 is used based on a 2008 study[12] 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. MOVES2014b use a load factor of 0.59 for yard hustlers based on a 1997 study prepared for the EPA[13].

MOVES2014b was run with default conditions to obtain emission factors in grams/hp-hr. ULSD fuel with a sulfur content of 15 ppm was used for CHE operated in 2017. A control factor was applied to equipment identified as being equipped with on-road engines.

[12]Ports of Los Angeles and Long Beach, *San Pedro Bay Ports Yard Tractor Load Factor Study*, December 2008.
[13]EPA, Evaluation of Power Systems Research (PSR) Nonroad Population Data Base, 1997.

Table 5.2: MOVES/NONROAD Engine Source Categories

Equipment Type	SCC	Load Factor	NONROAD Category
Aerial platform	2270003010	0.21	Aerial lift
Crane	2270003010	0.21	Crane
Diesel forklift	2270003020	0.59	Forklift
Water and dump truck	2270002051	0.59	Off-highway trucks
Portable light set	2270002027	0.43	Signal board / light plant
Skid-steer loader	2270002072	0.21	Skid-steer loader
Sweeper	2270003030	0.43	Sweeper / scrubber
Stacker	2270003040	0.43	General industrial equipment
Top loader	2270003050	0.21	Other material handling equipment
Backhoe, loader	2270003040	0.21	Tractors/Loaders/Backhoes
Tractor	2270003070	0.59	Terminal tractor

5.4 Cargo Handling Equipment Emission Estimates

Table 5.3 presents the estimated cargo handling equipment emissions. Forklifts have the highest emissions due to there being more forklifts than any other equipment type at the Port of Corpus Christi.

Table 5.3: Cargo Handling Equipment Emissions

Equipment Type	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e tonnes
Aerial lift	0.01	0.00	0.00	0.00	0.00	0.01	0.00	3
Backhoe	0.11	0.01	0.01	0.01	0.01	0.06	0.00	23
Crane	2.27	0.08	0.08	0.08	0.18	0.45	0.00	261
Forklift	6.15	0.74	0.71	0.74	0.77	3.49	0.01	602
Light plants	0.02	0.00	0.00	0.00	0.00	0.01	0.00	3
Loader	1.08	0.07	0.06	0.07	0.07	0.28	0.00	201
Skid steer loader	0.07	0.01	0.01	0.01	0.01	0.09	0.00	13
Sweeper	0.67	0.04	0.04	0.04	0.05	0.26	0.00	92
Top loader	0.84	0.03	0.03	0.03	0.04	0.22	0.00	158
Tractor	0.08	0.01	0.01	0.01	0.01	0.03	0.00	12
Truck	2.16	0.10	0.09	0.10	0.07	0.61	0.01	712
Yard hustler	1.91	0.16	0.16	0.16	0.59	0.76	0.00	303
Total	**15.38**	**1.25**	**1.21**	**1.25**	**1.78**	**6.25**	**0.02**	**2,381**

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 line haul and switching activity. 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

Information on five CCTR switching locomotives was provided by the Port. The information includes the model, year of manufacture, horsepower, and annual fuel consumption of each locomotive. Similar information was provided by UP for switching locomotives they operate in Nueces County.

For line haul operations, UP provided tonnage and fuel consumption information for their locomotives operating within the inventory domain, and tonnage information for locomotives owned by BNSF and KCS operating on UP's rails under trackage rights. KCS declined to provide information on their locomotives operating on their own rail line, so the activity for that portion of the inventory was estimated using the ratio of track mileage between the UP rail lines and the KCS.

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.

While EPA's MOVES2014 model, as described in a preceding section, was used for estimating non-road equipment such as CHE, it does not estimate emissions from locomotives. 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.[14] 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.

[14]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: 1990-2017*, April 2018

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

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

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[15] 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 2017 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. 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.

[15] EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016,* April 2018

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. The Port's switcher is a specialty ultra-low-emissions unit powered by two engines that are smaller than typical locomotive engines and are Tier 3 engines.

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

Activity /Tier Level	NO_x	PM_{10}	PM_{25}	VOC	CO g/hphr	SO_x	CO_2	N_2O	CH_4
Line haul									
2017 composite	5.48	0.14	0.14	0.22	1.28	0.005	490	0.012	0.038
Switching									
Uncontrolled	17.4	0.44	0.43	1.01	1.83	0.007	670	0.017	0.052
Tier 0	12.6	0.44	0.43	1.01	1.83	0.007	670	0.017	0.052
Tier 3	4.5	0.08	0.08	0.26	1.83	0.007	670	0.017	0.052

6.4 Locomotive Emission Estimates

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

Table 6.2: Estimated Emissions from Locomotives

Activity Component	NO_x tpy	PM_{10} tpy	PM_{25} tpy	DPM tpy	VOC tpy	CO tpy	SO_x tpy	CO_2 tonnes
Line Haul	604	15.6	15.6	15.6	25.6	141.1	0.55	49,462
Switching	24	0.8	0.8	0.8	2.0	3.5	0.02	1,156
Total	**628**	**16.4**	**16.4**	**16.4**	**27.6**	**144.6**	**0.57**	**50,618**

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 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 container trailers built to accommodate standard-sized cargo containers, as well as tankers, boxes, 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 cause newer trucks to 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 2017. 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 made separately for facilities handling liquid cargoes (based on barrels of throughput) and dry cargoes (based on tons of throughput). This method estimated a total of 136,820 truck visits related to liquid bulk terminals and 183,187 truck visits associated with dry cargo facilities, for a total of 320,007 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"[16] 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 2017 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 10.53 million highway miles and 1.80 million non-highway miles have been estimated for 2017. A sensitivity analysis on the effect of exclusively using the longer route to estimate VMT indicates a maximum overestimate of 8% compared with exclusively using the shorter route. Since trucks use a combination of the two routes in practice, the actual resulting overestimate is less than 8%.

In addition to VMT, another component of truck operations that results in emissions is idling in place, such as when waiting to unload or load cargo. The emission factors for on-road travel include idling that is incidental to routine driving but idling for longer periods is not included. Truck engines can idle at low speed when waiting in line, for example, or at a higher speed when idling for extended periods and the engine power is needed to run heating or cooling for driver safety or comfort. Emission estimates have been made for low speed idling at the facilities to account for wait times on loading and unloading. The amount of on-site idling is difficult to determine since few, if any, locations monitor or record duration of idling or wait times. A time estimate of 60 minutes of idling time per truck visit has been included in the estimates, for a total of 320,007 hours in 2017. The time estimate of 60 minutes was based on the average idling times reported for terminals, other than container terminals, in four recent port-related emissions inventories,[17] and on a study published by the Oak Ridge National Laboratory[18] that reported the most common range of idling times for heavy-duty trucks, excluding overnight idling, is in the 15- to 60-minute range.

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[16] *See: www.google.com/maps*

[17] Port of Los Angeles, *2017 Inventory of Air Emissions*, 2018.
See: *www.portoflosangeles.org/environment/studies_reports.asp*
Port of Long Beach, *2017 Air Emissions Inventory*, 2018
See*: www.polb.com/environment/air/emissions.asp*
Port Authority of New York & New Jersey, *2017 Multi-Facility Emissions Inventory*, 2019
See: *www.panynj.gov/about/port-initiatives.html*
Port of Houston Authority, *2007 Goods Movement Emissions Inventory*, 2009
See: *www.portofhouston.com/inside-the-port-authority/environmental-stewardship/air-quality/*

[18] Oak Ridge National Laboratory, *Class-8 Heavy Truck Duty Cycle Project Final Report*, Dec. 2008.
ORNL/TM-2008/122 See: *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 MOVES2014b, which estimates emissions and emission factors for on-road vehicles of all types, including HDVs.

The MOVES2014b 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 MOVES2014b 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)	5.839	0.238	0.219	0.243	1.369	0.015	1,759	0.001	0.025
Rural Unrestricted Access (g/mi)	6.005	0.275	0.253	0.296	1.563	0.015	1,780	0.002	0.033
Short-Term Idle (g/hr)	39.883	3.376	3.106	4.957	13.673	0.076	8,871	0.000	0.563

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 tpy	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	VOC tpy	CO tpy	SO_x tpy	CO_2 tonnes
On-road driving	80	3.3	3.0	3.3	3.4	19.0	0.20	21,732
On-site idling	14	1.2	1.1	1.2	1.7	4.8	0.03	2,843
Total	**94**	**4.5**	**4.1**	**4.5**	**5.2**	**23.8**	**0.23**	**24,575**

SECTION 8 COMPARISON OF 2017 AND 2013 EMISSION ESTIMATES

This section provides a comparison of the emission estimates for 2017 and 2013 by source category. When there was a difference in an emissions estimation methodology used for 2017 compared to 2013, the 2013 emissions were recalculated using 2013 activity data and the new or updated 2017 methodology to provide a valid basis for comparison. Calculation methodologies changed for each emission source category except for rail locomotives and heavy-duty vehicles. Emissions have been recalculated for marine vessel and cargo handling equipment emission source categories so reported emissions for these categories will not match the 2013 EI report. 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 2017 compared to 2013. Overall, NO_x emissions were higher in 2017 than in 2013. The significant decrease in PM and SO_x emissions between 2013 and 2017 is primarily due to the lower sulfur content for fuel used by ocean-going vessels in 2017. Fuel with 1% sulfur fuel was used in 2013 while a distillate fuel with 0.1% sulfur fuel was used in 2017 to comply with the North American ECA. This resulted in a significant decrease in PM (76% reduction) and SO_x (90% reduction). However, the reduction in NO_x emissions for OGV due to the fuel switch was only 6%.

Table 8.1: 2013-2017 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
2013	3,684	287	243	145	2,143	7,827	1,347	391,663
2017	4,226	134	127	90	1,550	7,668	129	396,615
Change	**542**	**-154**	**-116**	**-56**	**-594**	**-159**	**-1,218**	**4,952**
Change (%)	**15%**	**-54%**	**-48%**	**-38%**	**-28%**	**-2%**	**-90%**	**1%**

Table 8.2 provides a comparison of cargo volumes in short tons and barrels between 2013 and 2017. Compared to 2013, cargo in short tons was up by 15% and cargo in barrels was up 19% due to the growth seen at the Port between 2013 and 2017.

Table 8.2: 2013-2017 Cargo Volumes Comparison

Year	Cargo (short tons)	Cargo (barrels)
2013	88,699,848	511,703,921
2017	102,391,848	608,524,933
Change (%)	**15%**	**19%**

Table 8.3 presents the change in emissions by emission source category in 2017 compared to 2013. Despite the cargo volume increase, emissions decreased for most pollutants, except for NO_x and CO_2e. The NO_x emissions were higher in 2017 for OGV, harbor craft, and rail locomotives.

The particulate matter (PM_{10}, $PM_{2.5}$ and DPM) and SO_x emissions for ocean-going vessels are significantly lower due to the North American ECA that requires all engines within 200 nm from the coast of the United States and Canada to use distillate fuels with a maximum sulfur (S) content of 0.1%. In 2013, the first phase of the North American ECA was in effect which required all engines to use fuel with 1.0% S.

In 2017, the overall rail emissions were higher, and the truck emissions were lower. This is due to rail expansion projects occurring between 2013 and 2017 and cargo moves being shifted to use trains rather than trucks.

Table 8.3: 2013-2017 Emissions Comparison by Source Category, tons, metric tons and %

	NO_x tons	PM_{10} tons	$PM_{2.5}$ tons	DPM tons	VOC tons	CO tons	SO_x tons	CO_2e MT
2013								
Ocean-going vessels	1,699	200	159	95	54	140	1,329	200,518
Commerical harbor craft	820	24	22	24	23	276	16.02	57,737
Recreational vessels	434	38	38	1	2,027	7,254	1.16	58,128
Cargo handling equipment	21	2	2	2	3	7	0.06	2,822
Locomotives	504	14	13	14	26	96	0.40	33,394
Heavy-duty vehicles	205	11	10	11	12	54	0.30	39,064
Total	**3,684**	**287**	**243**	**145**	**2,143**	**7,827**	**1,347**	**391,663**
2017								
Ocean-going vessels	1,817	47	44	27	59	160	125	179,058
Commerical harbor craft	1,211	40	37	40	37	351	2.50	75,853
Recreational vessels	461	25	25	1	1,419	6,982	0.43	64,130
Cargo handling equipment	15	1	1	1	2	6	0.02	2,381
Locomotives	628	16	16	16	28	145	0.60	50,618
Heavy-duty vehicles	94	5	4	5	5	24	0.20	24,575
Total	**4,226**	**134**	**127**	**90**	**1,550**	**7,668**	**129**	**396,615**
Change between 2013 and 2017 (percent)								
Ocean-going vessels	7%	-77%	-72%	-71%	10%	14%	-91%	-11%
Commerical harbor craft	48%	64%	67%	66%	62%	27%	-84%	31%
Recreational vessels	6%	-34%	-34%	0%	-30%	-4%	-63%	10%
Cargo handling equipment	-28%	-24%	-24%	-24%	-38%	-13%	-63%	-16%
Locomotives	25%	21%	28%	21%	8%	51%	50%	52%
Heavy-duty vehicles	-54%	-58%	-58%	-58%	-57%	-56%	-33%	-37%
Total	**15%**	**-54%**	**-48%**	**-38%**	**-28%**	**-2%**	**-90%**	**1%**

8.1 Ocean-going Vessels

Overall energy consumption (in terms of kW-hr) by OGV emission sources for 2013 and 2017 are shown in Table 8.4. Overall, there was a 3% decrease for the OGV emission sources in 2017 as compared to 2013. The main and auxiliary engine activity increased by 12% and 31%, respectively. The boiler activity decreased by 20%. The decrease in boiler activity as compared to increase in main and auxiliary engine activity is due to different fleet mix and different boiler operations of vessel in the EI domain for 2017 as compared to 2013.

Table 8.4: 2013-2017 OGV Energy Consumption Comparison by Emissions Source, kW-hr

Year	All Emission Sources	Main Engine	Auxiliary Engine	Boiler
2013	226,707,627	27,640,540	58,859,679	140,207,408
2017	220,451,721	30,874,151	77,038,604	112,538,966
Change (%)	**-3%**	**12%**	**31%**	**-20%**

In 2017, the number of shifts was 40% higher and total movements were 6% higher than in 2013.

Table 8.5: 2013-2017 OGV Movements

Year	Arrivals	Departures	Shifts	Total
2013	1,820	1,766	680	4,266
2017	1,863	1,715	951	4,529
Change	**43**	**-51**	**271**	**263**
Change (%)	**2%**	**-3%**	**40%**	**6%**

The OGV emissions for 2013 were recalculated in 2017 due to methodology changes developed since the publication of the 2013 EI report. The methodology described in the OGV section of this report was used for both the 2013 and 2017 emissions calculations.

Table 8.6: 2013-2017 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
2013								
Main Engines	522	26	21	26	12	38	121	18,115
Auxiliary Engines	854	68	54	68	26	71	288	43,052
Boilers	325	105	83	0	15	31	921	139,351
Total	**1,700**	**200**	**159**	**95**	**54**	**140**	**1,329**	**200,518**
2017								
Main Engines	558	6	6	6	13	42	14	19,301
Auxiliary Engines	1,013	21	20	21	34	93	38	53,525
Boilers	245	20	18	0	12	25	74	106,232
Total	**1,817**	**47**	**44**	**27**	**59**	**160**	**125**	**179,058**
Change between 2013 and 2017 (percent)								
Main Engines	7%	-76%	-72%	-76%	2%	10%	-89%	7%
Auxiliary Engines	19%	-70%	-64%	-70%	31%	31%	-87%	24%
Boilers	-25%	-81%	-78%	0%	-20%	-20%	-92%	-24%
Total	**7%**	**-77%**	**-72%**	**-71%**	**10%**	**14%**	**-91%**	**-11%**

Due to the North American ECA that requires all engines within 200 nm from the coast of the United States and Canada to use distillate fuels with a maximum sulfur content of 0.1%, the 2017 PM/DPM and SO_x emissions decreased significantly as compared to 2013. The decrease in NO_x emissions from fuel switching is not as significant as for PM, DPM and SO_x. In 2013, the first phase of the North American ECA was in effect which required all engines to use fuel with 1.0% S.

Although overall, there was a slight decrease in vessel activity in terms of kW-hr, the NO_x, VOC, and CO emissions increase for main and auxiliary engine was higher than the decrease in boiler NO_x, VOC, and CO emissions due to a decrease in boiler activity. For CO_2 emissions, decrease in boiler emissions was higher than the increase in main and auxiliary engine CO_2 emissions.

8.2 Commercial Harbor Craft

As shown in Table 8.7, the harbor craft overall energy consumption (as measured by kilowatt hours) increased by 55% from 2013 to 2017, resulting in the emissions increase. Table 8.6 does not include the activity of offshore supply vessels.

Table 8.7: 2013-2017 Commercial Harbor Craft Energy Consumption Comparison and Vessel Maneuvering Time

Year	Activity (kW-hr)	Maneuvering Time
2013	75,054,937	2.59
2017	115,977,485	2.63
Change	**40,922,547**	**0.04**
Change (%)	**55%**	**2%**

The harbor craft emissions for 2013 were recalculated using the 2017 methodology due to methodology changes that occurred since the publication of the 2013 EI report. The methodology described in the harbor craft section of this report was used for both the 2013 and 2017 emissions calculations. In addition to emission factors and load factors changes, a significant difference in the recalculated 2013 emissions versus the published 2013 emissions is that the tugboat emissions were estimated using a different methodology to estimate the hours needed to assist/escort a vessel. In 2013, a default 36 minutes was used based on conversation with the Port of Corpus Christi, but an evaluation of the actual maneuvering time from AIS shows the average to be around 2.5 hours for both 2013 and 2017. The average maneuvering time from AIS shown on Table 8.6 was used to recalculate the 2013 emissions, in addition to emission factor updates.

Table 8.8 shows the harbor craft emissions comparison. For most pollutants, the emissions were higher in 2017 as compared to 2013 due to the increased activity (55%) shown in Table 8.6. The SO_x emissions were lower due to offshore supply vessels using a lower sulfur fuel (0.1%) in 2017. All other harbor craft used ULSD in 2017 and 2013.

Table 8.8: 2013-2017 Commercial Harbor Craft 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
2013	820	24	22	24	23	276	16	57,737
2017	1,211	40	37	40	37	351	3	75,854
Change	**391**	**16**	**15**	**16**	**14**	**75**	**-13**	**18,117**
Change (%)	**48%**	**64%**	**67%**	**67%**	**62%**	**27%**	**-84%**	**31%**

Recreational vessels for San Patricio and Nueces counties were also included in the inventory. Table 8.9 shows the comparison of emissions for recreational vessels. The vessel count increased in 2017 by 11%.

Table 8.9: 2013-2017 Recreational Vessel Emissions Comparison, tons, metric tons and %

Year	Vessel Count	NO_x tpy	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	VOC tpy	CO tpy	SO_x tpy	CO_2e tonnes
2013	10,304	434	37.5	37.5	0.8	2,027	7,254	1.16	58,128
2017	11,427	461	24.8	24.8	0.8	1,419	6,982	0.43	64,130
Change	**1,123**	**26.86**	**-12.72**	**-12.72**	**0.070**	**-607.24**	**-271.59**	**-0.73**	**6,002**
Change (%)	**11%**	**6%**	**-34%**	**-34%**	**9%**	**-30%**	**-4%**	**-63%**	**10%**

8.3 Cargo Handling Equipment

For cargo handling equipment, the overall energy consumption (as measured by horsepower hours) decreased 17% due to lower hours of engine use and 5% less equipment in 2017 as compared to 2013.

Table 8.10: 2013-2017 CHE Energy Consumption Comparison and Equipment Count

Year	Activity (hp-hr)	Diesel Equipment Count
2013	4,953,980	87
2017	4,108,051	83
Change	**-845,930**	**-4**
Change (%)	**-17%**	**-5%**

The 2013 CHE emissions were re-calculated using the latest model, MOVES2014b, in 2017. Table 8.11 shows the cargo handling equipment emissions comparison. In 2017, the emissions were lower than in 2013 due to less equipment and less activity and fleet turnover to newer equipment. The liquid and dry bulk facilities do not require extensive use of cargo handling equipment.

Table 8.11: 2013-2017 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
2013	21	1.65	1.60	1.65	2.88	7.16	0.056	2,822
2017	15	1.25	1.21	1.25	1.78	6.25	0.021	2,381
Change	**-6**	**-0.40**	**-0.39**	**-0.40**	**-1.10**	**-0.91**	**-0.035**	**-441**
Change (%)	**-28%**	**-24%**	**-24%**	**-24%**	**-38%**	**-13%**	**-63%**	**-16%**

8.4 Railroad Locomotives

Table 8.12 shows the rail locomotive activity in million gross tons (MMGT) of cargo moved in 2013 and 2017 which shows a 62% increase in 2017 as compared to 2013.

Table 8.12: 2013-2017 Rail Locomotive Activity

Year	Rail MMGT
2013	189
2017	305
Change (%)	**62%**

The locomotive emissions for 2013 were not recalculated since there was no methodology change from 2013 to 2017 for locomotives. The emissions increased due to rail expansion projects occurring between 2013 and 2017 that increased the rail locomotive activity and thus, locomotive emissions in 2017. Emissions did not increase as much (measured as percentage increase) as the increase in gross tons because of efficiency improvements and fleet turnover to newer, cleaner locomotives serving the area.

Table 8.13: 2013-2017 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
2013	504	13.6	12.8	13.6	25.5	95.5	0.4	33,394
2017	628	16	16	16	28	145	0.6	50,618
Change	**124**	**2.8**	**3.6**	**2.8**	**2.1**	**49.1**	**0.2**	**17,224**
Change (%)	**25%**	**21%**	**28%**	**21%**	**8%**	**51%**	**50%**	**52%**

8.5 Heavy-duty Vehicles

Table 8.14 compares the heavy-duty vehicles count and vehicle miles traveled for 2013 and 2017. In 2017, the truck counts decreased by 32% and vehicle miles traveled decreased by 35%. This decrease is believed to be due to a mode shift from truck to rail after the opening of new rail facilities associated with the Port.

Table 8.14: 2013-2017 HDV Count and Vehicle Miles Traveled

Year	Truck Count	Truck VMT
2013	473,060	19,014,288
2017	320,007	12,326,023
Change (%)	**-32%**	**-35%**

The HDV emissions for 2013 were not recalculated since there was no methodology change from 2013 to 2017 for HDV. Table 8.15 shows the emissions comparison for heavy-duty vehicles. The 2017 heavy-duty vehicle emissions decreased compared to 2013 due to the cargo shift noted above. Emissions of criteria pollutants decreased more than the decrease in VMT due to fleet turnover to newer, cleaner trucks. Emissions of CO_2e and SO_x decreased about the same amount as VMT because these emissions are directly related to fuel consumption, which does not vary significantly by truck model year.

Table 8.15: 2013-2017 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
2013	205	10.7	9.8	10.7	12.0	54.0	0.3	39,064
2017	94	4.5	4.1	4.5	5.2	23.8	0.2	24,575
Change	**-112**	**-6.2**	**-5.7**	**-6.2**	**-6.9**	**-30.2**	**-0.1**	**-14,490**
Change (%)	**-54%**	**-58%**	**-58%**	**-58%**	**-57%**	**-56%**	**-33%**	**-37%**

SECTION 9 CONCLUSION AND RECOMMENDATIONS

Between 2013 and 2017, the Port of Corpus Christi saw significant growth in cargo volume and moved up in port size rankings. During that period several expansion projects were completed, and new terminals commenced operations. In addition, cargo throughput increased by 15% in short tons and 19% in barrels over the period.

Despite the increase in cargo volume, emissions of most pollutants were significantly lower, except for NO_x and GHG emissions (as CO_2e). The PM and SO_x emissions decreased in 2017 primarily due to the use of lower sulfur content fuel by ocean-going vessels. There was no significant change for CO_2e emissions (1% increase), despite the increase in activity and cargo volume. The NO_x emissions increased in 2017 for most source categories, especially commercial harbor craft and locomotives.

Among the Port's projects occurring between 2013 and 2017 were rail expansion projects that resulted in cargo being shifted from truck to rail. This took trucks off the roads and decreased truck emissions while increasing emissions from locomotives.

Comparison to other Ports

Compared to other major U.S. ports that also prepare and 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) and activity 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. In addition, there has been a shift to using trains as opposed to trucks as previously discussed.

The Port of Corpus Christi OGV emissions inventory has higher tanker emissions than other vessel types due to the relatively large amount of tanker activity. 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.

The Port of Corpus Christi's towboat, pushboat, and barge activity and emissions are high compared with many other ports because of the Texas Gulf Intracoastal Waterway that runs through the Corpus Christ Bay and because liquid 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 to the number 3 spot in the nation. With this growth and increased activity, we expect NO_x and CO_2e emissions to increase in the future as compared to 2017. We also expect to continue to see larger vessels, specifically tankers, call the Port. Depending on vessel type and future fleet mix, the ocean-going vessels' emissions may decrease overall due to fewer vessel calls as a result of the larger vessels or may increase due to higher operating loads for engines and boilers on larger tankers. It will depend on the future vessel fleet mix, which is difficult to predict.

Recommendations

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 significantly through equipment turnover and through 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. While rail can be a more environmentally efficient mode of transportation as compared to trucks, advancements in emission standards for trucks have come earlier than for locomotives. This means that current truck fleet emissions may provide lower transportation emissions than rail transport by the current locomotive fleet, but this will vary greatly by pollutant and careful analysis would be required to establish which mode is "cleaner" and by which pollutants. 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.