APPENDIX 9

2020 TEXAS CMV EMISSIONS INVENTORY AND 2011 THROUGH 2050 TREND INVENTORIES

Dallas-Fort Worth and Houston-Galveston-Brazoria Moderate Areas Reasonable Further Progress State Implementation Plan Revision for the 2015 Eight-Hour Ozone National Ambient Air Quality Standard

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2020 Texas CMV Emissions Inventory and 2011 through 2050 Trend Inventories

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2020 Texas CMV Emissions Inventory and 2011 through 2050 Trend Inventories

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LIST OF ACRONYMS AND ABBREVIATIONS

AERR	Air Emissions Reporting Requirements
AIS	Automatic Identification System
C1/C2	Category 1 and 2 engines
C3	category 3 engines
CAGR	Compound Average Growth Rate
CAP	criteria air pollutant
CERS	Consolidated Emissions Reporting Schema
CMV	Commercial Marine Vessel
CO	carbon monoxide
ECA	Emission Control Area
EI	Emission Inventory
EPA	United States Environmental Protection Agency
GIS	geographic information systems
GSP	Gross State Product
HAPs	hazardous air pollutants
IHS	The HIS Markit's Sea-web Ships database
IMO	International Maritime Organization
kn	knot
kW	Kilowatt
MARINER	MARINe Emissions Resolver
MMSI	Maritime Mobile Service Identity
MS Excel	Microsoft Excel
NEI	National Emission Inventory
NOx	nitrogen oxides
OGV	Ocean Going Vessel
PM	particulate matter
QA	Quality Assurance
RPM	revolutions per minute
SCC	Source Classification Code
SIP	State Implementation Plan
SO_2	sulfur dioxide
TCEQ	Texas Commission on Environmental Quality
TEU	twenty-foot equivalent units
TexAER	Texas Air Emissions Repository
TPD	tons per day
TPY	tons per year
TTI	Texas Transportation Institute
US	United States
USCG	United States Coast Guard
VOC	volatile organic compounds
XML	Extensible Markup Language

EXECUTIVE SUMMARY

Ramboll developed two calendar year, 2019 and 2020, commercial marine vessel (CMV) emissions inventories (EI) for Texas using year-specific vessel tracking data from the Automatic Identification System (AIS) and vessel characteristics data from the Sea-web Ships database following the latest applicable EPA guidance and methodologies. The EIs were also formatted for upload to the air emissions reporting interfaces used by the United States Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ). Ramboll also developed trends in CMV emissions for the period 2011 to 2050 by using publicly available economic data in a separate task.

The CMV EI includes two major types of marine sources: 1) Ocean-Going vessels (OGV) and 2) harbor craft. OGV typically have Category 3 (C3) propulsion engines, which have a per-cylinder displacement of 30 liters or more; however, some OGV have smaller Category 1 (C1) or Category 2 (C2) engines. The harbor craft source sector covers all commercial marine vessels that are not considered in the OGV sector, such as tugboats and work boats. Unlike OGV, harbor craft typically spend most of their operating time in or near a single port or region and are typically equipped with C1 or C2 engines. Table E-1 and Table E-2 summarize CMV emissions by county for year 2019 and 2020, respectively. These include all criteria air pollutants: nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter with an aerodynamic diameter equal to or less than 10 microns, or equal to or less than 2.5 microns (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), and volatile organic compounds (VOC). Table E-3 and Table E-4 also summarize emissions at county level but for average summer weekday (tons per day). Note that these four emissions tables include only counties with annual emissions that exceed 1 tpy for any pollutant.

Table E-1. 2019 annual statewide controlled CMV emissions (tons per year) by county.

County	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Aransas	740	15	133	14	13	5
Brazoria	2,109	46	355	42	40	38
Calhoun	991	16	175	17	16	5
Cameron	256	7	41	5	5	5
Chambers	2,240	64	335	35	33	30
Galveston	8,667	253	1,302	161	152	172
Harris	10,218	321	1,557	238	223	356
Jefferson	5,222	148	832	113	107	142
Kenedy	164	1.9	30	2.6	2.6	0.1
Kleberg	80	0.9	15	1.3	1.2	0.0
Matagorda	1,564	24	278	26	25	4
Nueces	3,006	104	464	75	71	115
Orange	1,449	39	233	29	27	28
San Patricio	71	1.7	13	1.4	1.4	0.1
Victoria	29	0.5	5	0.5	0.5	0.0
Willacy	67	0.9	12	1.1	1.1	0.0
Total	**36,872**	**1,043**	**5,783**	**761**	**720**	**900**

Table E-2. 2020 annual statewide controlled CMV emissions (tons per year) by county.

County	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Aransas	664	14	111	12	11	6
Brazoria	1,992	46	335	41	39	39
Calhoun	806	13	143	14	13	4
Cameron	383	11	62	8	7	8
Chambers	2,025	59	311	32	30	27
Galveston	7,970	233	1,218	150	142	154
Harris	8,940	285	1,394	213	201	314
Jefferson	4,917	138	791	105	99	119
Kenedy	183	2.3	33.9	3.0	2.9	0.1
Kleberg	92	1.3	17.0	1.5	1.5	0.1
Matagorda	1,387	21	251	23	22	1
Nueces	3,111	111	485	81	77	130
Orange	1,484	42	231	30	28	32
San Patricio	232	6	39	5	5	3
Victoria	25	0.5	4.3	0.5	0.5	0.01
Willacy	77	1.1	14.2	1.3	1.3	0.1
Total	**34,287**	**983**	**5,441**	**719**	**681**	**837**

Table E-3. 2019 summer weekday statewide controlled CMV emissions (tons per day) by county.

County	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Aransas	10.6	0.2	1.8	0.2	0.2	0.2
Brazoria	13.0	0.5	1.7	0.3	0.3	0.6
Calhoun	4.2	0.1	0.6	0.1	0.1	0.1
Cameron	5.5	0.2	0.7	0.1	0.1	0.3
Chambers	13.4	0.3	2.2	0.3	0.3	0.2
Galveston	24.5	0.8	3.8	0.5	0.5	0.8
Harris	20.1	0.8	2.7	0.4	0.4	0.7
Jefferson	12.3	0.5	1.9	0.3	0.3	0.4
Kenedy	0.6	0.02	0.1	0.01	0.01	0.0
Kleberg	0.7	0.03	0.1	0.02	0.02	0.1
Matagorda	1.3	0.05	0.2	0.03	0.03	0.0
Nueces	14.4	0.4	2.3	0.3	0.3	0.5
Orange	7.9	0.3	1.0	0.2	0.2	0.3
San Patricio	0.9	0.04	0.13	0.02	0.02	0.04
Willacy	0.4	0.02	0.05	0.01	0.01	0.02
Total	**129.8**	**4.3**	**19.3**	**2.9**	**2.7**	**4.4**

Table E-4. 2020 summer weekday statewide controlled CMV emissions (tons per day) by county.

County	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Aransas	4.0	0.2	0.7	0.1	0.1	0.2
Brazoria	14.1	0.4	2.2	0.3	0.3	0.3
Calhoun	1.2	0.0	0.2	0.0	0.0	0.0
Cameron	8.7	0.4	1.1	0.2	0.2	0.6
Chambers	6.5	0.2	0.9	0.1	0.1	0.2
Galveston	15.8	0.5	2.4	0.4	0.3	0.5
Harris	14.1	0.6	1.9	0.3	0.3	0.6
Jefferson	25.1	0.6	4.2	0.5	0.5	0.5
Kenedy	0.14	0.01	0.01	0.003	0.003	0.01
Matagorda	1.3	0.1	0.2	0.0	0.0	0.1
Nueces	11.4	0.4	1.7	0.3	0.3	0.4
Orange	8.8	0.3	1.3	0.2	0.2	0.4
San Patricio	3.6	0.1	0.5	0.1	0.1	0.1
Total	**114.8**	**3.9**	**17.3**	**2.6**	**2.4**	**3.9**

Ramboll compared the resulting emission estimates to other CMV inventories including the EPA's CMV emissions in the 2017 National Emissions Inventories (NEI) and the 2017 EI recently developed for TCEQ's Air Modeling and Data Analysis project, WO 582-20-12636-017 "Automation of Commercial Marine Vessel Emissions Inventory Development", to ascertain the reasonableness of the emission estimates. Overall, Ramboll found the 2019 EI developed for this study to be comparable to the previous 2017 EIs and that differences are explained by improvements to methodology and input data.

For trend analysis, Ramboll approximated vessel activity relative to broad economic growth estimates (e.g., gross state product) and relative growth by ship-type by assessing the trends of the associated commodities which those ship types serve. The tonnage of cargo moved by ship-type from 2011 through 2019 was assessed to understand how each commodity was trending. These trends were compared with the gross state product (GSP) over that period and were used to inform future year activity estimates. Emission rates were assessed based on engine emissions (especially NO_X) controls and fuel sulfur limits using EPA default estimates. The resulting relative historic activity and emission rates for 2011 through 2019 and forecasted activity and emissions through 2050 were compiled as scaling values to apply to the 2019 EI as a base year for projections. The resulting emission trends for controlled and uncontrolled scenarios are presented in Figure E-1.

Ramboll provided 2011 through 2050 controlled and uncontrolled annual and ozone season daily statewide CMV EIs in a format that meets the requirements for upload into the TCEQ's Texas Air Emissions Repository (TexAER) database. In addition, Ramboll provided the 2020 controlled annual and ozone season daily statewide CMV EI in a format that fulfills the federal Air Emissions Reporting Requirements (AERR).

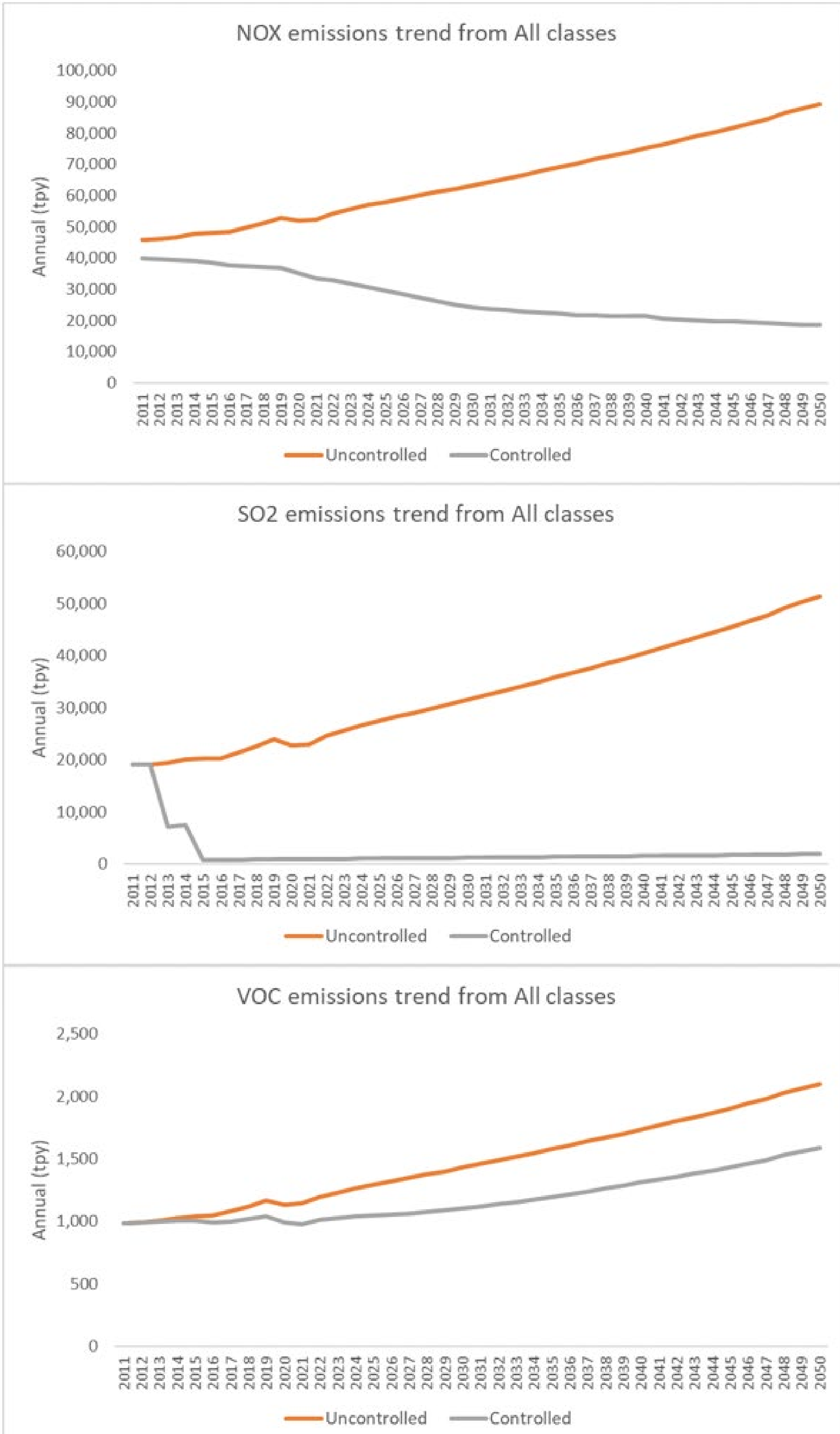


Figure E-1. Statewide annual controlled and uncontrolled emissions by year for NOx (top), SO_2 (middle), and VOC (bottom)

1.0 INTRODUCTION

The purpose of this project is to develop statewide EIs for all CMV source categories in Texas to fulfill the federal AERR and to support State Implementation Plan (SIP) development. Since 2009, the United States Coast Guard (USCG) has collected AIS data in real time to track the location and identity of large vessels operating in both US and international waters. AIS data sets are available from the USCG throughout the US and surrounding oceanic waters. The level of detail included in AIS data sets has expanded over time. Starting in 2015, the Maritime Mobile Service Identity (MMSI) code for each vessel became readily available in the AIS data sets. Starting in March 2016, nearly all commercially active vessels were required to install AIS transponders, including many smaller vessels that operate primarily within harbors and near-shore waters.[1] This high-resolution tracking system for all operational vessels is an excellent activity data set for use in CMV EI development.

The Sea-web Ships database is one of the most comprehensive registries available for identifying characteristics of specific vessels such as ownership, size, age, type of cargo transported, etc. Sea-web is commercially available from IHS Markit. AIS tracking data and Sea-web vessel characteristics are the two essential components for developing high-resolution CMV EIs. Both the AIS and Sea-web vessel characteristics data sets are comprehensive, but they are not readily available in a "plug-in" format for automating EI calculations. A processing tool is needed to combine, process, and quality assure the AIS and Sea-web Ships data sets and produce detailed EIs.

The MARINe Emissions Resolver (MARINER) tool was previously developed by Ramboll to support the production of a detailed CMV EI for use in photochemical modeling (TCEQ WO 582-20-12636-017) and implements the latest applicable EPA guidance and methodologies for estimating emissions from CMV sources. Ramboll used the MARINER tool to support the generation of a detailed CMV EI that can be readily imported to the air emissions reporting interfaces used by the EPA and TCEQ. The 2020 statewide CMV EI was developed using MARINER to process year-specific AIS data and vessel characteristics data from the Sea-web Ships database. Ramboll also developed projected trend inventories for 2011 through 2050 using publicly available economic data and the 2019 AIS data for the base activity as directed by the TCEQ project manager. TCEQ assumed the use of 2019 AIS data would be more representative of typical annual CMV activity in state waters than 2020 AIS data due to potential impacts from the COVID-19 pandemic, resulting in more consistent trend EI results. This report summarizes the development methodology and the resulting CMV EIs.

1.1 Background

The EPA requires states to collect and submit emissions data to EPA through the AERR. The EPA uses these AERR submittals, along with other data sources, to build the National Emissions Inventory (NEI). For some emissions categories, such as the CMV source category, EPA has developed default emissions data that states may use for reporting. Because the state of Texas has used for more detailed commercial marine data than EPA provides, TCEQ contracted with Ramboll to develop updated commercial marine vessel emissions by vessel type useful for air quality planning.

Ramboll's MARINER tool follows the latest EPA guidance (EPA, 2020a) for preparing CMV EIs, and so is consistent with the EPA default approach. MARINER uses AIS data of vessel activity combined with vessel characteristics data to provide CMV emissions with more detail in terms of vessel type than is required or permitted for the NEI. Ramboll converted the more detailed output of the MARINER tool into the more general AERR reporting requirements for submittal to the EPA.

[1] Vessel Requirements for Notices of Arrival and Departure, and Automatic Identification System, 80 Fed. Reg. 5281 (March 2, 2015).

1.2 Purpose and Objectives

The purpose of this project is to develop a set of statewide EIs for all CMV source categories in Texas. Ramboll developed annual (tons per year) and average summer weekday (tons per day) controlled and uncontrolled EI estimates of criteria air pollutants (CAP), CAP precursors, and hazardous air pollutants (HAP). The EIs were developed within a framework based on methods consistent with the pertinent EPA requirements and guidance on the development of actual emissions inventories as directed by the TCEQ Project Manager.

2.0 METHODOLOGY

The CMV EI includes two types of marine sources: 1) Ocean-Going vessels (OGV) and 2) harbor craft. The OGV source sector covers ships that transport cargo and/or people between different ports. The OGV source sector also covers vessels that transport cargo and/or people between different ports usually across the ocean but these ships also transit in the lakes (e.g. Great Lakes) and inland rivers (e.g. Columbia, Mississippi, and Hudson). OGV use Category 3 (C3) propulsion engines, which have a per-cylinder displacement of 30 liters or more; however, some OGV have smaller Category 1 (C1) or Category 2 (C2) engines. Most OGVs with C1/C2 engine in Texas are offshore support and drillship. The harbor craft source sector covers all commercial marine vessels that are not considered in the OGV sector, such as tugboats and work boats. Unlike OGV, harbor craft typically spend most of their operating time in or near a single port or region, and they typically have C1 or C2 engines. The methodologies used to calculate emissions from OGV and harbor craft differ and are discussed in subsequent sections.

Table 2-1 lists the various ship types that comprise the OGV and harbor craft source sector in this study. Recreational marine vessels operated primarily for pleasure, such as motorboats, cruisers, yachts, and other types of pleasure craft are not included as they are accounted for in the nonroad model mobile source EI.

Table 2-1. OGV and harbor craft ship types

Vessel Category	Vessel Type	Description
Ocean-going Vessels	Bulk Carrier	Dry-cargo vessels that carry loose cargo (e.g., grain, ore)
	Chemical Tanker	Liquid-cargo vessels that transport chemicals in bulk
	Container Ship	Dry-cargo vessels that carry containerized cargo
	Cruise	Passenger vessels used for commercial pleasure voyages
	General Cargo	Dry-cargo vessels that are not specialized for a particular type of cargo
	Liquified Gas Tanker	Cargo vessels specifically designed to transport liquified gas at high pressure and/or low temperature
	Miscellaneous (C3)	C3 vessels not otherwise designated in this table
	Offshore Support/Drillship	Vessels that support offshore oil and gas platforms or perform exploratory offshore drilling
	Oil Tanker	Liquid-cargo vessels that transport petroleum products in bulk
	Other Tanker	Liquid-cargo vessels that transport cargo not otherwise designated in this list
	Refrigerated (Reefer)	Vessels that carry refrigerated cargo
	Roll-on/Roll-off (RORO)	Vessels that handle cargo that is rolled on and off the ship, such as automobiles, trucks and construction equipment
Harbor Craft	Crew and Supply	Passenger vessels used to carry personnel and supplies to and from offshore and in-harbor locations
	Dredge	Vessels that perform or assist in performing dredging activities
	Fishing (C1/C2)	C1 or C2 vessels used in commercial fishing operations
	Government	Coast Guard, police, fire, or other government-owned vessels
	Harbor Ferry (C1/C2)	Commercial C1 or C2 vessels used for passenger transport
	Miscellaneous (C1/C2)	Commercial C1 or C2 vessels not otherwise designated in this list
	Pilot	Vessels used to transport pilots to or from OGV
	Towboat/Push boat	Vessels used to push barges and pontoons; typically used in harbors and inland waterways
	Tug Boat	Vessels that assist maneuvering other vessels; can be used in open sea, inland waterways, and harbor

Vessel Category	Vessel Type	Description
	Work Boat	Vessels used for utility, inspection, survey, spill response, research, mining, training, and construction

2.1 MARINER Tool

The MARINER tool was used to develop a full suite of CMV EIs for the vessels available in the AIS data. Broadly, the tool is designed to process vessel movement records to estimate vessel activity, merge the results with characteristics of the unique vessels where possible, and generate estimates of vessel emissions. The tool provides detailed results for air quality project planning as well as providing summary reporting results.

The data processing follows the latest guidance from the EPA (EPA, 2020a; hereinafter EPA guidance). The general process is depicted in Figure 2-1. MARINER has five primary functions:

(1) Combining AIS vessel tracking and IHS Sea-web vessel characteristics data sets
(2) Allocating the processed data to shapefiles (e.g. summarized by county)
(3) Detailed vessel type identification and assigning 10-character Source Classification Codes (SCC)
(4) Summarizing processed data by temporal extents (time of day, seasons, etc.)
(5) Performing emission calculations by geographic area, SCC, and time period

The remaining of this Chapter describes MARINER processing steps in more details.

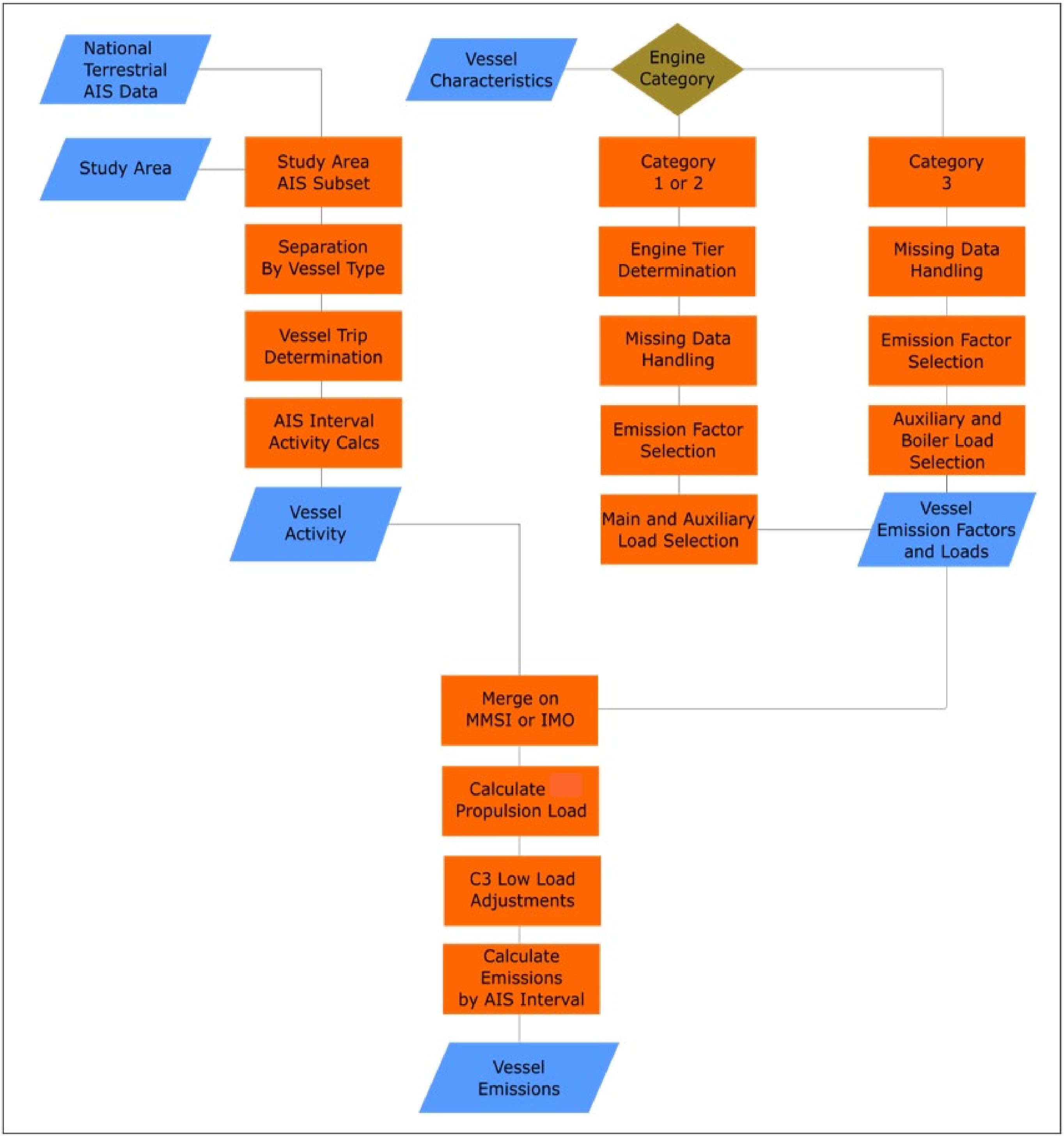


Figure 2-1. Overview of the MARINER emissions estimation process.

2.2 Data Sources

2.2.1 AIS Data

AIS equipment is used on vessels to aid navigation and to avoid collisions by broadcasting and receiving messages. The AIS data are available from the Marine Cadastre website and the IHS Sea-web vessel database. The AIS data are also available via Freedom of Information Act requests, but the data provided by the Marine Cadastre site has been quality assured via the Authoritative Vessel Identification System which corrects vessel identification codes and vessel type indicators. In this project, the AIS data reflecting 2019 (published in August 2020) and 2020 activities (published in April 2021) were obtained from the Marine Cadastre website[2].

The AIS records provide a variety of attributes associated with vessel movements, including position, date and time, speed over ground, course over ground, instantaneous draft, vessel identification codes, and vessel type. These attributes feed into emission calculations in a variety of ways:

- Spatial and temporal allocations can be produced through the use of position and timestamps;
- Ocean-going vessel propulsion engine load can be estimated using the Admiralty formula which relies on speed over ground and draft;
- Vessel specifications can be determined by relating MMSI and/or International Maritime Organization (IMO) codes to a vessel characteristics database;
- Operating mode was estimated using the speed over ground and port spatial definition; and
- Where vessel specifications are unavailable, vessel type from the AIS records was used to relate a vessel to EPA default vessel characteristics.

2.2.2 Vessel Characteristics

Vessel characteristics can be acquired through a variety of suppliers that maintain detailed databases of vessel characteristics. These databases provide a large expanse of data, but the fields which are pertinent to the development of emission estimates are limited to those which provide insight into engine attributes (e.g., bore, stroke, total installed power), design characteristics (e.g., service speed, maximum draft, keel laid date), and vessel use info (e.g., ship type detail). Additional fields can also be of use depending on the end-use of the emissions results. Such fields may include vessel owner, country flag, vessel capacities, or other design features (e.g., number of reefer plugs, shore power capability flag, etc.). This project used the Sea-web Ships database[3] (hereinafter, IHS data) for identifying characteristics of specific vessels.

2.3 Data Processing

The data processing includes AIS data subsetting, AIS data cleansing, voyage determination, activity calculation, vessel classification, and emission calculations. Each of these steps is discussed in the following subsections.

2.3.1 AIS Data subsetting

The extent of the AIS data analyzed for the 2019 and 2020 CMV EIs is shown in Figure 2-2. The resulting emissions are spatially filtered to include only emissions within Texas waters.

[2] https://marinecadastre.gov/ais/

[3] https://ihsmarkit.com/products/sea-web-maritime-reference.html

Figure 2-2. Extent of the AIS data analyzed for the Texas CMV EI

2.3.2 Cleaning AIS Data

While AIS data from the Marine Cadastre site has been quality assured, it is not uncommon for AIS data to contain errors or extraneous data that need to be identified and addressed before emissions can be calculated. For this project, Ramboll removed the following AIS records:

- Miscellaneous entities such as buoys and floats, non-propelled vessels, and helicopters based on the first two or three digits of their MMSI code (e.g. 111xxxxxx, 970xxxxxxx, 972xxxxxx, 974xxxxxx, and 99xxxxxxx).
- Records with negative speed or speed higher than 31.8 knots (kn)[4]
- Records with negative draft

[4] The maximum of default maximum speed across all vessel types based on EPA's 2020 guidance is 26.5 kn (container ship). Ramboll assumed that the valid speed cannot exceed the maximum default by more than 20% (a factor of 1.2).

2.3.3 Voyage Determination

Individual vessel voyages across the domain were established to enable the ability to distinguish unique vessel trips when the same vessel arrives and departs multiple times within a year. Here, a voyage is defined as an individual vessel's contiguous set of points traversing the domain (i.e., a voyage will not exit and reenter the domain). This definition of a voyage generally allows for the classification of distinct inbound and outbound movements.

Initially, the AIS data was sorted so each of the vessel movements is ordered by date and time. The time delta between subsequent AIS records is calculated. A default threshold delta time of 20 minutes is used to delineate voyages for all vessels except cargos and tankers (AIS Vessel Type 70-89). For cargos and tankers, the threshold delta time is set to be 4 hours to account for longer loading and unloading time. If the timespan between two records with the same vessel identification number is greater than the threshold, a new voyage is defined. Or, if a record has a different vessel identification number than the previous record, a new voyage is defined.

2.3.4 Activity Calculation

After voyage determination, activity is calculated for each vessel for each trip segment (or AIS interval). Segment distance is calculated from the latitudinal and longitudinal coordinates of the start and end of a given segment using the Pythagorean Theorem. Because vessel segments are short relative to the curvature of the earth, the segment midpoint is determined by using a simple mathematical average as the midpoint between start and end coordinates. Draft and speed over ground are both calculated as the average value between the start and end of a given segment. These average draft and speed are used in the admiralty formula (Section 2.4.2) to calculate propulsion engine operating power.

2.3.5 Vessel Classification

Unique vessels in the AIS data set are matched to the IHS data, which contains a comprehensive list of vessel engine characteristics, using vessel ID numbers (IMO and MMSI):

- For vessels that have a match in the IHS data set, IHS vessel characteristics are merged with the unique list of vessels from the current AIS domain, and missing fields are first gap-filled with IHS global averages per IHS ship type. IHS ship type is then mapped to EPA ship type to gap-fill any remaining missing fields with EPA best practice information and summarize emissions in later steps.
- For unmatched vessels, the AIS vessel type (from the AIS data set) is mapped to one of the EPA ship types described in the EPA guidance. For instance, Miscellaneous (C1/C2) is the default EPA ship type for AIS vessel type 0[5]. Any remaining missing fields are gap-filled with EPA best practice information for OGV and harbor craft respectively.

Table 2-2. Filling Gaps in Vessel Classification according to the EPA guidance

Parameters	EPA Guidance (EPA, 2020a)
Propulsion engine power, engine type, service speed, max draft	Table C.4. Average OGV Engine Category, Engine Type, Installed Power, Maximum Speed, and Maximum Draft by Ship Type
Propulsion engine power, auxiliary engine power	Table G.1. Default Harbor Craft Engine Sizes and Annual Activity

[5] AIS Vessel Type 0 ("Not available or no ship, default") includes all ships not classified by other categories.

For OGV, ship subtypes are assigned to each vessel according to its ship type and size class based on Table 3.4 in the EPA guidance (EPA, 2020a). If ship size information is not available, a default (most common) subtype will be assigned. For example, the default subtype for bulk carrier is handymax.

Engine category can be determined by calculating cylinder displacement in liters using Equation 2.1. Vessels that have propulsion engines with a per-cylinder displacement of 30 liters or greater are classified as C3, or C1/C2 if less than 30 liters.

$$Cylinder\ Displacement = \frac{\pi}{4} Bore^2 x\ Stroke\ x 10^{-6} \qquad \textbf{Equation 2.1}$$

where engine bore and stroke are measured in millimeters.

2.3.5.1 Vessel Engine Tier Determination

Vessels classified in the previous step as C1/C2 are further characterized as either C1 or C2, and engine tiers are determined for main and auxiliary engines based on cylinder displacement range, power range, and engine model year. Details can be found in Table B.1 in the EPA guidance. This step is conducted only for C1/C2 vessels and is not conducted for C3 vessels.

2.3.5.2 Emission Factors Determination

Emission factors vary by engine category (C1, C2, or C3), group (propulsion, auxiliary, or boiler), fuel type, keel-laid year, and engine type (diesel, turbine, liquified natural gas, electric drive). For inventories of 2015 activity and later, all diesel C3 marine vessels operating within the North American Emissions Control Area (ECA) can be assumed to be using distillate marine gas oil (MGO) or marine diesel oil (MDO) to comply with fuel sulfur regulations, unless local data indicate that specific vessels are using residual marine (RM) or heavy fuel oil (HFO) with exhaust scrubbers. For the 2019 and 2020 inventories, Ramboll assumed that all C3 vessels used MGO/MDO with sulfur levels of 0.1% or lower.

Emission factors are assigned for all (C1, C2, and C3) vessels based on the tables and equations found in the EPA guidance (see Table 2-3). Main and auxiliary engine emission factors are assigned for all vessels, and boiler emission factors are assigned for C3 vessels only.

Table 2-3. Emission factor tables and equations in the EPA guidance

Vessel Category	Parameters	EPA Guidance (EPA, 2020a)
C3	NO_X emission factor	Table 3.5. Category 3 Vessel NOx Emission Factors (g/kWh)
	Brake Specific Fuel Consumption (BSFC) rates	Table 3.6. Category 3 Vessel BSFC Rates (g/kWh)
	PM_{10} emission factor for slow-speed diesel (SSD), medium-speed diesel (MSD) and boilers	Equation 3.3
	PM_{10} emission factor for steam turbine (ST), gas turbine (GT), and liquefied natural gas (LNG) engines	Table 3.7. PM10 Emission Factors (g/kWh) for ST, GT, and LNG Engines on OGV
	CO emission factor	Table 3.8. Category 3 Vessel HC and CO Emission Factors (g/kWh)
	SO_2 emission factor	Equation 3.5
C1/C2	C1/C2 BSFC rates	Table 4.3. Category 1 and 2 BSFC Rates (g/kWh)

Vessel Category	Parameters	EPA Guidance (EPA, 2020a)
	SO_2 emission factor	Equation 4.5
	NO_X emission factor	Table H.1. Category 1 and 2 NO_X Emission Factors (g/kWh)
	PM emission factor	Table H.2. Category 1 and 2 PM ULSD Emission Factors (g/kWh)
	VOC emission factor	Table H.4. Category 1 and 2 HC, VOC, and CH_4 Emission Factors (g/kWh)
	CO emission factor	Table H.5. Category 1 and 2 CO Emission Factors (g/kWh)

PM_{10} and SO_2 emission factor calculation considers actual fuel sulfur level (weight ratio), and for this project, Ramboll assumed that all vessels use 0.1% sulfur content fuel which is applicable to areas within the ECA in year 2015 and beyond. For C3 vessels, $PM_{2.5}$ emission factors are calculated as 92% of the PM_{10} emission factors. VOC emission factors are calculated as 1.053 times the HC emission factors for all vessels.

2.4 Ocean-Going Vessels Emissions Methodology

2.4.1 Emission Estimation Overview

OGV typically have three kinds of emission sources:

- Propulsion engines, also referred to as main engines, which supply power to move the vessel
- Auxiliary engines, which supply power for non-propulsion (e.g., electrical) loads
- Boilers, which heat fuel and water

OGV base year emissions from each type of emission source can be estimated for each vessel:

$$E = P \times A \times E\text{F} \times LLA\text{F} \qquad \textbf{Equation 2.2}$$

Where E = per vessel emissions (g)
P = engine operating power (kW)
A = engine operating activity (h)
$E\text{F}$ = emission factor (g/kWh)
$L\text{LAF}$ = low load adjustment factor, a unitless factor that reflects increasing propulsion emissions during low load operations (always 1 for auxiliary engines and boilers)

Each of the above parameters models a specific emissions source (propulsion engine, auxiliary engine, or boiler) and thus will change for each vessel or vessel population. Table 2-4. summarizes tables that are used in OGV emissions calculation.

Table 2-4. OGV related parameters in the EPA guidance

Parameters	EPA Guidance
Low load adjustment factors (LLAF)	Table 3.10. C3 Propulsion Engine Low Load Adjustment Factors (unitless)
Operating mode	Table 3.11. Considerations for Determining Operating Mode
Auxiliary engine loads by operating mode	Table E.1. Default OGV Auxiliary Engine Operating Loads by Mode
Boiler loads by operating mode	Table E.2. Default OGV Boiler Loads by Operating Mode

2.4.2 Propulsion Engine Operating Power

Propulsion engine operating power is calculated for each AIS record using the admiralty formula:

$$P_p = P_{ref} \times (\frac{V}{V_{ref}})^3 \times (\frac{D}{D_{ref}})^{\frac{2}{3}} \times SM$$ **Equation 2.3**

Where P_p = propulsion engine operating power (kW)
P_{ref} = vessel's total installed propulsion power (kW)
V = average speed in a segment as calculated in Section 2.3.4 (kn)
V_{ref} = vessel's service speed (kn)
D = average draft in a segment as calculated in Section 2.3.4 (m)
D_{ref} = vessel's maximum draft (m)
SM = sea margin, which accounts for average weather conditions, assumed to be 1.10 for coastal operations and 1.15 at-sea operations (unitless)

Sea margin accounts for the resistance from waves and wind that puts additional load on the propeller, which increases the propulsion engine operating power. See Section 2.6 on how sea margin is defined.

2.4.3 Propulsion Engine Load Factor

Load factor describes how much power an engine is producing as a fraction of its maximum rated power. It is also used to determine the vessel's operating mode (see Section 2.4.5) and to determine if low load adjustment factors need to be applied when calculating propulsion engine emissions. The propulsion engine load factor is calculated for each AIS record:

$$LF = \frac{P_p}{P_{ref}}$$ **Equation 2.4**

Where LF = propulsion engine load factor (unitless)
P_p = propulsion engine operating power for each AIS record (kW), from Equation 2.3
P_{ref} = vessel's total installed propulsion power (kW)

The maximum limit of P_p is set to the vessel's total installed propulsion power (P_{ref}), such that its load factor does not exceed 100%. The maximum limit of load factor is set to be 82% with the assumption that service speed is approximately 94% of maximum speed. Therefore, if the calculated load factor is higher than 82%, it's capped as 82%.

2.4.4 Low Load Adjustment Factor

The propulsion engine emission factors presented in Section 2.3.5.2 assume that the vessel's propulsion load is more than 20% of its total installed propulsion power. Below that threshold, emissions per unit of energy tend to increase as the engine load decreases. This is because diesel engines are less efficient at low loads and BSFC tends to increase. To account for this, low load adjustment factors should be applied in Equation 2.2 when the propulsion engines are operating at less than 20% load. Electric drive (MSD or GT) engines do not need low load adjustment factors.

2.4.5 Operating Mode Assignment

The ship's operating mode is determined for each AIS record, as this information is used to determine if the propulsion engine is being used, as well as to calculate auxiliary engine and boiler emissions. When transiting, emissions are produced by the main and auxiliary engines, but the boiler is not used under typical loads because heat is recovered from main engines. In maneuvering, all three sources are typically used because at these low loads inadequate heat is generated by the main engines. When hotelling, a vessel either uses auxiliary engines and boilers, or shore power if available and the ship is equipped to use it. Information on shore power is not readily available and thus not being considered in this project.[6] While at anchor (hoteling), a vessel uses its auxiliary engines and boilers; propulsion engines are not used in this mode.

This study binned speeds to operating mode (Table 2-5) as transiting (>= 3 kn), maneuvering (> 1 kn and < 3 kn), or hotelling (< 1 kn) and associated them with the respective loads provided in the EPA guidance.

Table 2-5. Criteria for determining operating mode

Operating Mode	Speed	Propulsion Engine Load Factor
Hotelling	<= 1 kn	N/A
Maneuvering	> 1 kn	<= 20%
	> 1 kn and < 3 kn	> 20%
Transiting	> 3 kn	> 20%

2.4.6 Auxiliary and Boiler Emissions

Unlike propulsion engine loads (the calculation of which is discussed in Sections 2.4.2), auxiliary engine and boiler usage cannot be obtained from vessel activity data sets. Instead, once the operating mode is assigned for each AIS record, auxiliary engine and boiler loads can be determined using Tables E.1 and E.2 in the EPA guidance (EPA, 2020a). Emissions for auxiliary engines and boilers can be calculated for each time interval between consecutive AIS records for each vessel:

$$E = P \times A \times EF \qquad \textbf{Equation 2.5}$$

Where E = auxiliary engine or boiler emissions for each AIS record (g)

P = auxiliary engine operating power or boiler load for each AIS record based on operating mode (kW)
A = time interval between consecutive AIS records (h)
EF = emission factor (g/kWh)

[6] Shore power or alternative emissions control (such as shore-based scrubbers) in use while hotelling can be incorporated as an additional feature of the model provided the time connected to shore power and/or the emissions control impact is available.

2.5 Harbor Craft Emissions Methodology

2.5.1 Emission Estimation Overview

Unlike OGV, harbor craft typically do not have boilers and only have propulsion engines and auxiliary engines as emission sources, resulting in simpler emission calculations. Harbor craft base year emissions from both propulsion and auxiliary engines can be determined for each vessel using Equation 2.6:

$$E = P \times \mathrm{LF} \times A \times E\mathrm{F} \qquad \textbf{Equation 2.6}$$

Where E = per vessel emissions (g)
P = engine operating power (kW)
$L\mathrm{F}$ = engine load factor (unitless)
A = engine operating activity (h)
$E\mathrm{F}$ = emission factor (g/kWh) [See Table 2-3]

Engine operating power is obtained for each vessel as described in Section 2.3.5. Ramboll applied the default propulsion engine load factors from California Air Resources Board, as presented in Table 4.4 in the EPA guidance. In order to have consistency in the inventory, the same criteria for determining the operating mode for OGV (Section 2.4.5) was used to assign operating modes to harbor craft.

2.6 Spatial Analyses

The MARINER tool uses the latitude and longitude obtained from the AIS data to intersect with a geographic information system (GIS) shapefile (or set of multiple shapefiles) for spatial analysis. Three shapefiles were used to generate the CMV EIs (see Table 2-6):

- Coastal Shapefile: The coastal shapefile provides sea margin boundary which is used by the Propeller Law and admiralty formula to adjust propulsion operating powers for coastal operations (EPA, 2020a).
- EPA CMV Shapefile: As part of the 2017 NEI, EPA released a CMV shapefile for states to assign emissions related to port or underway activities.
- County Shapefile: The county shapefile is used to assign emissions within state waters to applicable counties in Texas. State waters generally extend 3-10 nautical miles from the coastal lines as defined by the TCEQ county shapefile. As illustrated in Figure 2-4, the EPA CMV shapefile defines state waters as starting from coastal barriers which are further out from coastal lines. Using the EPA's shapefile would result in higher emissions assigned to Texas counties.

Table 2-6. Shapefile used in spatial analysis

Shapefile	Function	Data Source
Coastline Shapefile	Define Sea Margin	GIS Basemap https://catalog.data.gov/dataset/tiger-line-shapefile-2019-nation-u-s-coastline-national-shapefile
Port and Underway	Assign emissions related to port or underway activities	EPA's 2017 CMV Shapefile (see Figure 2-3) https://www.epa.gov/sites/production/files/2019-10/2017cmv_gisshapeid_currentandretired_21oct2019.zip
County Boundary	Assign emissions to county	TCEQ County Boundary Shapefile (provided by TCEQ) (alternatively, EPA's 2017 CMV Shapefile may be used)

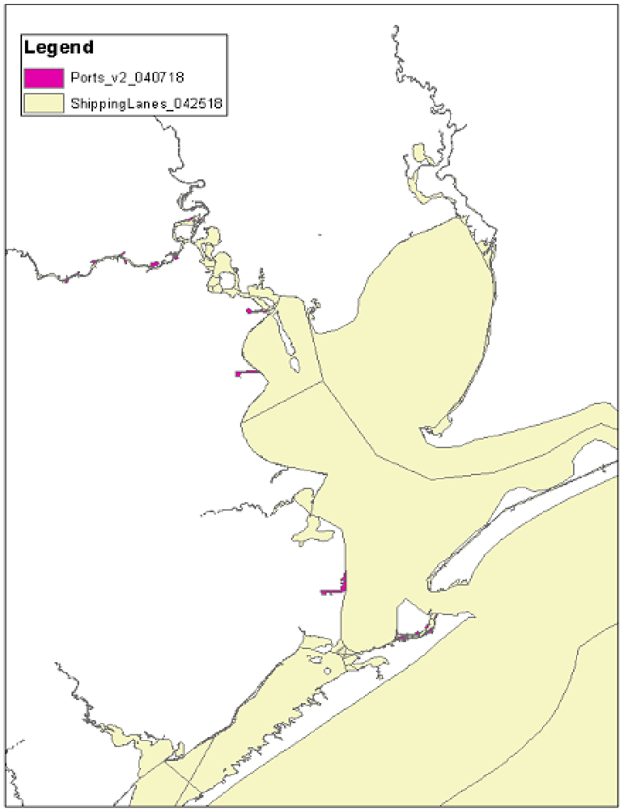
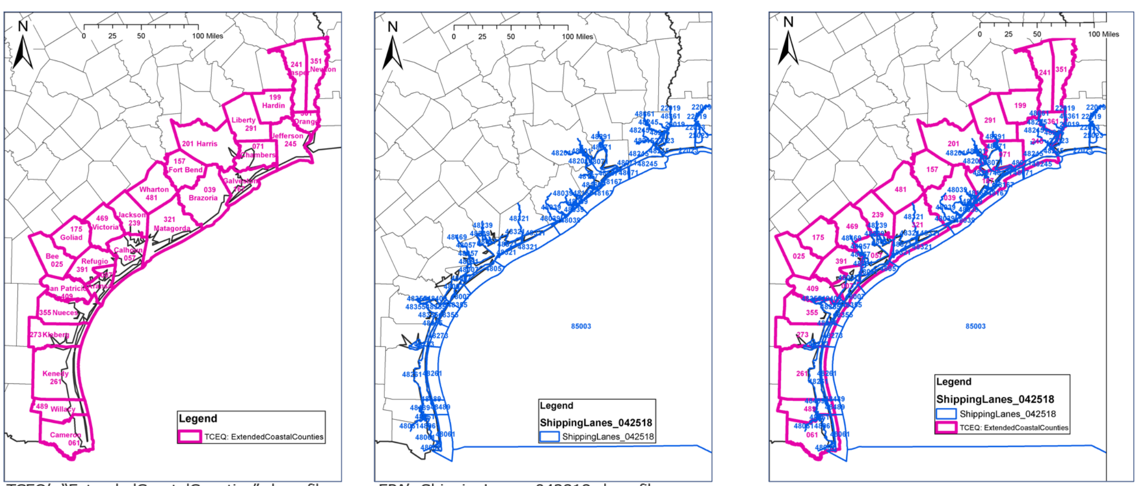


Figure 2-3. Example of EPA's 2017 Shapefile that defines at-port (pink) and underway (yellow) activities



TCEQ's "ExtendedCoastalCounties" shapefile that extends counties offshore and defines county boundaries in water bodies

EPA's ShippingLanes_042818 shapefile

TCEQ and EPA overlay

Figure 2-4. State waters defined by the TCEQ county shapefile (left) and by the EPA's CMV shapefile (middle). Overlay of these two shapefiles shown in the right panel.

2.7 Reporting to EPA's AERR

The MARINER tool outputs emissions by diverse ranges of vessel types, engine types, and/or fuel types. These levels of detail were carried through all calculations, but can be aggregated according to reporting requirements. EPA only requires 12 CMV SCCs (Table 2-7) to distinguish vessels primarily powered by C1/C2 and C3 engines. Ramboll discussed with EPA and TCEQ the proper method to define C1/C2 or C3 vessels, the spatial definition of 'Port' and 'Underway,' over-water county, and sea margin definitions. The spatial analyses to define these spatial definitions are described in detail in Section 2.6.

Since January 1, 2015, the North American ECA regulation has required that vessels use 0.1% sulfur or less fuel in US waters. Residual fuels are heavy fuel oils with high sulfur content (up to 3.5%) and therefore do not meet the ECA requirement. Therefore, only 8 SCCs are used for the 2019 baseline emissions and trends, but this does not necessarily mean that diesel fuel is used to meet this fuel quality requirement.

Table 2-7. SCC Definitions for Commercial Marine Sources[7]

SCC	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four
2280002101	Mobile Sources	Marine Vessels, Commercial	Diesel	C1/C2 Port emissions: Main Engine
2280002102	Mobile Sources	Marine Vessels, Commercial	Diesel	C1/C2 Port emissions: Auxiliary Engine
2280002201	Mobile Sources	Marine Vessels, Commercial	Diesel	C1/C2 Underway emissions: Main Engine
2280002202	Mobile Sources	Marine Vessels, Commercial	Diesel	C1/C2 Underway emissions: Auxiliary Engine
2280002103	Mobile Sources	Marine Vessels, Commercial	Diesel	C3 Port emissions: Main Engine
2280002104	Mobile Sources	Marine Vessels, Commercial	Diesel	C3 Port emissions: Auxiliary Engine
2280002203	Mobile Sources	Marine Vessels, Commercial	Diesel	C3 Underway emissions: Main Engine
2280002204	Mobile Sources	Marine Vessels, Commercial	Diesel	C3 Underway emissions: Auxiliary Engine
2280003103	Mobile Sources	Marine Vessels, Commercial	Residual	C3 Port emissions: Main Engine
2280003104	Mobile Sources	Marine Vessels, Commercial	Residual	C3 Port emissions: Auxiliary Engine
2280003203	Mobile Sources	Marine Vessels, Commercial	Residual	C3 Underway emissions: Main Engine
2280003204	Mobile Sources	Marine Vessels, Commercial	Residual	C3 Underway emissions: Auxiliary Engine

The MARINER tool can process and summarize emissions for a defined temporal period. The tool was configured to report emissions for all applicable Texas counties for 1) summer work weekday (ozone season) in tons per day (i.e., averaged emissions from June through August, Monday through Friday) and 2) annual in tons per year for all 8,760 hours that occur in a 365-day calendar year.

Ramboll provided Consolidated Emissions Reporting Schema (CERS) Extensible Markup Language (XML) files formatted as non-point inventories (per EPA's suggestion) that meet the requirements to

[7] 2017 National Emissions Inventory Technical Support Document (TSD) available from the US EPA at https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-technical-support-document-tsd

be uploaded into the EPA's AERR for the 2020 controlled annual statewide CMV EI. A test CERS XML file was uploaded and exported through the EPA's Emission Inventory System (EIS) Bridge Tool[8] in Quality Assurance (QA) mode (Submission Type = QA). The XML conversion report is shown in Figure 2-5.

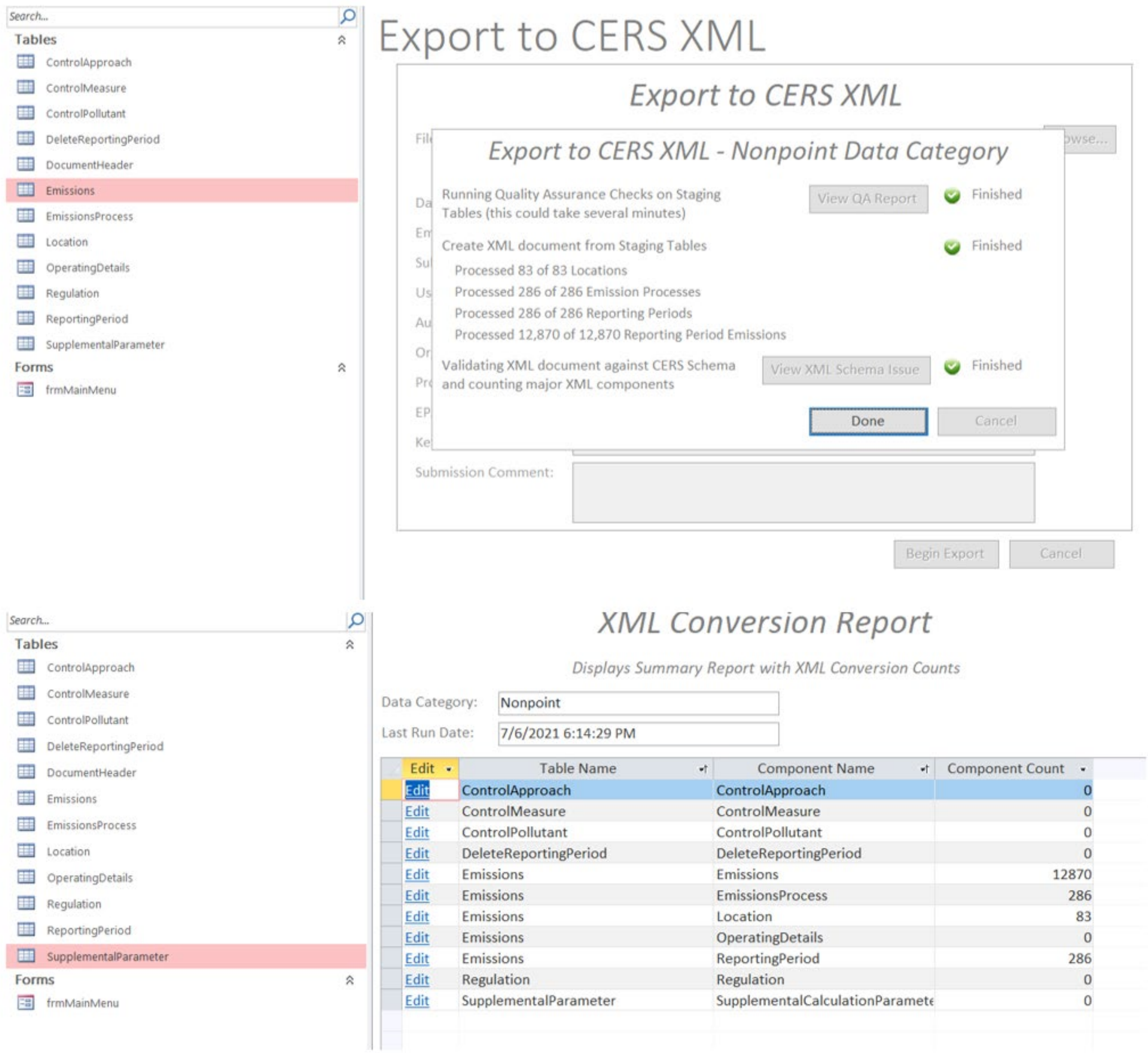


Figure 2-5. Screen capture of the XML conversion report through the Bridge Tool

2.8 Reporting to TCEQ's AERR

Ramboll provided XML files formatted as non-road mobile inventories that meet the requirements to be uploaded into the TCEQ's TexAER database for all 2011 through 2050 controlled and uncontrolled annual and ozone season daily statewide CMV EIs. A test CERS XML file has been provided to the TCEQ Project Manager to confirm that the file can be successfully entered into the TexAER test environment. This test ensures correct formatting for all CERS XML files is met.

[8] https://www.epa.gov/sites/production/files/2021-03/area_bridgetool_v2.accdb

3.0 TEXAS 2019 AND 2020 CMV EI

Ramboll developed two calendar year, 2019 and 2020, CMV EIs for Texas using the 2019 and 2020 AIS data, respectively, together with the methods and assumptions described in Chapter 2. The 2019 EI serves as a basis for trend analysis (Chapter 4). Developing a 2020 EI serves two purposes: 1) to provide TCEQ with another option for NEI submission and 2) to compare with a forecasted 2020 CMV EI completed in this study. Statewide annual (tons per year) controlled CMV emissions for 2019 and 2020 are presented in this Chapter.

3.1 Texas 2019 CMV EI

Statewide annual (tons per year) controlled CMV emissions for 2019 are summarized in Table 3-1 and Table 3-2.

Table 3-1. 2019 statewide annual controlled CMV emissions (tons) by ship type.

Source	Ship Type	NO_x	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Ocean-going Vessels	Bulk Carrier	961	46	111	20	19	48
	Chemical Tanker	4,875	229	556	104	96	242
	Container Ship	1,109	60	128	21	19	51
	Cruise	540	23	59	10	10	23
	General Cargo	1,565	69	171	31	28	71
	Liquified Gas Tanker	831	42	91	37	34	102
	Miscellaneous (C3)	74	3	8	1	1	3
	Offshore Support/Drillship	20	1	3	1	0	1
	Oil Tanker	3,267	159	361	110	101	289
	Other Tanker	330	15	34	10	9	25
	Reefer	30	1	3	1	1	1
	RORO	646	28	69	14	12	32
	Subtotal	**14,247**	**677**	**1,595**	**359**	**330**	**887**
Harbor Craft	Crew and Supply	246	8	41	5	5	0
	Dredge	342	7	60	6	6	0
	Fishing (C1/C2)	739	17	124	13	12	0
	Government	5	0	1	0	0	0
	Harbor Ferry (C1/C2)	356	5	69	7	7	0
	Miscellaneous (C1/C2)	1,650	54	305	38	37	2
	Pilot	105	3	32	2	2	0
	Towboat/Push boat	16,089	205	2,918	267	259	8
	Tug Boat	3,015	64	624	62	60	2
	Work Boat	79	2	13	2	2	0
	Subtotal	**22,625**	**366**	**4,188**	**402**	**390**	**13**
	Total	**36,872**	**1,043**	**5,783**	**761**	**720**	**900**

Table 3-2. 2019 statewide annual controlled CMV emissions (tons) by SCC

Vessel Category	SCC	Mode	Engine	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
C1/C2	2280002101	Port	Prop	587	8	114	10	9	0
	2280002102	Port	Aux	1,361	40	222	31	30	1
	2280002201	Underway	Prop	17,047	204	3,273	278	269	9
	2280002202	Underway	Aux	3,630	113	579	84	81	3
	Subtotal			**22,625**	**366**	**4,188**	**402**	**390**	**13**
C3	2280002103	Port	Prop	24	3	4	0	0	1
	2280002104	Port	Aux	4,729	222	556	151	139	383
	2280002203	Underway	Prop	4,254	209	424	52	48	113
	2280002204	Underway	Aux	5,240	243	611	156	143	390
	Subtotal			**14,247**	**677**	**1,595**	**359**	**330**	**887**
	Total			**36,872**	**1,043**	**5,783**	**761**	**720**	**900**

3.2 Texas 2020 CMV EI

Statewide annual (tons per year) controlled CMV emissions for 2020 are summarized in Table 3-3 and Table 3-4.

Table 3-3. 2020 statewide annual controlled CMV emissions (tons) by ship type.

Vessel Category	Ship Type	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Ocean-going Vessels	Bulk Carrier	886	43	103	19	18	45
	Chemical Tanker	4,258	204	498	94	86	219
	Container Ship	1,122	60	129	21	20	52
	Cruise	362	15	40	7	6	16
	General Cargo	1,306	58	145	26	24	60
	Liquified Gas Tanker	891	46	99	42	38	114
	Miscellaneous (C3)	77	3	8	1	1	3
	Offshore Support/Drillship	16	1	3	1	1	1
	Oil Tanker	2,791	137	313	97	89	254
	Other Tanker	270	13	28	8	8	21
	Reefer	24	1	3	1	0	1
	RORO	741	32	78	16	14	37
	Subtotal	**12,745**	**614**	**1,449**	**332**	**306**	**824**
Harbor Craft	Crew and Supply	235	7	39	5	5	0
	Dredge	643	16	113	11	11	0
	Fishing (C1/C2)	816	20	136	14	14	0
	Government	5	0	1	0	0	0
	Harbor Ferry (C1/C2)	390	5	75	8	7	0
	Miscellaneous (C1/C2)	2,098	73	391	50	48	2

Vessel Category	Ship Type	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
	Pilot	107	3	33	2	2	0
	Towboat/Push boat	14,433	185	2,615	240	233	7
	Tug Boat	2,746	59	578	55	54	2
	Work Boat	70	2	12	1	1	0
	Subtotal	**21,542**	**369**	**3,992**	**387**	**375**	**13**
	Total	**34,287**	**983**	**5,441**	**719**	**681**	**837**

Table 3-4. 2020 statewide annual controlled CMV emissions (tons) by SCC

Vessel Category	SCC	Mode	Engine	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
C1/C2	2280002101	Port	Prop	519	7	105	9	8	0
	2280002102	Port	Aux	1,427	43	232	33	32	1
	2280002201	Underway	Prop	15,575	190	3,007	252	245	9
	2280002202	Underway	Aux	4,021	128	647	93	90	3
	Subtotal			**21,542**	**369**	**3,992**	**387**	**375**	**13**
C3	2280002103	20	3	3	0	0	1	0	1
	2280002104	4,290	205	511	139	128	355	128	355
	2280002203	3,625	179	363	45	41	96	41	96
	2280002204	4,810	227	571	148	136	373	136	373
	Subtotal			**12,745**	**614**	**1,449**	**332**	**306**	**824**
	Total			**34,287**	**983**	**5,441**	**719**	**681**	**837**

4.0 TREND ANALYSIS

The marine emissions forecasts developed for this project are based on the predicted change in vessel activity and expected emission reductions due to emission regulations and fleet turnover occurring from calendar years 2011 through 2050. The 2019 CMV EI serves as a basis for all emissions forecasts.

Ramboll approximated vessel activity relative to broad economic growth estimates (e.g., gross state product) and considered relative growth by ship-type by assessing the trends of the associated commodities which those ship types serve. Ramboll assessed how the tonnage of cargo moved by ship-type varied from 2011 through 2019 to understand how each commodity was trending. These trends were compared with the gross state product (GSP) over that period and were used to inform future year activity estimates.

Emission rates were assessed based on engine emissions (especially NO_x) controls and fuel sulfur limits using EPA default estimates. The resulting relative historic activity and emission rates for 2011 – 2019 and forecasted activity and emissions through 2050 were compiled as scaling values to adjust the AIS-derived 2019 emissions.

4.1 Economic Trends

The broad economic growth trends and, importantly, forecasts were taken from the Texas GSP estimates, shown in Table 4-1, and developed by Texas Comptroller's Office. The GSP relative to 2019 provides one mechanism to forecast AIS-derived 2019 activity and emissions to future years or backcast to previous years. The compound average growth rate (CAGR) for 2011 to 2019 averaged about 3.7% per year. After the downturn in economic activity in 2020 that is expected to continue in 2021, the State of Texas Comptroller expects that the Texas economy will rebound at 4.0% per year growth rates between 2021 and 2025 before gradually returning to an average growth rate of about 2.5% per year after 2025 to 2050.

Table 4-1. Gross State Product (GSP, Billion 2012$)[9]

Calendar Year	GSP	Relative to 2019		Calendar Year	GSP	Relative to 2019
2011	1,344	0.751		2031	2,388	1.335
2012	1,411	0.789		2032	2,451	1.370
2013	1,472	0.823		2033	2,515	1.406
2014	1,523	0.852		2034	2,583	1.444
2015	1,596	0.893		2035	2,651	1.482
2016	1,600	0.895		2036	2,717	1.519
2017	1,646	0.920		2037	2,785	1.557
2018	1,713	0.958		2038	2,852	1.594
2019	1,789	1.000		2039	2,919	1.632
2020	1,729	0.967		2040	2,991	1.672
2021	1,741	0.973		2041	3,065	1.714
2022	1,815	1.015		2042	3,137	1.754
2023	1,897	1.060		2043	3,210	1.795

9 https://comptroller.texas.gov/transparency/reports/forecasts/

Calendar Year	GSP	Relative to 2019		Calendar Year	GSP	Relative to 2019
2024	1,974	1.103		2044	3,285	1.837
2025	2,033	1.137		2045	3,364	1.881
2026	2,090	1.169		2046	3,446	1.927
2027	2,148	1.201		2047	3,531	1.974
2028	2,207	1.234		2048	3,638	2.034
2029	2,265	1.267		2049	3,719	2.080
2030	2,328	1.301		2050	3,802	2.126

To assess type-specific trends in vessel activity, tonnage data[10] for the major Texas ports were used to compare yearly shipments from 2011 through 2019, as shown in Table 4-2. The Texas ports are affected by world and regional trends in addition to the general business climate in Texas. The overall business activity growth over the past few years has been reflected in the Port traffic. Trade disputes, infrastructure, and other factors may affect future years' activity. In addition, unique factors affect port traffic by freight type. One important freight category for Texas ports is tanker traffic carrying crude oil, petroleum gases, and refined petroleum product marine shipments affected by increased domestic oil and gas production, lifting export restrictions on crude oil, natural gas shipping infrastructure improvements and other factors.

Another factor affecting port business besides overall business activity was the Panama Canal expansion allowing more Pacific shipping to reach Texas. The Panama Canal expansion, opened at the end of June 2016, could have increased Gulf port traffic incrementally to the overall business climate. A study by the Texas Transportation Institute (TTI, 2018) outlined the rationale for forecasting freight trends with more ships to and from Texas ports due the Canal expansion. A significant upward step change in container traffic was seen in the time frame after 2016, but it is difficult to know whether that trend would have persisted without the business disruption during 2020.

Table 4-2 shows that the recent trend of freight tonnage through Texas ports (2.7% per year) has been comparable but consistently lower than the overall Texas economic activity of 3.7% per year between 2011 and 2019. The Texas intracoastal traffic (exclusively served by smaller C1/C2 vessels) activity rose from 2011 to a peak in 2014 and declined to 2019 with overall growth during that period averaging 0.4% per year lower but comparable to the 0.9% per year that EPA (2008) forecasted activity growth for smaller C1/C2 engine powered vessels.

Table 4-2. Major Texas Freight Ports (short tons). [11]

Summary	2011	2012	2013	2014	2015	2016	2017	2018	2019
Brownsville	5,907,041	5,600,977	5,533,332	6,947,890	7,779,109	7,275,272	7,763,455	8,348,358	6,632,612
Corpus Christi	70,537,732	69,001,357	76,157,693	84,928,330	85,674,966	81,981,061	87,322,735	93,468,323	111,223,976
Houston	237,798,639	238,185,582	229,246,833	234,304,391	240,933,410	247,981,663	260,070,837	268,930,047	284,944,468
Freeport	23,311,868	22,084,551	19,716,053	22,327,032	21,132,931	19,635,949	24,484,399	25,258,109	29,608,995
Galveston	13,743,671	11,618,368	11,406,750	10,669,437	10,380,588	9,880,157	7,836,405	9,111,500	10,958,425

[10] http://www.navigationdatacenter.us/wcsc/wcsc.htm

[11] http://www.aapa-ports.org/unifying/content.aspx?ItemNumber=21048 or https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center/

Summary	2011	2012	2013	2014	2015	2016	2017	2018	2019
Sabine-Neches Waterway	137,217,861	141,090,169	159,426,717	160,164,823	159,032,698	158,309,165	178,506,826	193,735,364	192,438,408
Texas City	57,757,532	56,721,627	49,674,036	47,884,949	42,923,997	41,260,475	37,751,062	42,682,311	41,338,934
Victoria	3,528,265	4,517,632	5,519,511	6,475,670	6,733,044	5,082,077	4,337,003	3,860,635	2,672,649
Major Ports Subtotal	549,802,609	548,820,263	556,680,925	573,702,522	574,590,743	571,405,819	608,072,722	645,394,647	679,818,467
Ports Trend	**2.7% per year**								
Gulf Intracoastal Waterway, Sabine River to Galveston	59,131,793	59,577,157	60,540,011	67,560,374	64,893,380	62,940,576	64,955,410	63,509,367	63,366,609
Gulf Intracoastal Waterway, Galveston to Corpus Christi	25,560,943	29,313,821	29,943,854	33,788,775	29,342,116	25,834,871	23,759,783	24,285,093	23,992,155
Gulf Intracoastal Waterway, Corpus Christi to Mexican Border	2,211,700	1,920,242	1,772,809	1,808,531	1,516,728	1,613,635	2,030,352	2,193,040	2,495,732
Intracoastal Subtotal	86,904,436	90,811,220	92,256,674	103,157,680	95,752,224	90,389,082	90,745,545	89,987,500	89,854,496
Intracoastal Trend	**0.4% per year**								

For an investigation into the other cargo types, the Port of Houston provided an overview of recent activity through a limited set of Houston facilities shown in Table 4-3 and Table 4-4. Non-containerized general cargo has increased in the last few years at a higher rate than the Port tonnage. Bulk cargo fluctuates year to year but has been trending level or down for several years. Containerized cargo has shown steady increases year over year, averaging 10-11% per year growth from 2016 through 2019 until 2020, perhaps reflecting the Panama Canal expansion, but growth was slower averaging 3.1% per year from 2011 to 2016. Most of the liquid bulk cargo comes through private terminals in Houston and are not shown in the Table 4-3 and Table 4-4 figures.

Table 4-3. Port Houston Authority Freight by Type (not including private facilities) [12]

Type	2016	2017	2018	2019	2020	2019/2016
Containerized (TEU)*	2,182,720	2,459,107	2,699,850	2,990,175	2,989,347	1.370
Containerized (tons)	21,907,270	24,290,910	26,587,883	29,064,799	28,750,334	1.327
Gen. Cargo: Steel	2,231,515	3,694,676	4,363,788	4,013,157	2,253,366	
Gen. Cargo: Other General Cargo	870,556	892,217	701,029	890,466	704,431	
Total General Cargo	25,009,341	28,877,803	31,652,700	33,968,422	31,708,131	1.358
Total Bulk Cargo* (w/o Bayport chemicals)	10,053,452	9,396,090	9,210,586	9,267,268	9,979,479	0.922
Total PHA Tonnage	35,062,793	38,273,893	40,863,286	43,235,690	41,687,610	1.233

* twenty-foot equivalent units

[12] https://porthouston.com/about-us/statistics/ , "Annual Summary of Port Houston Cargo Tonnage stats"

Table 4-4. Port Houston Authority Container TEU (not including small private facilities) [13]

Houston	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TEU	1,866,439	1,922,479	1,950,071	1,951,088	2,130,540	2,182,720	2,459,107	2,699,850	2,990,175	2,989,347
Change from Previous Year	1.03	1.03	1.01	1.00	1.09	1.02	1.13	1.10	1.11	1.00

Galveston cruise ship growth has been strong in recent years and, through 2019, was reported[14] to show an increase from 2012 of 10% per year as indicated in Table 4-5. Part of the recent growth at Galveston is due to the Port of Houston abandoning its cruise ship terminal business in 2016.[15] It is unlikely that growth would have continued at the 2013-2019 rate for many more years. With the suspension of cruise ship operations in 2020 and likely much of 2021, growth in cruise ship traffic is unlikely to continue until after 2021. Ramboll estimated that incremental growth will begin again in 2022 and be relative to the State GSP compared with 2019.

Table 4-5. Texas Cruise Passenger Ship Activity[16]

Port	2013	2014	2015	2016	2017	2018	2019
Houston	26,904	110,643	125,856	83,810	0	0	0
Galveston	1,208,802	1,285,884	1,658,070	1,730,289	1,861,549	1,966,176	2,195,648
Total	**1,235,706**	**1,396,527**	**1,783,926**	**1,814,099**	**1,861,549**	**1,966,176**	**2,195,648**
Relative to 2013		1.13	1.44	1.47	1.51	1.59	1.78 10% CAGR

Much of the freight tonnage through Texas ports is liquid bulk freight that is largely affected by petroleum oil, gas, and associated products. Lower crude oil imports were mostly offset by increased exports[17], so the demand for crude oil tanker traffic has been generally unaffected. Crude oil shipments in Table 4-6 reflect both import and exports and reflect the changing nature of the industry and where petroleum is produced. Some year over year increases and decreases have been experienced over the past decade, with 2018 and 2019 being the busiest years, indicating an overall average growth of 2.9% per year. Refinery products shipped by tanker are a large portion of port freight totals and contribute to tanker business activity.

Table 4-6. Crude Petroleum Shipments (tons) by Selected Texas Ports

Port \ Year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Corpus Christi	23,055,280	22,529,123	29,322,537	37,045,792	39,727,637	34,004,475	37,400,099	42,991,919	57,361,104
Houston	50,892,083	57,079,809	48,999,430	49,735,310	45,338,068	45,780,894	45,290,239	55,020,456	68,068,188
Freeport	14,416,799	14,187,785	11,764,138	13,024,153	10,844,508	9,002,594	9,580,316	10,400,194	12,650,262
Sabine-Neches Waterway	51,391,962	57,447,444	68,804,118	64,933,944	58,820,223	51,697,442	60,118,274	68,010,144	66,973,268
Texas City	30,953,558	28,596,225	21,404,145	17,864,941	13,927,679	13,339,723	11,479,711	11,615,389	10,106,847
Total of Ports	170,709,682	179,840,386	180,294,368	182,604,140	168,658,115	153,825,128	163,868,639	188,038,102	215,159,669

[13] https://porthouston.com/wp-content/uploads/Container-Volume-TEU-stats-in-depth-February-2021.pdf

[14] https://www.portofgalveston.com/CivicAlerts.aspx?AID=73

[15] https://www.houstonchronicle.com/business/article/With-cruise-ships-gone-Port-of-Houston-decides-8425454.php

[16] https://www.portofgalveston.com/122/Statistics

[17] https://www.eia.gov/energyexplained/index.php?page=oil_imports

There are reasons to anticipate that some types of commercial marine activity will be higher or lower than overall Texas business activity in future years. Container and cruise passenger (regardless of the disruption of this industry in 2020 and 2021) growth could be higher than the overall Texas business activity. Solid bulk in Houston has not shown any growth in activity during the past decade, and overall port (including crude petroleum) traffic has been slower than Texas GSP. Both EPA data (2008) and evidence from the intracoastal waterway activity indicate that smaller C1/C2 vessel activity growth will be slower than general economic activity suggest.

In summary, Ramboll chose to rely on historic freight movement to backcast vessel activity, and Texas GSP for forecasting for the larger Category 3 shipping activity. Container traffic measured in twenty-foot equivalent units (TEU) is well documented, and, though container numbers do not directly translate to vessel activity, TEU statistics reflect freight demand. Solid bulk (e.g. sand and gravel, grain, cement, limestone) growth has lagged overall in the recent past, so Ramboll chose to include that lower demand for projections. Cruise ship activity was severely curtailed in 2020 and into 2021, but the demand is expected to return in 2022. Total freight tonnage is assumed to best represent the remaining vessel activity (primarily tankers but also general cargo) over the past few years with the Texas GSP representing future forecasted demand.

The smaller C1/C2-powered vessel activity has historically lagged behind indicated economic activity growth, especially for long-haul intracoastal freight. It is often impossible to separate all C1/C2 business activity from the overall port freight statistics predominately carried by Category 3 vessels, and other C1/C2 sectors (off-shore support, ship assist, short-haul movements) might have grown faster than the historic trend along the intracoastal waterway. Ramboll relied on the EPA (2008) estimated average growth rate for smaller C1/C2 vessel activity.

Table 4-7 summarizes the selection of activity surrogates (presented in Table 4-1 through Table 4-6) to project 2019 AIS vessel activity to past and future years.

Table 4-7. Surrogate to develop vessel activity trends

<table>
<tr><th>Propulsion</th><th colspan="4">Category 3</th><th>Category 1&2</th></tr>
<tr><th>Year \ Type</th><th>Container</th><th>Solid Bulk</th><th>Cruise</th><th>All Others</th><th>All</th></tr>
<tr><td>2011 - 2015</td><td rowspan="3">Houston TEUs</td><td>Texas GSP</td><td rowspan="2">Galveston Passengers</td><td rowspan="2">Texas Major Ports Tonnage Trend</td><td rowspan="5">EPA (0.9% per year)</td></tr>
<tr><td>2016 - 2019</td><td rowspan="2">Houston Tonnage</td></tr>
<tr><td>2020</td><td>2 months</td><td rowspan="3">Texas GSP</td></tr>
<tr><td>2021</td><td rowspan="2">Texas GSP</td><td rowspan="2">Texas GSP</td><td>2 months</td></tr>
<tr><td>2021+</td><td>Texas GSP</td></tr>
</table>

4.2 Emissions Forecasting

4.2.1 Category 3 Ocean-Going Vessels

Emissions from ship engines and boilers have been regulated by the IMO[18], including limited fuel sulfur levels and new ship engine NOx emission rates as well as other air emissions from ships including those from incineration, tanker venting, and ozone depleting substances. IMO regulations set worldwide maximum fuel sulfur levels and NOx emission rates, and more stringent emission standards when ships operate within ECAs.

[18] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx

For US waters, an ECA was declared and began implementation in 2012, with an additional level of fuel sulfur limits beginning in 2015:

- Late 2012, <10,000 ppm (1.0%) sulfur
- 2015 onwards, <1,000 ppm (0.1%) sulfur

NOx emission standards for Tier I and II apply worldwide and Tier III engine NOx emission rate limits apply when operating within an ECA. The Tier emissions standards are outlined in Table 4-8. Applying these emission level limits for current and especially future years requires estimates of the ship fleet age distributions.

Table 4-8. International NOx Emission Limits for Ship Engines

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	January 1, 2000	17.0	45 x $n^{(-0.2)}$ e.g., 720 rpm – 12.1	9.8
II	January 1, 2011	14.4	44 x $n^{(-0.23)}$ e.g., 720 rpm – 9.7	7.7
III	January 1, 2016 when operating in an ECA	3.4	9 x $n^{(-0.2)}$ e.g., 720 rpm – 2.4	2.0

The emission factors used for the 2019 CMV EI estimates assumed 0.1% sulfur content fuel. The application or determination of the fleet age distribution is not straightforward because each ship transit was used in this work and has a unique activity profile as well as a ship or engine model year.

The PM emission control scenarios for C3 vessels used for this work are based on EPA (2009) forecasted emission factor adjustments shown in Table 4-9. The ECA includes the entire region modeled, and therefore all activity was assumed to be governed by the ECA. The ECA was declared in EPA rulemaking with international approval in 2009, and emissions and fuel controls within the ECA began in August 2012 with a fuel sulfur limit of 1.0%. Additional fuel sulfur limits to 0.1% sulfur began in 2015, and NOx controls were required for new ships built in 2016 or later. The relative PM emission factors shown in Table 4-9 are specific to the operational sulfur levels in each calendar year.

Table 4-9. PM and NO_X Emission Factors Scaling (EPA 2009, Table 2-12)

Main	2010 – 2012	2013 – 2014	2015+		2010	2015	2020	2025	2030
	PM EF	PM EF	PM EF		NO_X EF	NO_X EF	NO_X EF	NO_X EF	NO_X EF
	ECA	ECA	ECA		ECA	ECA	ECA	ECA	ECA
EF Adjustment (1.00 is pre-controlled)	1.0	0.3169	0.1352		0.8750	0.8020	0.5958	0.4278	0.3184
Auxiliary									
Other (except passenger)	1.0	0.3403	0.1250		0.8767	0.8059	0.5842	0.4108	0.2989

EPA (2021) provided their updated (from Table 4-9) estimate of the relative NO_X fleet-averaged emissions for the Gulf Coast with activity growth from which this study determined relative to 2019 NO_X fleet-average emission rates shown in Table 4-9. The average NO_X emission factor adjustments in Table 4-10 reflect the emission standards beginning with new ships in 2000, 2011, and 2016 along with fleet turnover.

Table 4-10. Emission Factor Adjustment of Category 3 NOx Emission Rates to 2019

Year	Relative to 2019		Year	Relative to 2019		Year	Relative to 2019
2002	1.648		2018	1.024		2034	0.466
2003	1.588		2019	1.000		2035	0.455
2004	1.532		2020	0.977		2036	0.445
2005	1.480		2021	0.917		2037	0.435
2006	1.431		2022	0.861		2038	0.425
2007	1.386		2023	0.808		2039	0.415
2008	1.343		2024	0.758		2040	0.406
2009	1.303		2025	0.711		2041	0.396
2010	1.264		2026	0.667		2042	0.387
2011	1.229		2027	0.625		2043	0.378
2012	1.195		2028	0.585		2044	0.370
2013	1.162		2029	0.547		2045	0.361
2014	1.132		2030	0.511		2046	0.353
2015	1.103		2031	0.499		2047	0.345
2016	1.075		2032	0.488		2048	0.337
2017	1.049		2033	0.477		2049	0.329
						2050	0.322

4.2.2 Category 1 and 2 Harbor Craft Vessels' Fleet Average Emissions Rates

Emissions from the lower displacement engines, less than 30 liters per cylinder C1 and C2 engines used for main propulsion power, largely result from domestic harbor craft vessel activity from vessels such as tugs, towboats, dredges, ferries, excursion, fishing and other work boats. The C1/C2 vessel sizes that have AIS records will be the larger commercial marine vessels (but smaller than ships with Category 3 main engines) relative to recreational or very small commercial boats.

New C1/C2 engines are regulated by the EPA[19], and fleet emissions decrease as vessels and engines are replaced with new versions meeting more stringent emissions limits. Most new marine engines met the international standards starting in 2000, but EPA regulated further emission controls beginning with new engines in 2004 and staged to ever increasing stringency through 2018.

Using the EPA (2008) estimate of baseline (without emission regulations) and forecasted (with emission regulations), Ramboll determined the emissions rates relative to the 2019 CMV EI. The projected emissions were compared with the fleet-average emissions levels in 2019 with the ratio shown in Table 4-11.

[19] https://www.epa.gov/regulations-emissions-vehicles-and-engines/domestic-regulations-emissions-marine-compression

Table 4-11. Fleet Average C1/C2 Emission Factors Relative to 2019

Year	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	1.358	1.358	1.297	1.331	1.331	1.000	1.078
2003	1.358	1.358	1.297	1.331	1.331	1.000	1.078
2004	1.358	1.358	1.297	1.331	1.331	1.000	1.078
2005	1.358	1.358	1.297	1.331	1.331	1.000	1.078
2006	1.358	1.358	1.297	1.331	1.331	1.000	1.078
2007	1.358	1.358	1.297	1.331	1.331	1.000	1.078
2008	1.345	1.345	1.282	1.331	1.331	1.000	1.078
2009	1.331	1.331	1.268	1.331	1.331	1.000	1.078
2010	1.316	1.316	1.256	1.331	1.331	1.000	1.078
2011	1.301	1.301	1.244	1.331	1.330	1.000	1.078
2012	1.274	1.274	1.231	1.320	1.320	1.000	1.078
2013	1.239	1.238	1.216	1.303	1.303	1.000	1.078
2014	1.197	1.197	1.180	1.261	1.261	1.000	1.078
2015	1.172	1.172	1.156	1.220	1.220	1.000	1.078
2016	1.134	1.134	1.123	1.172	1.172	1.000	1.061
2017	1.089	1.089	1.085	1.116	1.116	1.000	1.028
2018	1.042	1.042	1.043	1.058	1.058	1.000	1.003
2019	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2020	0.957	0.958	0.957	0.943	0.943	1.000	1.028
2021	0.914	0.914	0.915	0.889	0.889	1.000	1.009
2022	0.872	0.872	0.873	0.835	0.835	1.000	0.993
2023	0.829	0.829	0.832	0.784	0.784	1.000	0.981
2024	0.787	0.787	0.791	0.734	0.734	1.000	0.969
2025	0.746	0.745	0.752	0.688	0.688	1.000	0.957
2026	0.706	0.706	0.715	0.646	0.646	1.000	0.945
2027	0.668	0.668	0.679	0.610	0.610	1.000	0.934
2028	0.632	0.632	0.646	0.577	0.577	1.000	0.923
2029	0.597	0.598	0.614	0.547	0.547	1.000	0.912
2030	0.565	0.565	0.586	0.521	0.521	1.000	0.901
2031	0.535	0.535	0.560	0.498	0.498	1.000	0.891
2032	0.507	0.507	0.537	0.477	0.478	1.000	0.881
2033	0.480	0.480	0.515	0.459	0.459	1.000	0.871
2034	0.455	0.455	0.494	0.442	0.442	1.000	0.862
2035	0.430	0.430	0.475	0.426	0.426	1.000	0.853
2036	0.408	0.408	0.458	0.412	0.412	1.000	0.844
2037	0.389	0.389	0.444	0.401	0.401	1.000	0.836
2038	0.372	0.372	0.435	0.393	0.393	1.000	0.828
2039	0.357	0.357	0.427	0.385	0.385	1.000	0.822

Year	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2040	0.347	0.347	0.421	0.380	0.380	1.000	0.817
2041	0.322	0.322	0.394	0.358	0.358	1.000	0.805
2042	0.306	0.306	0.381	0.346	0.346	1.000	0.797
2043	0.291	0.291	0.368	0.335	0.335	1.000	0.789
2044	0.277	0.277	0.356	0.325	0.325	1.000	0.781
2045	0.263	0.263	0.344	0.315	0.314	1.000	0.773
2046	0.251	0.251	0.333	0.305	0.304	1.000	0.766
2047	0.238	0.238	0.322	0.295	0.295	1.000	0.758
2048	0.227	0.227	0.311	0.286	0.286	1.000	0.750
2049	0.216	0.216	0.300	0.277	0.276	1.000	0.743
2050	0.205	0.205	0.290	0.268	0.268	1.000	0.736

EFs for year 2041-2050 were extrapolated from EFs for period 2031- 2040

4.3 Trend Results

SO_2 and PM emissions sharply declined from 2011 to 2015 due to the fuel-related ECA standards but they have slowly increased since with increasing activity levels (Figure 4-1). NO_X emissions decrease from 2011 through 2050 with a faster pace during period 2011 through 2030 compared to period 2030 through 2050 in the controlled scenario due to compliance with the EPA's engine exhaust standards. There are no marine standards targeting VOC and CO, thus economic trends drive both pollutants to increase by 61% and 74%, respectively, from 2011 through 2050 in the controlled scenario.

A Microsoft (MS) Excel spreadsheet containing the 2011 through 2050 emissions data set, summed to the vessel type level and also to the county level, will be provided to TCEQ accompanying this report. All relevant data to develop emissions trends are included in the MS Excel spreadsheet.

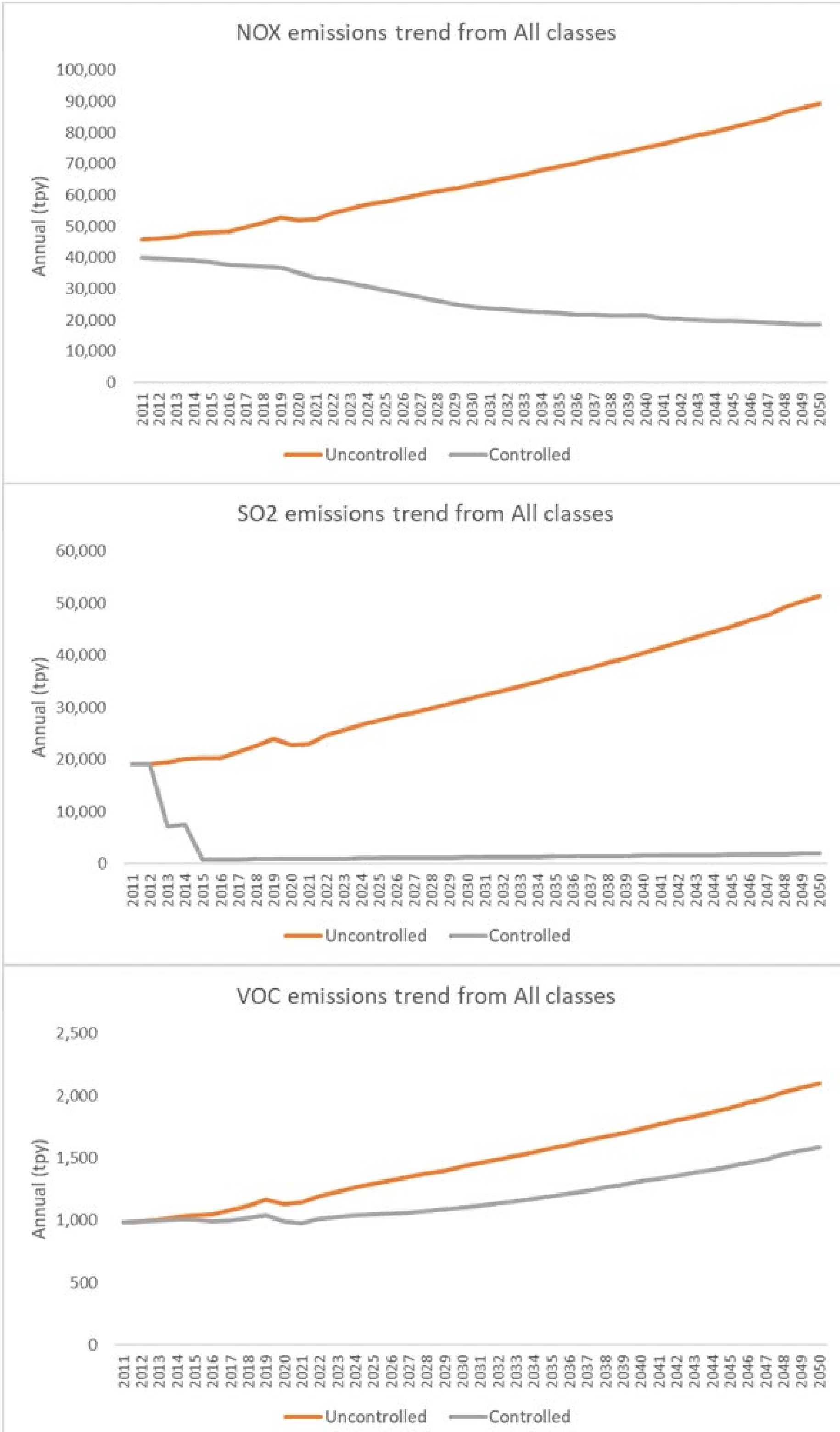


Figure 4-1. Statewide annual controlled and uncontrolled emissions by year for NOx (top), SO_2 (middle), and VOC (bottom)

5.0 QUALITY ASSURANCE

Ramboll implemented several QA strategies to confirm the integrity of emission calculations and evaluate the EIs produced for this project using the MARINER tool. Processing steps within the MARINER tool incorporate numerous QA checks that identify erroneous input data and remove them from the emission calculations. In addition, Ramboll compared the resulting emission estimates to other CMV inventories to ascertain the reasonableness of MARINER emission estimates. The following QA analyses were performed:

- Comparing the 2019 base case EI to other recent CMV EIs by vessel type and other aggregate characteristics;
- Comparing the back-cast 2017 and forecast 2023 and 2028 emissions developed as part of this project to the EPA's NEI emissions for the same years; and
- Processing the recently released 2020 AIS data to develop a base case 2020 EI that was then compared to the forecast 2020 EI (described in Chapter 4) using 2019 activity data as the base case.

Table 5-1 lists more recent CMV studies that were used for comparison to the emissions developed for this project. Although 2011 and 2014 CMV NEIs are available from EPA, the activity data and methodology used to develop these older EIs may be too outdated to provide meaningful comparisons.

Table 5-1. CMV EIs used to quality assure MARINER tool emission estimates.

Data Sources	Year	Short Name	MARINER tool EIs compared
EPA 2017 National Emission Inventory (NEI) https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data#datas (last accessed 06/08/21)	2017	EPA 2017	Back-cast 2017 and base case 2019
TCEQ 2017 CMV EI from Work Order 582-20-12636-017 "Automation of Commercial Marine Vessel Emissions Inventory Development"	2017	Ramboll 2017	Back-cast 2017 and base case 2019
EPA projected future year CMV EI https://gaftp.epa.gov/Air/emismod/2016/v1/reports/2011v63_2014v71_2016v1_state-SCC_summary_21-Feb-2020.zip (last accessed 06/08/21)	2023 and 2028 (projected from 2016)	EPA 2023 EPA 2028	Forecast 2023, 2028

5.1 MARINER Tool 2019 CMV EI

5.1.1 Comparison of the MARINER Tool 2019 Base Case EI to Ramboll 2017

The controlled CMV emissions developed using the MARINER tool for the 2019 base case were compared to the 2017 CMV emission estimates produced by Ramboll under TCEQ WO 582-20-12636-017 to assess the appropriateness of the emission totals over Texas state waters (Table 5-2).

This study estimates statewide total NO_X emissions for 2019 to be 36,872 tons (22,625 tons from C1/C2 and 14,247 tons from C3). The prior Ramboll study estimated statewide total NOX emissions for 2017 to be 34,309 tons (17,722 tons from C1/C2 and 16,587 tons from C3).

Finding higher C1/C2 NO_x emissions in 2019 (approximately a 27% increase) is expected due to the use of updated AIS and IHS vessel data in this study which identified and captured significantly more C1/C2 vessels than in the previous study (see vessel counts in Table 5-3). Additionally, C1/C2 vessels tend to have much higher operating hours in state waters compared to larger C3 vessels. The updated IHS vessel dataset (version 2020) includes many more vessel types than the previous version used to develop the 2017 emissions. C1/C2 vessel types included in the 2019 base year EI but not in the previous 2017 EI are dredge (342 tpy), fishing (739 tpy), government (5 tpy), harbor ferry (356 tpy), and miscellaneous C1/C2 (1,650 tpy). It is possible that the 2017 EI captured some of these vessels, but their characteristics were not found in the IHS data and/or were miscategorized. In the previous 2017 EI, emissions from tug boats are much higher than towboats but this is reversed in the 2019 EI as Ramboll improved vessel type assignments by using AIS vessel type as a secondary cross-reference (primary being the IHS vessel type). This results in more towboats identified which otherwise would have been classified as tugs by default.

C3 NO_x emissions differ by 14% between the two studies which can be attributed to several factors: 1) different levels of activity, 2) use of updated IHS vessel characteristics database, 3) changes made per updated EPA guidance (2020a) such as incorporation of sea margin, and 4) modification of cross references and updates to gap-filling procedures for vessels not available in the IHS data. The cross-reference updates resulted in more vessels being classified as C1/C2 rather than being misclassified as C3 in the 2017 EI. This is the case for 'liquified gas tanker' formerly being used as a default vessel for the AIS Vessel group '0'. Ramboll determined that miscellaneous C1/C2 is a better surrogate as most C3 vessels would have been identified by the IHS data. This update lowers NO_x emissions from liquified gas tankers by 80% (-3,303 tpy) in 2019 from 2017 (Figure 5-1). Emissions reductions due to the reclassification of AIS Vessel group '0' is seen in other pollutants as well. SO_2 emissions are mostly emitted by C3 vessels and they are lower in 2019 by 20%. $PM_{2.5}$ and VOC from C3 are lower in 2019 by about the same extent (19%).

Overall, Ramboll found the 2019 EI developed for this study to be comparable to the previous 2017 EI and that differences are explained by improvements to methodology and input data.

Table 5-2. Comparison of MARINER 2019 and Ramboll 2017 NO_X and SO_2 emissions (tons).

Vessel Category	SCC	Mode	Engine	2017 NO_X	2019 NO_X	2017 SO_2	2019 SO_2
C1/C2	2280002101	Port	Prop	531	587	0	0
	2280002102	Port	Aux	1,409	1,361	1	1
	2280002201	Underway	Prop	11,971	17,047	5	9
	2280002202	Underway	Aux	3,810	3,630	2	3
	Subtotal			**17,722**	**22,625**	**8**	**13**
C3	2280002103	Port	Prop	42	24	2	1
	2280002104	Port	Aux	5,966	4,729	509	383
	2280002203	Underway	Prop	4,833	4,254	145	113
	2280002204	Underway	Aux	5,746	5,240	461	390
	Subtotal			**16,587**	**14,247**	**1,117**	**887**
	Total			**34,309**	**36,872**	**1,125**	**900**
	% Difference				**7%**		**-20%**

Table 5-3. Comparison between MARINER 2019 and Ramboll 2017 statewide vessel counts.

Source	EPA ShipType	MARINER 2019	Ramboll 2017
Ocean-going Vessels	Bulk Carrier	803	884
	Chemical Tanker	1,033	932
	Container Ship	245	221
	Cruise	8	9
	General Cargo	496	435
	Liquified Gas Tanker	476	474
	Miscellaneous (C3)	26	2
	Offshore Support/Drillship	14	18
	Oil Tanker	649	522
	Other Tanker	142	120
	Reefer	5	2
	RORO	159	146
	Subtotal	**4,056**	**3,765**
Harbor Craft	Crew and Supply	109	304
	Dredge	10	--
	Fishing (C1/C2)	561	--
	Government	3	--
	Harbor Ferry (C1/C2)	5	--
	Miscellaneous (C1/C2)	562	--
	Pilot	8	2
	Towboat/Push boat	1,132	12
	Tug Boat	283	1,356
	Work Boat	17	86
	Subtotal	**2,690**	**1,760**
	Total	**6,746**	**5,525**

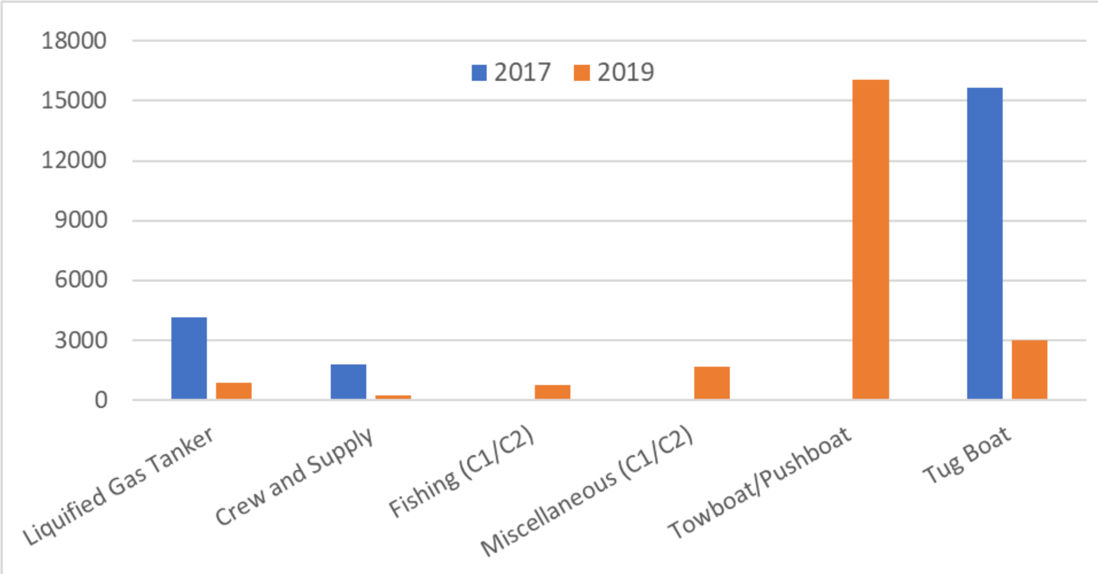


Figure 5-1. MARINER 2019 and Ramboll 2017 NO_X emissions (tons) by ship type.

5.1.2 Comparison of the MARINER 2019 Base Case EI to EPA 2017

Comparison with the EPA 2017 NEI is less detailed because the EPA emissions are aggregated to the SCC level. Overall, the two EIs differ by less than 25% except for VOC (60% lower with the MARINER tool-developed EI). The 2019 base case emissions are lower for all pollutants except CO (Table 5-4). NO_x emissions are lower by 7% and SO_2 emissions are lower by 17%. There are several differences with the CMV EI development approaches such as the use of different vessel characteristics datasets and the release of updated EPA methodology and guidance which came out after the 2017 NEI. Additionally, EPA's approach for developing the 2017 CMV NEI for Texas may have defined slightly larger state water boundaries (e.g., resulting in more activity) but Ramboll was not able to confirm (EPA's CMV shapefiles were discussed in Section 2.6).

Table 5-4. Comparison of EPA 2017 and MARINER 2019 CMV emissions (tons).

Vessel Category	Mode	Engine	2017 NO_x	2019 NO_x	2017 SO_2	2019 SO_2	2017 VOC	2019 VOC
C1/C2	Port	Prop	258	587	0	0	26	8
	Port	Aux	3,016	1,361	37	1	92	40
	Underway	Prop	5,578	17,047	3	9	335	204
	Underway	Aux	9,911	3,630	121	3	297	113
	Subtotal		**18,763**	**22,625**	**160**	**13**	**750**	**366**
C3	Port	Prop	765	24	15	1	140	3
	Port	Aux	3,615	4,729	283	383	168	222
	Underway	Prop	9,526	4,254	190	113	1,257	209
	Underway	Aux	7,093	5,240	479	390	322	243
	Subtotal		**20,998**	**14,247**	**968**	**887**	**1,886**	**677**
	Total		**39,761**	**36,872**	**1,128**	**900**	**2,636**	**1,043**
	% Difference			**-7%**		**-20%**		**-60%**

Vessel Category	Mode	Engine	2017 CO	2019 CO	2017 $PM_{2.5}$	2019 $PM_{2.5}$	2017 PM_{10}	2019 PM_{10}
C1/C2	Port	Prop	20	114	9	9	9	10
	Port	Aux	467	222	82	30	85	31
	Underway	Prop	679	3,273	159	269	164	278
	Underway	Aux	1,535	579	270	81	279	84
	Subtotal		**2,700**	**4,188**	**520**	**390**	**537**	**402**
C3	Port	Prop	143	4	14	0	15	0
	Port	Aux	421	556	103	139	112	151
	Underway	Prop	1,507	424	143	48	155	52
	Underway	Aux	816	611	178	143	194	156
	Subtotal		**2,886**	**1,595**	**438**	**330**	**476**	**359**
	Total		**5,587**	**5,783**	**958**	**720**	**1,013**	**761**
	% Difference			**4%**		**-25%**		**-25%**

Lower emission factors in the MARINER tool can explain lower VOC emissions in 2019 (51% for C1/C2 and 64% for C3). These emission factors vary by engine category, group, cylinder displacement, engine power, and model year (EPA, 2020a, Table H-4). Based on the 2019 C1/C2 population, most vessels are categorized as Tier 0 (pre-control) C2 with an emission factor of 0.1411 g/kWh (Table 5-5). For Tier 0, the EPA 2017 EI used 0.296 g/kWhr[20] which is a factor of two higher and would be consistent with C1 dominance per the latest EPA guidance (EPA, 2020a). This difference in vessel classification would impact other pollutants to a lesser extent than VOC because the other emission factors have narrow ranges within the same Tier. Ramboll believes that C2 dominance in Tier 0 is appropriate and the MARINER 2019 emission factors are consistent with current EPA guidance.

Table 5-5. VOC emission factors by C1/C2 tier used in this study.

Main Engine Tier	VOC (g/kWh)	# of Vessels
Tier 0	0.1411	1,791
	0.2843	171
Tier 1	0.1411	24
	0.2843	119
Tier 2	0.1411	41
	0.2001	57
Tier 3	0.0737	2
	0.0948	1
	0.1053	444
	0.4528	2
Tier 4	0.0105	2
	0.0211	1
	0.0421	18
	0.0632	10
	0.0737	6
	0.4528	1

[20] This emission factor is a population-weighted per tier grouped by engine displacement. ERG, 2019a, Table 5.

Underway operating auxiliary engines dominate C1/C2 NO_X emissions (9,911 tpy) in the EPA 2017 CMV EI, almost by a factor of two higher than emissions from underway propulsion engines (5,578 tpy) (see Table 5-4). This is due to anchorage mode being assigned to the majority of C1/C2 underway activities. Since anchorage mode was assumed to operate with only auxiliary engine power, emissions from auxiliary engines dominate. The latest EPA guidance does not assign anchorage mode for C1/C2. Since C1/C2 vessels are largely tugs and towboats, Ramboll assumed that these vessels operate predominantly with power from propulsion engines in underway mode, as reflected in the MARINER 2019 EI.

The 2017 and 2019 EIs agree within 4% and 12% of total NO_x emissions for Harris and Galveston Counties, respectively, which are the counties with the largest CMV NO_x emissions. Larger differences are seen for other counties (Table 5-6), but it is difficult to identify specific reasons for differences in each county other than the overall difference in activity year and development approaches.

Table 5-6. MARINER 2019 and EPA 2017 NO_X emissions (tons) by county.

FIPS Code	County	MARINER 2019	EPA 2017	% Difference [2019-2017]
48201	Harris	10,218	10,676	-4%
48167	Galveston	8,667	9,815	-12%
48245	Jefferson	5,222	4,114	27%
48355	Nueces	3,006	4,031	-25%
48071	Chambers	2,240	3,819	-41%
48039	Brazoria	2,109	1,809	17%
48321	Matagorda	1,564	882	77%
48361	Orange	1,449	1,307	11%
48057	Calhoun	991	895	11%
48007	Aransas	740	1,459	-49%
48061	Cameron	256	562	-54%
48261	Kenedy	164	46	258%
Total		**36,872**	**39,761**	**-7%**

5.2 CMV Emission Trends

Back-cast and forecast emissions developed using the MARINER tool in this study were compared to EPA inventories for base year 2017 and projection years (2023 and 2028)[21]. Analyses in this section focus on comparing total emissions only given the differences in vessel identification and classification among these EIs, as discussed above.

5.2.1 Comparison of MARINER back-cast 2017 EI to Ramboll 2017 and EPA 2017

The MARINER back-cast 2017 EI for NO_X agrees within 9% to the Ramboll 2017 EI and within 6% to the EPA 2017 EI as shown in Table 5-7. Most C3 activities were predicted to grow during 2017-2019 by more than 10% and as high as 27% for containers. Bulk carrier (C3) and all C1/C2 activities had minimal change (1-2%). These growth rates were partly offset by fleet turnover leading to lower emission factors. Using these projection factors, the MARINER back-cast 2017 EI is found to be comparable to two inventories that directly used 2017 activity.

[21] https://www.epa.gov/air-emissions-modeling/2016v1-platform

Table 5-7. Comparison of CMV NO_X emissions (tons/year) for the MARINER back-cast 2017 controlled EI, Ramboll 2017 EI, and EPA 2017 EI.

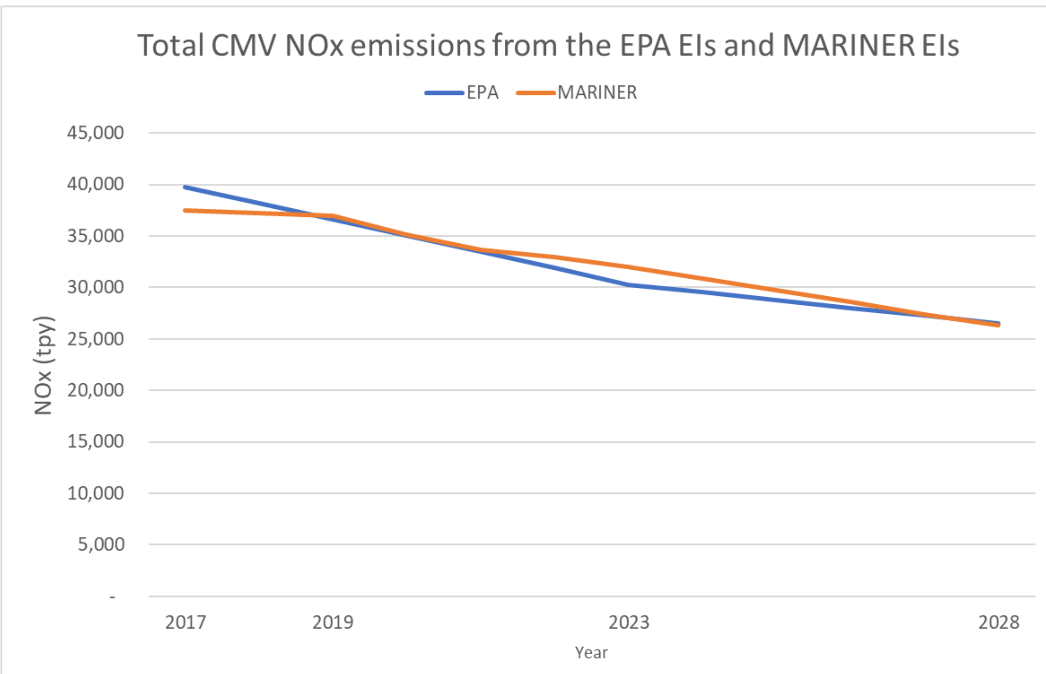
Vessel Category	Mode	Engine	Back-cast 2017	Ramboll 2017	EPA 2017
C1/C2	Port	Prop	627	531	258
	Port	Aux	1,455	1,409	3,016
	Underway	Prop	18,215	11,971	5,578
	Underway	Aux	3,881	3,810	9,911
	Subtotal		**24,179**	**17,722**	**18,763**
C3	Port	Prop	22	42	765
	Port	Aux	4,438	5,966	3,615
	Underway	Prop	3,950	4,833	9,526
	Underway	Aux	4,924	5,746	7,093
	Subtotal		**13,334**	**16,587**	**20,998**
	Total		**37,513**	**34,309**	**39,761**
	% Difference			**9%**	**-6%**

5.2.2 Comparison of MARINER forecast 2023 and 2028 EIs to EPA 2023 and 2028 EIs

The MARINER forecast EIs for NO_X agree within 6% and 1% to the EPA projected 2023 and 2028 EIs as shown in Table 5-8. It is more meaningful, however, to compare changes from baseline (Figure 5-2). EPA estimated 33% NO_X reduction between 2017 and 2028 which is comparable to the MARINER forecast of 30% reduction over the same period.

Table 5-8. Comparison of MARINER 2023 and 2028 CMV NO_X emissions (tons/year) to EPA's projected EIs.

Vessel Category	MARINER 2023	EPA 2023	MARINER 2028	EPA 2028
C1/C2	19,565	12,754	15,887	9,994
C3	12,405	17,532	10,450	16,492
Total	**31,970**	**30,286**	**26,336**	**26,487**
% Difference		**6%**		**-1%**



* EPA's 2019 data was interpolated between 2017 and 2023 to provide a continuous display.

Figure 5-2. Total CMV NO_X emissions (tons) for years 2017, 2019, 2023, and 2028.

5.3 MARINER 2020 CMV EI

5.3.1 Comparison of MARINER 2019 and 2020 Base Case EIs

In 2020, vessel activities were altered substantially by the COVID-19 pandemic, with reports of port restrictions and changes in consumption patterns impacting multiple maritime sectors globally, most notably fisheries, passenger ferries and cruise ships (March et al., 2021). In Texas, the 2020 emissions are lower across all pollutants and for most ship types, notably for cruise ships which suspended operation post-April (Figure 5-3). Total NO_X, SO_2, and VOC emissions in 2020 decrease by 7%, 7% and 6%, respectively, from the 2019 levels (Table 5-9).

Table 5-9. Comparison of MARINER 2020 and 2019 NOx and SO_2 emissions (tons)

Vessel Category	Mode	Engine	2020 NO_x	2019 NO_x	2020 SO_2	2019 SO_2	2020 VOC	2019 VOC
C1/C2	Port	Prop	519	587	0	0	7	8
	Port	Aux	1,427	1,361	1	1	43	40
	Underway	Prop	15,575	17,047	9	9	190	204
	Underway	Aux	4,021	3,630	3	3	128	113
	Subtotal		**21,542**	**22,625**	**13**	**13**	**369**	**366**
C3	Port	Prop	20	24	1	1	3	3
	Port	Aux	4,290	4,729	355	383	205	222
	Underway	Prop	3,625	4,254	96	113	179	209
	Underway	Aux	4,810	5,240	373	390	227	243
	Subtotal		**12,745**	**14,247**	**824**	**887**	**614**	**677**
	Total		**34,287**	**36,872**	**837**	**900**	**983**	**1,043**
	% Difference		**-7%**		**-7%**		**-6%**	

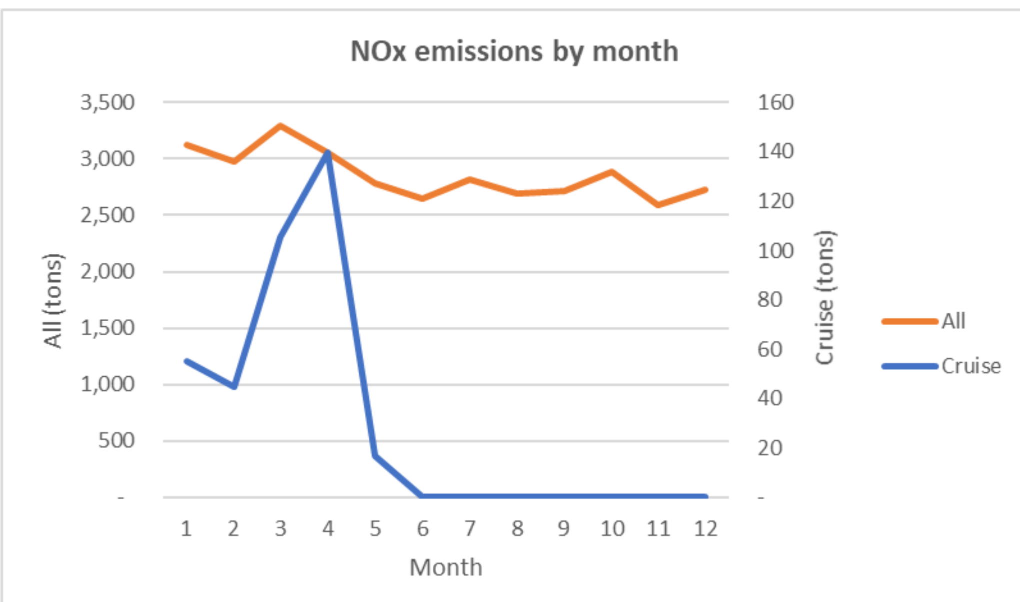


Figure 5-3. MARINER 2020 monthly NO_X emissions (tons per month) for all ships (left axis) and cruise ships (right axis).

5.3.2 Comparison of MARINER forecast 2020 EI to MARINER actual 2020 EI

The forecast 2020 CMV EI agrees within 3% to the actual 2020 CMV EI in Table 5-10. This level of accuracy suggests that the activity projections, despite limited granularity, can reasonably capture a complex change in activities due to the COVID-19 pandemic.

Table 5-10. Comparison of CMV NOx emissions (tons/year) for the MARINER forecast 2020 EI and MARINER actual 2020 EI

Vessel Category	Mode	Engine	Forecast NO_X	Actual NO_X	Forecast SO_2	Actual SO_2	Forecast VOC	Actual VOC
C1/C2	Port	Prop	568	519	0	0	8	7
	Port	Aux	1,319	1,427	1	1	39	43
	Underway	Prop	16,504	15,575	9	9	195	190
	Underway	Aux	3,516	4,021	3	3	108	128
	Subtotal		**21,907**	**21,542**	**13**	**13**	**349**	**369**
C3	Port	Prop	24	20	1	1	3	3
	Port	Aux	4,466	4,290	372	355	215	205
	Underway	Prop	4,021	3,625	109	96	203	179
	Underway	Aux	4,727	4,810	368	373	225	227
	Subtotal		**13,237**	**12,745**	**850**	**824**	**646**	**614**
	Total		**35,145**	**34,287**	**864**	**837**	**995**	**983**
	% Difference			**3%**		**3%**		**1%**

6.0 SUMMARY

Ramboll developed two base case CMV EIs, 2019 and 2020, for Texas using the MARINER tool developed previously in a separate TCEQ contract. The MARINER tool uses AIS vessel tracking data and Sea-web vessel characteristics to develop high-resolution CMV EIs. Ramboll made several enhancements to the MARINER tool to improve accuracy and upgraded MARINER to support the generation of detailed CMV EIs in formats that can be readily imported to the air emissions reporting systems used by the EPA and TCEQ.

As a QA step, the CMV EIs developed in this effort were compared to emissions developed during the previous "Automation of Commercial Marine Vessel Emissions Inventory Development" project, WO 582-20-12636-017, and to emissions developed by the EPA for the state of Texas for the CMV component of the 2017 NEI. The QA comparison found that the CMV estimates for the base case EIs are comparable to other inventories. The forecast estimates compared well with the EPA's projected EIs for years 2023 and 2028. The 2020 EI shows good agreement with the forecast 2020 EI, suggesting that the projections can reasonably capture a complex change in activities.

While the emission estimates overall compare well with other inventories, there are differences that may be attributed to several factors: 1) different levels of activities (year-specific), 2) different vessel characteristics databases, 3) gap-filling approaches, and 4) changes in methodology per EPA's updated guidance (2020a) such as emission factors, the incorporation of sea margin to adjust load, and the exclusion of anchorage mode for C1/C2.

As more smaller vessels adopt AIS transponders, AIS data will provide increasing vessel population and activity data over what is currently available. Similarly, ship characteristics databases like IHS will continue to expand with better accuracy. The MARINER tool enables the rapid development of CMV EIs by eliminating manual processing of these large datasets as was done in the past. Nevertheless, appropriate gap-filling approaches are necessary, and implemented by the MARINER tool, because the datasets are incomplete.

While this inventory effort provides improvement over the previous TCEQ 2017 EI, future improvements could be made.

- Analysis of the IHS data to provide distribution of various ship characteristics (such as age, engine power, etc.) that are representative of each vessel type and may be used to gap fill missing IHS entries.
- Average age by ship type over global datasets was used as default. This results in conservative emission estimates because the default put tier designation (dependent on age and engine size) to Tier 0 (pre-control) which has the highest emission factors. In reality the age will be a distribution, and because the fleet average emission factor will be how much of the leading edge of the distribution is newer than 2004, the distribution matters and should be considered to use gap-fill the age information.
- Accounting for shore power or alternative emissions control in use while hoteling at berth may indicate more accurate emissions estimates for some vessel types. Calculation of these emissions can be incorporated as an additional feature of the Mariner tool or a separate analysis provided the time connected to shore power and/or the emissions control impact is available. Information on shore power and time connection would be recorded by the shore personnel at the port. It would be crucial to use the same calculation method used in the CMV EI to estimate emissions pertaining to the elapsed time at berth excluding time before and after each connection when these ships are not on shore power and still at berth.

6.1 Deliverables

Completed deliverables are listed below by task:

Task 4. Processing of Vessel Activity Data to Develop Base Year 2019 CMV EIs

Deliverable 4.1: Technical memorandum detailing the processing of vessel activity data and development of the base year 2019 CMV EI.

Deliverable 4.2: MS Excel spreadsheet containing the 2019 emissions data set.

Task 5. Development of 2011 through 2050 CMV Trend EIs

Deliverable 5.1: Technical memorandum detailing the development of 2011 through 2050 CMV trend EIs (this document).

Deliverable 5.2: MS Excel spreadsheets containing 2011 through 2050 controlled and uncontrolled trend EI data sets.

Deliverable 5.3: TexAER-formatted CERS XML files for 2011 through 2050 controlled and uncontrolled trend EIs.

Task 6. Quality Assurance

Deliverable 6.1: Technical memorandum detailing quality assurance of the CMV EIs (this document).

Deliverable 6.2: MS Excel spreadsheet containing summaries of QA comparison.

Task 7. Development of 2020 CMV EI for submittal to EPA for AERR

Deliverable 7.1: 2020 statewide EI for all CMV sources and all other associated data developed in the CERS XML format suitable for upload to the EPA EIS.

Task 8. Draft and Final Report

Deliverable 8.1: Draft Report.

Deliverable 8.2: Final Report (This document).

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