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Commercial Marine Vessel Emissions Inventory Development for 2022 Modeling Platform

Final Report

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Commercial Marine Vessel Emissions Inventory Development for 2022 Modeling Platform
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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	Automatic Identification System
AI	Artificial Intelligence
C1C2	Category 1 and 2 engines
C3	category 3 engines
CARB	California Air Resources Board
CMV	Commercial Marine Vessels
CO	Carbon monoxide
EI	Emission Inventory
ECA	Emission Control Area
EPA	United States Environmental Protection Agency
EPS3	Emission Processor System Version 3
IMO	International Maritime Organization
ML	Machine Learning
MARAD	U.S. Department of Transportation Maritime Administration
MARINER	MARINe Emissions Resolver
MMSI	Maritime Mobile Service Identity
NO_X	Nitrogen oxides
OGV	Ocean Going Vessel
PM	Particulate matter
QA	Quality Assurance
SCC	Source Classification Code
SIP	State Implementation Plan
SO_2	Sulfur dioxide
TCEQ	Texas Commission on Environmental Quality
VOC	Volatile organic compounds
PM_{10}	Particulate Matter with diameter smaller than 10 μm
$PM_{2.5}$	Particulate Matter with diameter smaller than 2.5 μm

Project Summary

Ship traffic in the Gulf of Mexico and Texas ports can produce emissions that influence Texas air quality. Ramboll improved how the MARINe Emissions Resolver (MARINER) estimates shipping emissions by combining vessel tracking data with ship characteristics data. Ramboll developed 2022 commercial marine emission inventories for Texas. MARINER can be used to estimate current, past, and future emissions from commercial marine vessels for Texas air quality planning.

Executive Summary

The MARINe Emissions Resolver (MARINER) automates the generation of highly resolved commercial marine vessel (CMV) emissions from Automatic Identification System (AIS) data and vessel characteristics data, such as the S&P Global Sea-web Ships database. The Texas Commission on Environmental Quality (TCEQ) uses MARINER to generate CMV emissions for State Implementation Plan (SIP) attainment demonstrations.

MARINER was updated with the following changes or new features:

- Improved the algorithm for matching vessels between AIS data and the vessel characteristics database.
- Updated Source Classification Codes (SCCs), in consultation with TCEQ, to identify vessel types with greater specificity.
- Updated the output of temporal profiles for Emission Processor System Version 3 (EPS3) to use the updated SCCs.
- Added an option to use harbor craft load factors from either the EPA or the California Air Resources Board (CARB).
- Added an option to zero out engine emissions when vessels use shore power at berth.

The updated MARINER model code and User’s Guide were delivered to TCEQ. Ramboll generated 2022 Texas CMV emission inventories (EI) with alternative harbor craft load factors and compared MARINER EIs to EPA’s 2022 CMV EI. Overall, the EPA’s 2022 CMV EI is more comparable to the MARINER EI using CARB’s harbor craft load factors than EPA’s default load factors.

1.0 INTRODUCTION

The MARINe Emissions Resolver (MARINER) automates the generation of highly resolved commercial marine vessel (CMV) emissions from Automatic Identification System (AIS) data and vessel characteristics data (e.g., S&P Global Sea-web Ships database). The Texas Commission on Environmental Quality (TCEQ) uses MARINER to generate CMV emissions for SIP attainment demonstrations. Ramboll developed MARINER to generate spatially and temporally resolved CMV emission inventories (EI) for air quality modeling (Ramboll, 2020) and later enhanced MARINER to report emissions over geographic areas, e.g., counties, for EI reporting. MARINER was later updated to follow the United States Environmental Protection Agency (EPA) guidance on the generation of CMV EI that can be easily imported into the air emissions reporting interfaces used by the EPA and TCEQ (Ramboll, 2021). Runtime and memory usage were improved for usability and new capabilities to generate temporal profiles and additional summary reports were implemented (Ramboll, 2022b). Most recently, new options such as estimating future year emissions and outputting emissions at finer spatial resolution were added to MARINER (Ramboll, 2023).

This report summarizes the activities undertaken for this work order. Chapter 2.0 describes the changes made to further expand the usability of MARINER and to improve the accuracy of emission estimates. An updated MARINER User's Guide along with the updated MARINER code were provided to TCEQ as separate deliverables. Any reader interested in more details on hardware and software requirements as well as the general configuration of the tool should consult this user's guide which will not be discussed any further in this report. Chapter 3.0 summarizes the 2022 EIs generated by MARINER and compares MARINER EIs to EPA's 2022 CMV EI. The EIs include all criteria air pollutants (CAPs, i.e., nitrogen oxides (NO_X), carbon monoxide (CO), particulate matter with an aerodynamic diameter equal to or less than 10 microns and equal to or less than 2.5 microns (PM_{10} and $PM_{2.5}$), and sulfur dioxide (SO_2)), and CAP precursors (i.e., volatile organic compounds (VOC)). Finally, Ramboll discusses recommendations for future improvements to MARINER.

2.0 MARINER MODIFICATIONS

This chapter describes changes made to further expand the usability of MARINER and to improve the accuracy of emission estimates.

- Improved the algorithm for matching vessels between AIS data and the vessel characteristics database.
- Updated Source Classification Codes (SCCs), in consultation with TCEQ, to identify vessel types with greater specificity.
- Updated the output of temporal profiles for Emission Processor System Version 3 (EPS3) to use the updated SCCs.
- Added an option to use harbor craft load factors from either the EPA or the California Air Resources Board (CARB).
- Added an option to zero out engine emissions when vessels use shore power at berth.

2.1 Improve Vessel Matching Algorithm

MARINER has been using Maritime Mobile Service Identity (MMSI) and International Maritime Organization (IMO) identification codes to match vessels between the AIS data and vessel characteristics data. The MMSI is a unique nine-digit number used to identify a ship's radio communications, while the IMO number is a unique identifier assigned to ships, as well as to registered ship owners and management companies.

The previous approach in MARINER prioritized matching vessels using MMSI first and then IMO because MMSI is a required field in the AIS data, whereas IMO is optional. However, this method could lead to mismatches since the MMSI number can change when a ship changes its flag state, ownership, or radio communication equipment. Conversely, the IMO number remains constant throughout the vessel's lifetime, regardless of changes in name, owner, or flag.

Upon investigating the effect of using IMO as the first criterion for matching vessels, we found that prioritizing IMO results in more accurate matches. Table 2-1 lists three vessels with both MMSI and IMO available in AIS data as an example. Table 2-2 shows the vessels identified by matching MMSI whereas Table 2-3 shows the vessels identified by matching IMO. These examples demonstrate that MMSI or IMO matching can identify completely different ships. For example, Ship No.1’s MMSI matches an LPG Tanker, while its IMO matches an Oil/Chemical Tanker. An online search confirmed that IMO matching produced the correct result for these example vessels.

Given that the IMO number is permanently associated with each ship, the order of operation for matching vessels in MARINER has been improved so that IMO has priority over MMSI. This adjustment ensures more reliable and consistent vessel identification.

Table 2-1. List of three vessels with MMSI and IMO found as in AIS data.

Ship No.	MMSI	IMO
1	355437000	9213909
2	356546000	9550371
3	372267000	9330305

Table 2-2. Vessel identified by matching on MMSI from Table 2-1.

Ship No.	MMSI	IMO	VesselName	Ship Type
1	355437000	9889552	GAS PLANET	LPG Tanker
2	356546000	9864095	MARVELOUS STAR	Bulk Carrier
3	372267000	9800116	NORDIC AQUA	Oil/Chemical Tanker

Table 2-3. Vessel identified by matching on IMO from Table 2-1.

Ship No.	IMO	MMSI	VesselName	Ship Type
1	9213909	636020112	CORAL PEARL	Oil/Chemical Tanker
2	9550371	636019574	CALYPSO	Container Ship
3	9330305	636017968	MOUNT CARMEL	Bulk Carrier

2.2 Update Custom SCCs and Temporal Profiles

Previously, the EPA only required 12 CMV SCCs to distinguish vessels primarily powered by Category 1/2 (C1/C2) and Category 3 (C3) engines. Since 2023, the EPA has been expanding the list of CMV SCCs to include more detailed vessel type information. MARINER had been using TCEQ custom 10-character SCCs, which distinguish vessels by ship type and operating mode (i.e., hotelling, maneuvering, and transiting).

After revisiting the SCCs and consulting with the TCEQ project manager, the custom SCCs were updated to include more details, such as category (C1/C2 or C3) and engine type (propulsion, auxiliary, or boiler). Figure 2-1 shows the decoding scheme for the updated custom SCCs, and Figure 2-2 provides an example of the EPS3 PRESHP input file, with the red box highlighting the updated SCCs.

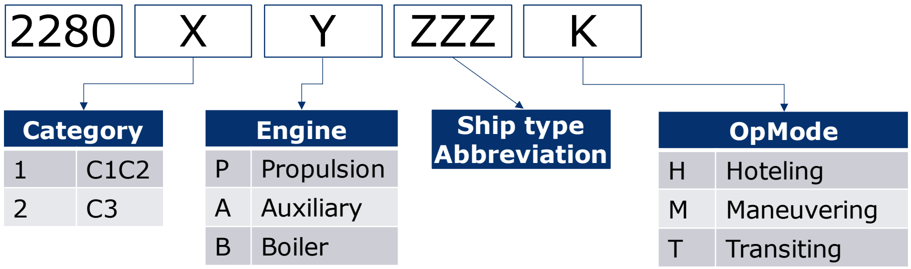
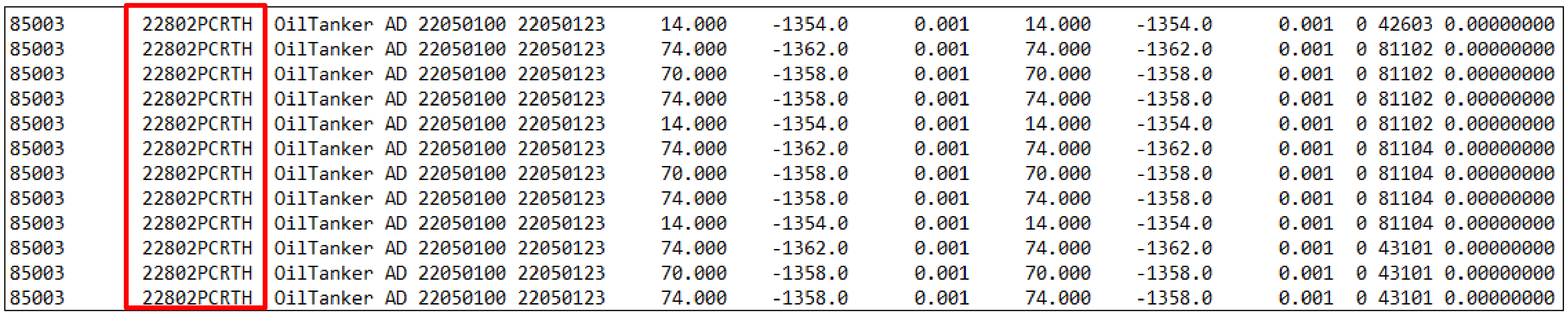


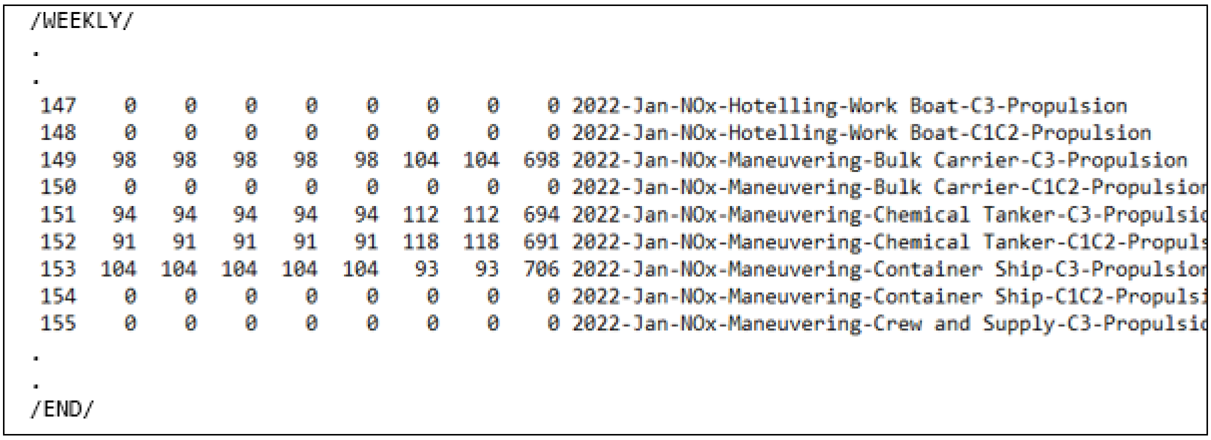
Figure 2-1. Decoding scheme for the updated custom SCCs.



```
85003         22802PCRTH OilTanker AD 22050100 22050123     14.000     -1354.0         0.001      14.000     -1354.0         0.001  0 42603 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     74.000     -1362.0         0.001      74.000     -1362.0         0.001  0 81102 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     70.000     -1358.0         0.001      70.000     -1358.0         0.001  0 81102 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     74.000     -1358.0         0.001      74.000     -1358.0         0.001  0 81102 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     14.000     -1354.0         0.001      14.000     -1354.0         0.001  0 81102 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     74.000     -1362.0         0.001      74.000     -1362.0         0.001  0 81104 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     70.000     -1358.0         0.001      70.000     -1358.0         0.001  0 81104 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     74.000     -1358.0         0.001      74.000     -1358.0         0.001  0 81104 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     14.000     -1354.0         0.001      14.000     -1354.0         0.001  0 81104 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     74.000     -1362.0         0.001      74.000     -1362.0         0.001  0 43101 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     70.000     -1358.0         0.001      70.000     -1358.0         0.001  0 43101 0.00000000
85003         22802PCRTH OilTanker AD 22050100 22050123     74.000     -1358.0         0.001      74.000     -1358.0         0.001  0 43101 0.00000000
```

Figure 2-2. Example EPS3 PRESHP input file. Red box highlights the updated SCCs.

Ramboll (2022b) added the option to generate temporal profiles that are useful for processing emissions for air quality modeling with EPS3. MARINER can generate three different types of temporal profiles by month or by season: weekly, weekday, and weekend profiles. Due to the changes to the EPS SCCs, temporal profiles were also updated to be at the new detailed SCC level, so they can be matched when emissions are processed through EPS. Figure 2-3 shows an example of the weekly temporal profiles.



```
/WEEKLY/
.
.
 147   0   0   0   0   0   0   0   0 2022-Jan-NOx-Hotelling-Work Boat-C3-Propulsion
 148   0   0   0   0   0   0   0   0 2022-Jan-NOx-Hotelling-Work Boat-C1C2-Propulsion
 149  98  98  98  98  98 104 104 698 2022-Jan-NOx-Maneuvering-Bulk Carrier-C3-Propulsion
 150   0   0   0   0   0   0   0   0 2022-Jan-NOx-Maneuvering-Bulk Carrier-C1C2-Propulsio
 151  94  94  94  94  94 112 112 694 2022-Jan-NOx-Maneuvering-Chemical Tanker-C3-Propulsi
 152  91  91  91  91  91 118 118 691 2022-Jan-NOx-Maneuvering-Chemical Tanker-C1C2-Propul
 153 104 104 104 104 104  93  93 706 2022-Jan-NOx-Maneuvering-Container Ship-C3-Propulsio
 154   0   0   0   0   0   0   0   0 2022-Jan-NOx-Maneuvering-Container Ship-C1C2-Propulsi
 155   0   0   0   0   0   0   0   0 2022-Jan-NOx-Maneuvering-Crew and Supply-C3-Propulsi
.
.
/END/
```

Figure 2-3. Example Weekly Temporal Profile.

2.3 Harbor Craft Load Factors

MARINER follows the latest EPA guidance for estimating port emissions and uses EPA's default harbor craft load factors (EPA, 2022b). CARB (2020) conducted a study of harbor craft vessel activity, analyzing fuel consumption rates of 3,200 vessels and engine control module records from 34 engines. The CARB study revised the load factors for propulsion and auxiliary engines used in the California emissions inventory. The CARB load factors are generally lower than EPA's load factors, as shown in Table 2-4. Since barges do not have propulsion engines, load factors for propulsion are not applicable. EPA did not provide estimates for dredge propulsion engines, and CARB did not provide estimates for Miscellaneous (C1/C2) vessel engines.

Table 2-4. Default Harbor Craft Propulsion and Auxiliary Engine Load Factors (EPA, 2022b and CARB, 2021).

Vessel Type	Main/Propulsion Engine		Auxiliary Engine	
	EPA	**CARB**	**EPA**	**CARB**
Barge	None	None	0.43	0.31
Crew/Supply	0.45	0.26	0.43	0.40
Dredge	N/A	0.44	0.43	0.57
Excursion	0.42	0.27	0.43	0.40
Fishing	0.52	0.29	0.43	0.45
Government[1]	0.45	0.32	0.43	0.44
Harbor Ferry (C1/C2)	0.42	0.31	0.43	0.39
Miscellaneous (C1/C2)	0.52	N/A	0.43	N/A
Pilot	0.51	0.33	0.43	0.32
Tugboat-ATB[2]	0.68	0.50	0.43	0.50
Tugboat	0.50	0.16	0.43	0.34
Towboat/Pushboat	0.68	0.33	0.43	0.37
Workboat	0.45	0.33	0.43	0.32

[1] CARB Reseach Vessel is mapped as Government.

[2] EPA doesn't distinguish Tugboat-ATB (Articulate Tug Barge), so Towboat/Pushboat load factors apply.

After consulting with the TCEQ Project Manager, Ramboll added a new option for users to choose between harbor craft load factors from EPA or CARB by specifying the `HC_LF` parameter in the configuration file. An example of the parameter setting is shown Figure 2-4.

```
# specify the source of harbor craft load factors
# EPA or CARB
HC_LF = 'EPA'
```

Figure 2-4. Example of the load factor source parameter within the configuration file.

To compare harbor craft emissions using alternative load factors, we conducted two separate MARINER runs for January 2022 and summarized the NO_X emissions in Table 2-5. Emissions from OGVs are not included in the summary table because their emissions are not affected by these load factors. Emissions derived from EPA load factors for the main engine are significantly higher than those from CARB, although total auxiliary engine emissions are relatively similar between the two inventories. For miscellaneous (C1/C2) vessels, EPA's load factors were applied in both inventories by necessity, resulting in identical emissions.

Total NO_X emissions from all harbor craft vessels estimated by MARINER with EPA harbor craft load factors are 40% (957 tons) higher than those estimated with CARB load factors. Tugboats and towboats/pushboats together account for the majority of harbor craft emissions, comprising 83% of the EPA inventory and 72% of the CARB inventory. The main engine emissions of these vessel types dominate the difference (920 of 957 tons) between the two inventories.

Table 2-5. Comparison of 2022 January domain-wide NO_X emissions (tons) from harbor craft.

Vessel Type	Main/Propulsion Engine		Auxiliary Engine		Total		
	EPA	CARB	EPA	CARB	EPA	CARB	Change (%)
Crew/Supply	26	15	8	7	34	22	34%
Dredge	15	13	115	152	130	165	-27%
Excursion	<1	<1	<1	<1	<1	<1	10%
Fishing	18	10	39	41	57	51	10%
Government	4	3	11	12	15	14	5%
Harbor Ferry (C1/C2)	7	5	28	26	36	31	13%
Miscellaneous (C1/C2)	60	60	48	48	108	108	0%
Pilot	15	10	1	1	16	10	35%
Tugboat	1,302	632	162	139	1,464	771	47%
Towboat/Pushboat	411	161	124	105	535	265	50%
Workboat	1	1	9	6	10	7	26%
Total	**1,859**	**909**	**544**	**537**	**2,403**	**1,446**	**40%**

[a] Percentage change is calculated as: 100 x (EPA emissions – CARB emissions)/EPA emissions

2.4 Incorporate Shore Power Usage

Ramboll (2022a) identified vessels known to use shore power at their home berth, including the U.S. Department of Transportation Maritime Administration (MARAD) Ready-Reserve Ships at the Port of Beaumont and the McFadden Bend Cutoff facility on the Neches River, as well as vessels owned and operated by Texas A&M University at Galveston. We updated MARINER to eliminate engine emissions from vessels capable of using shore power at berth when AIS signals indicate that these vessels were stationary at their home berth.

We identified areas at or near the home berths of the shore-power enabled vessels and assumed zero emissions when the vessels were at near-zero speed (less than 0.5 knots) within these areas as shown in Figure 2-5. Emissions for these vessels while transiting were not changed and are included in the EI.

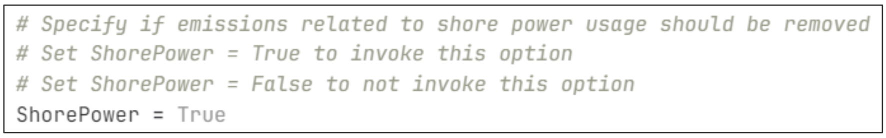
Figure 2-5. Locations of Shore Power Usage at Port of Galveston, Port of Beaumont, and McFadden Bend Cutoff.

For MARINER processing, a shapefile is necessary to identify the areas and the user can specify the path to the shapefile with the `PORTS_FILE` variable as shown in Figure 2-6.

```
# specify path to shapefiles
GRIDFILE = '/disk8/TCEQ_Mariner_2024/GIS/txt_4km/Mariner_txt_4km_198_243_srcmap.shp'
SeaMargin_FILE = '/disk8/TCEQ_Mariner/devel/GIS/SeaMargin/TXRectangleSplitIntoLandOceanSeaMargin2.shp'
PORTS_FILE = '/disk8/TCEQ_Mariner_2024/GIS/shorepower_ports/Shorepower_ports.shp'
```

Figure 2-6. Example of the paths to shapefiles within the configuration file.

To turn on this option, the user must set the following variable to `True` in the configuration file, as shown in Figure 2-7.



```
# Specify if emissions related to shore power usage should be removed
# Set ShorePower = True to invoke this option
# Set ShorePower = False to not invoke this option
ShorePower = True
```

Figure 2-7. Example of the shore power parameter within the configuration file.

To turn off this option, the user must set the ShorePower parameter to False. Table 2-6 summarizes the emissions that were set to zero for 2022 MARINER emissions processing.

Table 2-6. Summary of 2022 eliminated emissions due to shore power usage (tons/year).

Category	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
C3	399	12	32	6	6	15
C1/C2	35	<1	7	<1	<1	<1
Total	**434**	**13**	**39**	**7**	**7**	**15**

3.0 MARINER 2022 EIS

Ramboll used MARINER to generate two versions of the 2022 base year EI. One version incorporated EPA's default harbor craft load factors, while the other utilized CARB harbor craft load factors.

For the US waters, an emission control area (ECA) was declared and began implementation, with the first level of fuel sulfur limits that began in August 2012 with further control beginning in 2015:

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

The emission factors used for the 2022 emission inventory estimates assumed 0.1% sulfur content fuel. The application or determination of the fleet age distribution is not straightforward because individual ship transits were used in this work and have a unique activity profile as well as a ship or engine model year.

To compare harbor craft emissions using alternative load factors, a comparison of domain-wide NO_X emissions is shown in Table 3-1. Emissions from OGVs are not included in the summary table because their emissions are not affected by these load factors. Emissions derived from EPA load factors for the main engine are significantly higher than those from CARB, although total auxiliary engine emissions are relatively similar between the two inventories. For miscellaneous (C1/C2) vessels, EPA’s load factors were applied in both inventories by necessity, resulting in identical emissions.

Total NO_X emissions from all harbor craft vessels estimated by MARINER with EPA harbor craft load factors are 39% (11,870 tons) higher than those estimated with CARB load factors. Tugboats and towboats/pushboats together account for the majority of harbor craft emissions, comprising 79% of the EPA inventory and 66% of the CARB inventory. The main engine emissions of these vessel types dominate the difference (11,136 of 11,870 tons) between the two inventories. This comparison highlights the significant impact that different load factor methodologies can have on estimated emissions. Using CARB load factors, which are generally lower than EPA’s, results in noticeably lower NO_X emissions.

Table 3-1. Comparison of 2022 domain-wide NO$_X$ emissions (tons/year) from harbor craft.

	Auxiliary Engine		Main /Propulsion Engine		Total		
Ship Type	**EPA**	**CARB**	**EPA**	**CARB**	**EPA**	**CARB**	**Change %**
Crew and Supply	125	116	516	298	641	414	-35%
Dredge	1,480	1,962	446	392	1,926	2,354	22%
Excursion	3	3	2	1	5	4	-18%
Fishing (C1/C2)	988	1,034	700	390	1,688	1,424	-16%
Government	92	95	45	32	137	126	-8%
Harbor Ferry (C1/C2)	291	264	80	59	371	323	-13%
Miscellaneous (C1/C2)	615	615	810	810	1,426	1,426	0%
Pilot	11	8	162	105	173	113	-35%
Towboat/Pushboat	1,891	1,627	15,304	7,427	17,194	9,054	-47%
Tug Boat	1,566	1,318	5,356	2,097	6,923	3,415	-51%
Work Boat	107	80	46	34	153	114	-26%
Total	**7,169**	**7,120**	**23,468**	**11,646**	**30,637**	**18,766**	**-39%**

[a] Percentage change is calculated as: 100 x (CARB emissions – EPA emissions)/EPA emissions

Table 3-2 and Table 3-3 summarize the annual domain-wide emissions by ship type using EPA's or CARB's harbor craft load factors, respectively. Ocean-going vessels (OGVs) account for 63,072 tons of NO$_X$ and 2,900 tons of VOC emissions in both EIs. For the EI using EPA harbor craft load factors, the total domain-wide NO$_X$ emissions are 93,709 tons. In contrast, for the EI using CARB harbor craft load factors, the total domain-wide NO$_X$ emissions are 81,839 tons, representing a 13% reduction compared to the EPA EI.

Table 3-2. 2022 annual domain-wide emissions (tons/year) by ship type using EPA harbor craft load factors.

Vessel Category	Vessel Class	Ship Type	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Ocean Going Vessels	C1C2	Chemical Tanker	586	7	109	9	9	0
		General Cargo	11	0	2	0	0	0
		Offshore Support/Drillship	1,044	34	174	24	24	1
		Other Tanker	3	0	1	0	0	0
		RORO	2	0	0	0	0	0
	C3	Bulk Carrier	3,944	168	387	64	58	142
		Chemical Tanker	15,746	693	1,630	277	255	624
		Container Ship	7,107	333	718	113	104	264
		Cruise	3,027	120	273	47	43	103
		General Cargo	3,481	136	324	55	50	123
		Liquified Gas Tanker	6,457	388	830	193	177	481
		Miscellaneous (C3)	182	8	17	3	3	6
		Offshore Support/Drillship	50	2	5	1	1	2
		Oil Tanker	18,319	888	1,961	470	432	1,176
		Other Tanker	1,171	48	107	23	21	55
		Reefer	174	7	16	2	2	5
		RORO	1,769	68	158	27	25	62
		Subtotal	**63,072**	**2,900**	**6,712**	**1,308**	**1,205**	**3,044**
Harbor Craft	C1C2	Crew and Supply	641	20	110	13	13	0
		Dredge	1,791	41	304	32	31	1
		Excursion	5	0	2	0	0	0
		Fishing (C1/C2)	1,688	35	289	29	28	1
		Government	137	3	26	3	3	0
		Harbor Ferry (C1/C2)	371	5	72	8	7	0
		Miscellaneous (C1/C2)	1,426	52	276	33	32	2
		Pilot	173	5	39	4	4	0

Vessel Category	Vessel Class	Ship Type	NO$_X$	VOC	CO	PM$_{10}$	PM$_{2.5}$	SO$_2$
		Towboat/Pushboat	17,194	218	3,128	286	277	8
		Tug Boat	6,507	122	1,348	126	122	5
		Work Boat	125	4	22	3	3	0
	C3	Dredge	135	5	11	2	2	4
		Tug Boat	415	17	38	6	6	14
		Work Boat	28	1	2	0	0	1
		Subtotal	**30,637**	**530**	**5,667**	**545**	**528**	**37**
		Total	**93,709**	**3,429**	**12,378**	**1,853**	**1,733**	**3,080**

Table 3-3. 2022 annual domain-wide emissions (tons/year) by ship type using CARB harbor craft load factors.

Vessel Category	Vessel Class	Ship Type	NO$_X$	VOC	CO	PM$_{10}$	PM$_{2.5}$	SO$_2$
Ocean Going Vessels	C1C2	Chemical Tanker	586	7	109	9	9	0
		General Cargo	11	0	2	0	0	0
		Offshore Support/Drillship	1,044	34	174	24	24	1
		Other Tanker	3	0	1	0	0	0
		RORO	2	0	0	0	0	0
	C3	Bulk Carrier	3,944	168	387	64	58	142
		Chemical Tanker	15,746	693	1,630	277	255	624
		Container Ship	7,107	333	718	113	104	264
		Cruise	3,027	120	273	47	43	103
		General Cargo	3,481	136	324	55	50	123
		Liquified Gas Tanker	6,457	388	830	193	177	481
		Miscellaneous (C3)	182	8	17	3	3	6
		Offshore Support/Drillship	50	2	5	1	1	2
		Oil Tanker	18,319	888	1,961	470	432	1,176
		Other Tanker	1,171	48	107	23	21	55

Vessel Category	Vessel Class	Ship Type	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
		Reefer	174	7	16	2	2	5
		RORO	1,769	68	158	27	25	62
		Subtotal	**63,072**	**2,900**	**6,712**	**1,308**	**1,205**	**3,044**
Harbor Craft	C1C2	Crew and Supply	414	13	70	9	8	0
		Dredge	2,224	53	375	40	38	1
		Excursion	4	0	1	0	0	0
		Fishing (C1/C2)	1,424	32	240	24	24	1
		Government	126	3	24	3	3	0
		Harbor Ferry (C1/C2)	323	4	63	7	6	0
		Miscellaneous (C1/C2)	1,426	52	276	33	32	2
		Pilot	113	3	26	3	3	0
		Towboat/Pushboat	9,054	126	1,624	155	151	5
		Tug Boat	3,088	67	631	64	62	2
		Work Boat	93	3	17	2	2	0
	C3	Dredge	130	5	11	2	2	4
		Tug Boat	326	13	30	5	5	11
		Work Boat	21	1	2	0	0	1
		Subtotal	**18,766**	**376**	**3,389**	**346**	**335**	**27**
		Total	**81,839**	**3,276**	**10,100**	**1,654**	**1,540**	**3,071**

As more engine details were included in the Source Classification Code (SCC) updates under Task 4 (i.e., C1C/2 or C3, propulsion/auxiliary/boiler), domain-wide CMV emissions by engine and operating modes for 2022 using EPA's or CARB's harbor craft load factors are summarized in Table 3-4 and Table 3-5, respectively. When vessels are hotelling, they typically use their auxiliary engines and boilers, or they utilize shore power if available and the ship is equipped for it. Propulsion engines are not used during hotelling and thus are not listed in these tables. Vessels with C1/C2 engines, comprising most harbor craft, are equipped with propulsion and auxiliary engines but do not have boilers.

Table 3-4. 2022 annual domain-wide emissions (tons/year) by engine and operating mode using EPA harbor craft load factors.

Vessel Class	Mode	Engine	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
C1/C2	Hotelling	Auxiliary	6,295	187	1,007	139	135	4
	Maneuvering	Propulsion	71	3	19	2	1	0
		Auxiliary	107	3	17	2	2	0
	Transit	Propulsion	23,531	303	4,588	389	377	13
		Auxiliary	1,700	51	271	37	36	1
	Subtotals		**31,704**	**547**	**5,902**	**570**	**553**	**19**
C3	Hotelling	Auxiliary	19,793	772	2,015	346	318	777
		Boiler	3,571	188	357	360	331	1,047
	Maneuvering	Propulsion	4,013	358	577	58	54	153
		Auxiliary	3,046	120	313	54	49	121
		Boiler	148	8	15	15	14	43
	Transit	Propulsion	28,801	1,334	2,934	401	369	805
		Auxiliary	2,586	100	262	45	41	101
		Boiler	46	2	5	5	4	14
	Subtotals		**62,005**	**2,882**	**6,477**	**1,283**	**1,180**	**3,061**
	Total		**93,709**	**3,429**	**12,378**	**1,853**	**1,733**	**3,080**

Table 3-5. 2022 annual domain-wide emissions (tons/year) by engine and operating mode using CARB harbor craft load factors.

Vessel Class	Mode	Engine	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
C1/C2	Hotelling	Auxiliary	6,287	185	1,010	137	133	4
	Maneuvering	Propulsion	71	3	19	2	1	0
		Auxiliary	107	3	17	2	2	0
	Transit	Propulsion	11,823	158	2,323	196	190	7
		Auxiliary	1,646	49	263	36	35	1
	Subtotal		**19,935**	**398**	**3,633**	**373**	**362**	**12**
C3	Hotelling	Auxiliary	19,799	772	2,016	346	318	777
		Boiler	3,571	188	357	360	331	1,047
	Maneuvering	Propulsion	4,013	358	577	58	54	153
		Auxiliary	3,046	120	313	54	49	121
		Boiler	148	8	15	15	14	43
	Transit	Propulsion	28,687	1,329	2,923	399	367	802
		Auxiliary	2,593	100	262	45	41	101
		Boiler	46	2	5	5	4	14
	Subtotal		**61,904**	**2,877**	**6,468**	**1,281**	**1,179**	**3,058**
	Total		**81,839**	**3,276**	**10,100**	**1,654**	**1,540**	**3,071**

Table 3-6 and Table 3-7 summarize 2022 annual emissions at the county level for Texas and outside Texas using EPA's or CARB's harbor craft load factors, respectively. Note that these emissions tables only explicitly list counties with emissions that exceed 1 ton per year for NO_X or VOC. Total NO_X emissions within Texas are estimated to be 39,291 tons and 30,172 tons with EPA's or CARB's harbor craft load factors, respectively. Using CARB's harbor craft load factors results in 23% (9,119 tons) lower NO_X emissions within Texas compared to EPA's load factors. The counties of Galveston, Harris, and Jefferson together account for 5,307 tons of difference in NO_X emissions.

Table 3-6. 2022 annual domain-wide emissions (tons/year) by county using EPA harbor craft load factors.

County	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Aransas	954	22	158	17	17	11
Brazoria	2,121	47	349	42	40	37
Calhoun	849	13	150	14	14	4
Cameron	357	10	56	7	7	6
Chambers	2,450	71	382	38	36	32
Galveston	8,761	248	1,290	158	150	158
Harris	11,412	343	1,618	245	230	366
Jefferson	5,637	151	859	113	107	136
Kenedy	235	3	44	4	4	0
Kleberg	100	1	19	2	2	0
Matagorda	1,392	19	254	23	22	1
Nueces	3,149	108	470	75	71	123
Orange	971	23	165	19	19	18
Refugio	4	0	1	0	0	0
San Patricio	794	29	125	24	23	41
Victoria	27	0	5	0	0	0
Willacy	79	1	15	1	1	0
Other Counties[a]	0	0	0	0	0	0
Texas Total	**39,291**	**1,091**	**5,959**	**785**	**742**	**932**
Outside of Texas: US Waters	47,526	2,154	5,328	940	869	2,038
Outside of Texas: Others[b]	6,892	184	1,092	128	122	110
Total	**93,709**	**3,429**	**12,378**	**1,853**	**1,733**	**3,080**

[a] Other Texas counties with NO_X and VOC emissions less than 1 ton/year
[b] Includes Alabama, Louisiana, Oklahoma, Mexico, and International Water

Table 3-7. 2022 annual domain-wide emissions (tons/year) by county using CARB harbor craft load factors.

County	NO_X	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
Aransas	685	19	107	13	12	10
Brazoria	1,434	39	219	31	29	36
Calhoun	497	10	85	9	9	4
Cameron	282	9	42	6	5	6
Chambers	1,806	63	259	28	26	31
Galveston	7,077	228	972	130	123	157
Harris	9,197	316	1,197	208	195	364
Jefferson	4,228	133	585	90	85	136
Kenedy	133	2	25	2	2	0
Kleberg	50	1	9	1	1	0
Matagorda	768	12	139	13	13	1
Nueces	2,628	101	355	66	62	123
Orange	637	19	101	14	13	17
Refugio	2	0	0	0	0	0
San Patricio	686	27	100	22	20	41
Victoria	16	0	3	0	0	0
Willacy	46	1	9	1	1	0
Other Counties[a]	0	0	0	0	0	0
Texas Total	**30,172**	**979**	**4,208**	**634**	**597**	**927**
Outside of Texas: US Waters	46,707	2,138	5,162	925	853	2,035
Outside of Texas: Others[b]	4,960	159	731	95	90	109
Total	**81,839**	**3,276**	**10,100**	**1,654**	**1,540**	**3,071**

[a] Other Texas counties with NO_X and VOC emissions less than 1 ton/year
[b] Includes Alabama, Louisiana, Oklahoma, Mexico, and International Water

3.1 AIS Activity Analysis

The EPA raised an issue about missing AIS data for a few days between April to June 2022 and considered gap-filling this data when developing their 2022 CMV emissions. We conducted an analysis of the AIS data used by MARINER for the April to July periods for years 2019, 2022, and 2023. It is worth noting that the AIS data used by MARINER is published by Marine Cadastre, which has undergone quality assurance, whereas the EPA received AIS data directly from the United States Coast Guard. The AIS data can differ depending on the source and initial processing methods.

Figure 3-1 and Figure 3-2 present time series plots of AIS records and NO_X emissions using EPA harbor craft load factors in the Texas 4km modeling domain, respectively. Our analysis did not reveal any days with zero activity data. Although several dips are noticeable in 2022, these are likely attributable to weather or natural events, such as tornadoes and heavy precipitation, which are infrequent but can influence marine activity when they occur. For instance, on May 22, 2022, the National Oceanic and Atmospheric Administration (2022) issued a severe thunderstorm outlook for Texas with significant precipitation reported near the Galveston area (Community Collaborative Rain, Hail & Snow Network, n.d.) that can explain the slowdown in marine activities seen in Figure 3-1 for May 22, 2022. Table 3-8 summarizes the monthly number of AIS records and NO_X emissions for the analysis period. For 2022, the monthly activity and NO_X emissions are generally consistent and comparable month-to-month and to the other two years. Following a review by the TCEQ project manager, it was concluded that the AIS data used by MARINER is acceptable and does not require gap-filling.

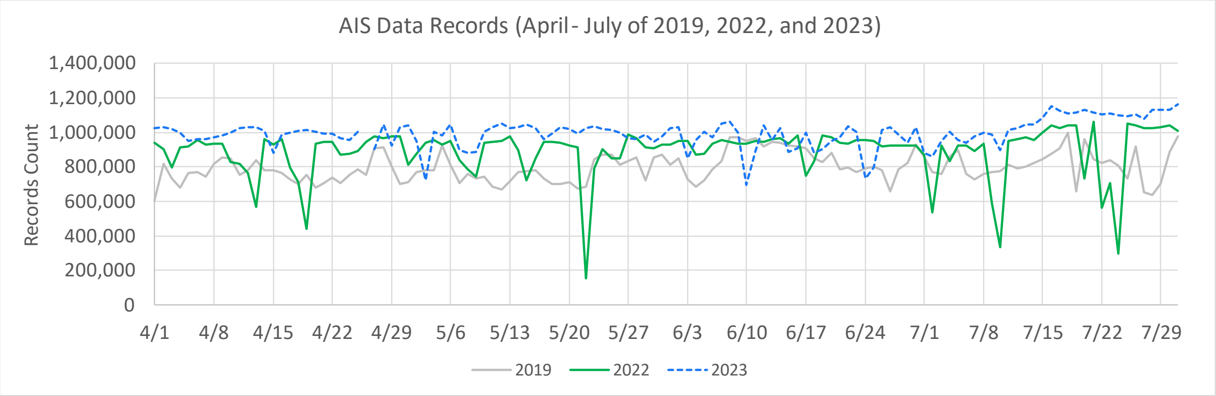


Figure 3-1. 2019, 2022, 2023 April to July AIS data records.

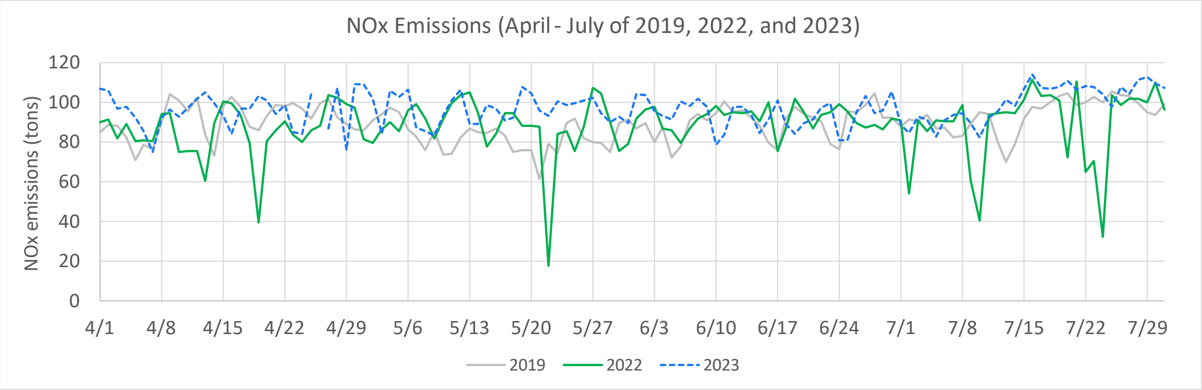


Figure 3-2. 2019, 2022, 2023 April to July NO_X emissions.

Table 3-8. Summary of monthly number of AIS records and NO_X emissions.

	Records	Records	Records	NO_X (tons)	NO_X (tons)	NO_X (tons)
Month	**2019**	**2022**	**2023**	**2019**	**2022**	**2023**
April	22,963,869	26,323,743	28,696,332	2,740	2,569	2,765
May	23,859,780	27,027,765	29,560,459	2,571	2,709	2,897
June	25,312,891	27,914,642	27,675,227	2,692	2,752	2,727
July	25,227,726	27,323,403	32,557,650	2,905	2,752	3,110

3.2 Comparison between MARINER 2022 EI and EPA 2022 CMV Emissions

Ramboll developed a comparison between the MARINER 2022 EI and EPA’s 2022 CMV EI for Texas from the 2022v1 Emissions Modeling Platform (EPA, 2024). The following analysis provides a detailed comparison of emission totals for all pollutants, with a discussion focusing on NO_X emissions.

Figure 3-3, Figure 3-4, and Figure 3-5 present the 2022 Texas emissions by pollutant for all vessels, C3 vessels, and C1/C2 vessels, respectively. Emissions from C1/C2 vessels show substantial variation across the three inventories. Specifically, when comparing MARINER EIs using CARB harbor craft load factors to the EPA's 2022 NO_X emissions, we found that the MARINER EI using EPA load factors resulted in 46% higher NO_X emissions, while the MARINER EI using CARB load factors resulted in 11% lower NO_X emissions. For C3 vessels, the percent differences between MARINER EIs and the EPA EI are less than 13% across all pollutants.

Overall, the EPA’s 2022 CMV EI is more comparable to the MARINER EI using CARB’s harbor craft load factors than EPA’s default load factors (Figure 3-3) which is likely due to cancellation between offsetting effects. The differences in NO_X emissions between MARINER EI using CARB’s harbor craft load factors and the EPA EI are negligible, with MARINER showing close to 0.3% difference in NO_X, whereas differences are larger for other pollutants, namely 2% in SO_2, 5% in CO, 21% in PMs, and 27% in VOC.

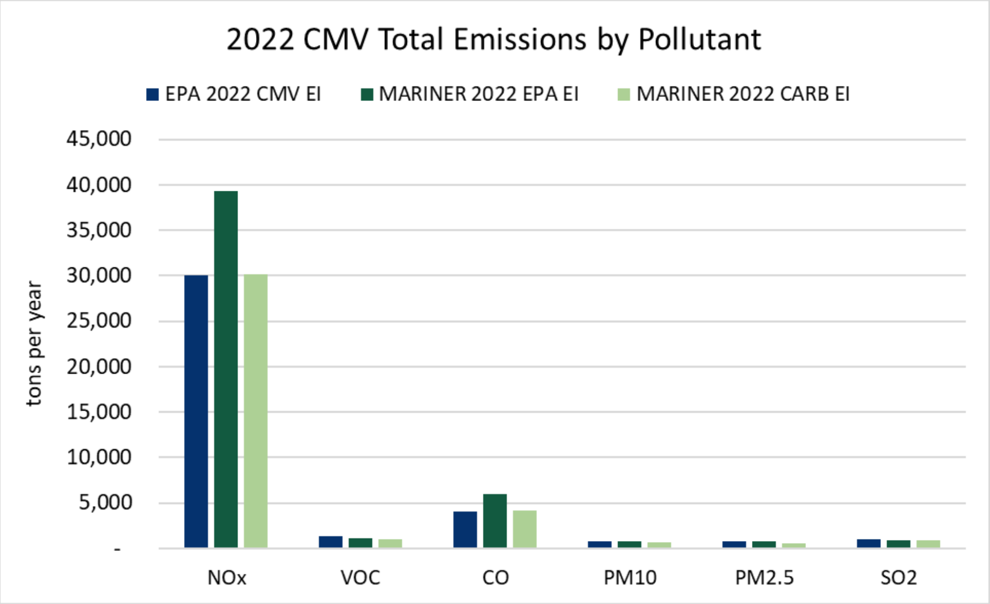


Figure 3-3. **EPA 2022 CMV EI and MARINER 2022 CMV emissions by pollutant.**

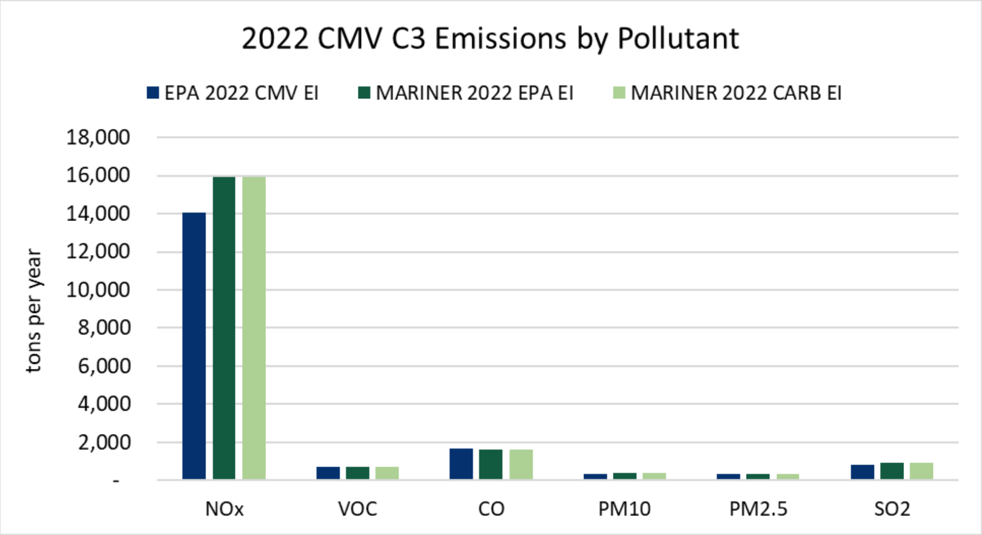


Figure 3-4. **EPA 2022 CMV EI and MARINER 2022 CMV emissions by pollutant for C3 vessels.**

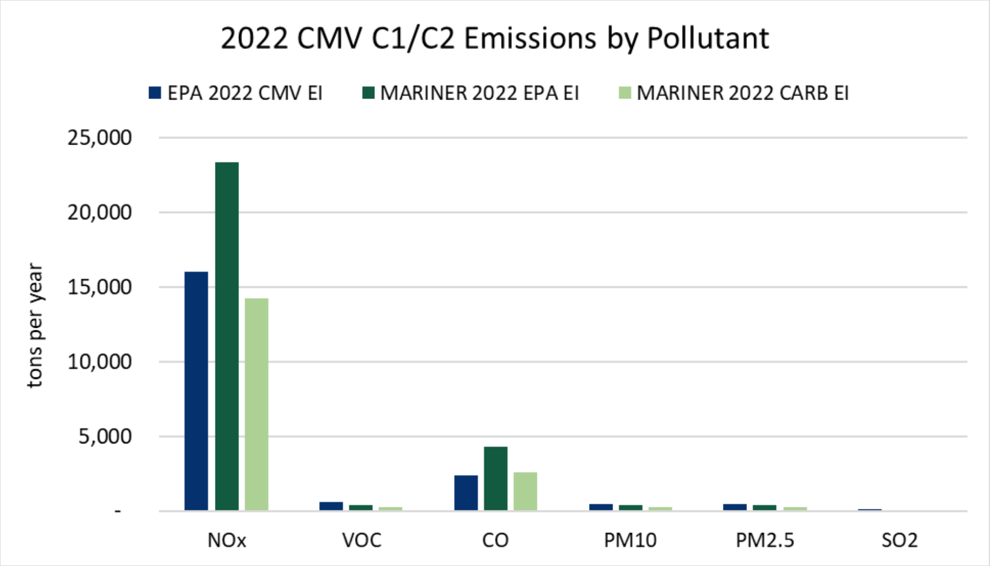
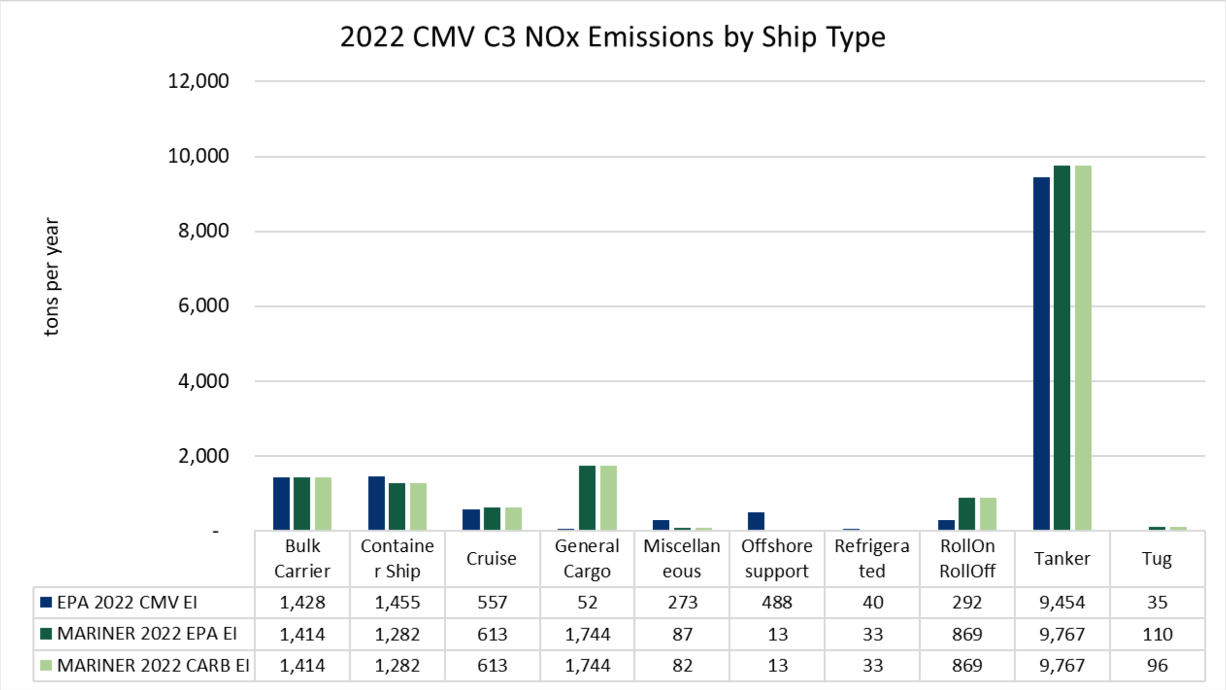


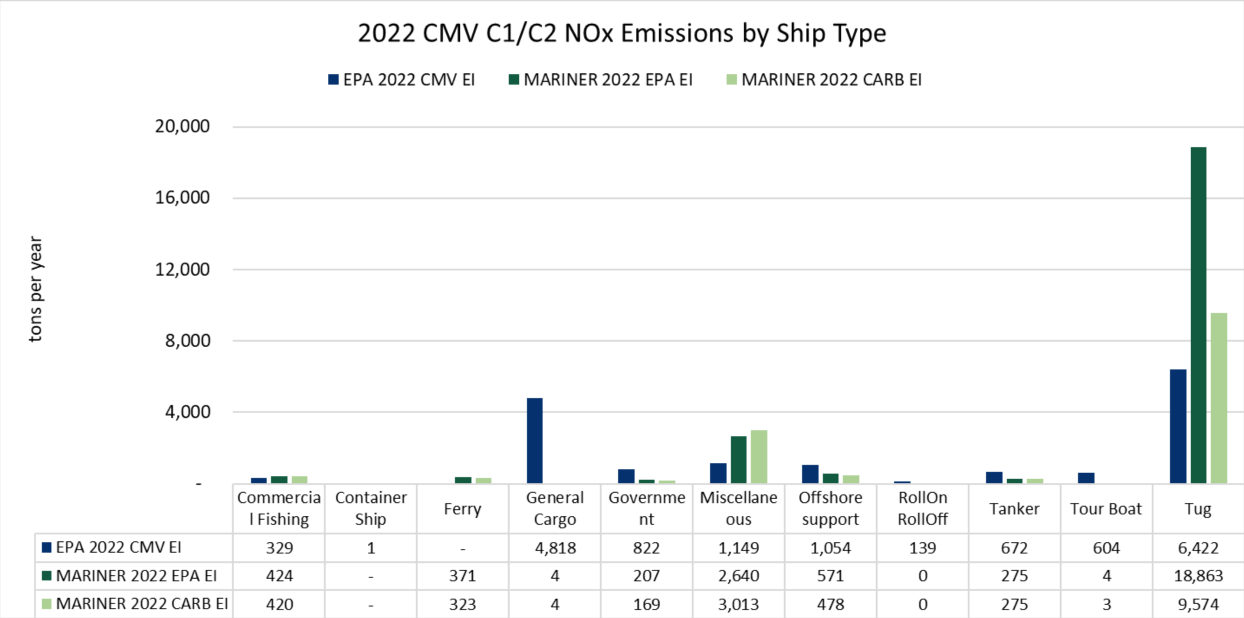
Figure 3-5. EPA 2022 CMV EI and MARINER 2022 CMV emissions by pollutant for C1/C2 vessels.

The 2022 CMV NO_X emissions by ship type are summarized for C3 vessels and C1/C2 vessels in Figure 3-6 and Figure 3-7, respectively. Notably, two ship types, General Cargo and Tug, demonstrate substantial differences between the inventories. The EPA inventory attributes nearly 5,000 tons of NO_X emissions to General Cargo (C1/C2), whereas the MARINER inventory reports only 1,744 tons for General Cargo (C3) and virtually none for General Cargo (C1/C2). Additionally, MARINER inventories indicate substantially higher Tug emissions compared to the EPA, which contributes to the overall NO_X emissions difference. This discrepancy may be due to the EPA categorizing many barges pushed by tugs as General Cargo, while MARINER identifies them more precisely. The difference between Ferry and Tour Boat also could be caused by different vessel mapping between EPA and MARINER as the two vessel types are similar.



	Bulk Carrier	Container Ship	Cruise	General Cargo	Miscellaneous	Offshore support	Refrigerated	RollOn RollOff	Tanker	Tug
■ EPA 2022 CMV EI	1,428	1,455	557	52	273	488	40	292	9,454	35
■ MARINER 2022 EPA EI	1,414	1,282	613	1,744	87	13	33	869	9,767	110
■ MARINER 2022 CARB EI	1,414	1,282	613	1,744	82	13	33	869	9,767	96

Figure 3-6. EPA 2022 CMV NO$_X$ and MARINER 2022 CMV NO$_X$ emissions by ship type for C3 vessels.



	Commercial Fishing	Container Ship	Ferry	General Cargo	Government	Miscellaneous	Offshore support	RollOn RollOff	Tanker	Tour Boat	Tug
■ EPA 2022 CMV EI	329	1	-	4,818	822	1,149	1,054	139	672	604	6,422
■ MARINER 2022 EPA EI	424	-	371	4	207	2,640	571	0	275	4	18,863
■ MARINER 2022 CARB EI	420	-	323	4	169	3,013	478	0	275	3	9,574

Figure 3-7. EPA 2022 CMV NO$_X$ and MARINER 2022 CMV NO$_X$ emissions by ship type for C1/C2 vessels.

Figure 3-8 compares NO$_X$ emissions between the inventories by county. Spatial discrepancies are expected between the EPA and MARINER EI due to the different methodologies used for county assignment. MARINER uses the TCEQ 4 km modeling grids for spatial assignment whereas EPA uses precise county boundaries. For instance, Chambers County and San Patricio County, despite having fewer shipping lanes, show higher emissions in the MARINER inventories. This could be due to their proximity to other counties with busy shipping lanes, such as Galveston County and Aransas/Nueces counties, respectively. Similarly, Jefferson County and Orange County show higher emissions in the MARINER inventories. These counties border Louisiana so there may be different spatial distributions between MARINER and the EPA inventories, as emissions from vessels transiting nearby waterways might be allocated differently.

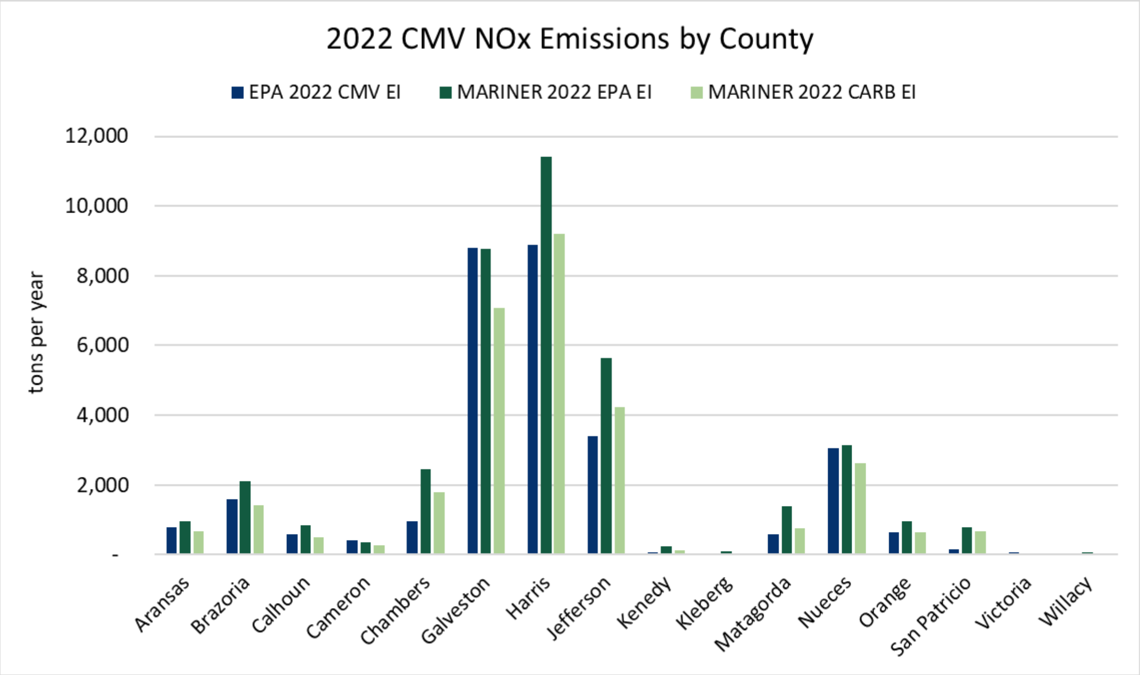


Figure 3-8. **EPA 2022 CMV NO_X and MARINER 2022 CMV NO_X emissions by county.**

When comparing NO_X emissions by engine category, as shown in Figure 3-9, we find that C3 emissions align more closely between the different inventories than C1/C2 emissions. For C1/C2 vessels, the MARINER EI using EPA’s harbor craft load factors reports 247% more NO_X emissions from the main engine, while using CARB’s load factors results in 68% more NO_X emissions than the EPA’s inventory. Both MARINER EIs have 47% less NO_X emissions from auxiliary engines than the EPA's inventory. These variations are consistent with the differences observed in Tug emissions, as shown in Figure 3-9.

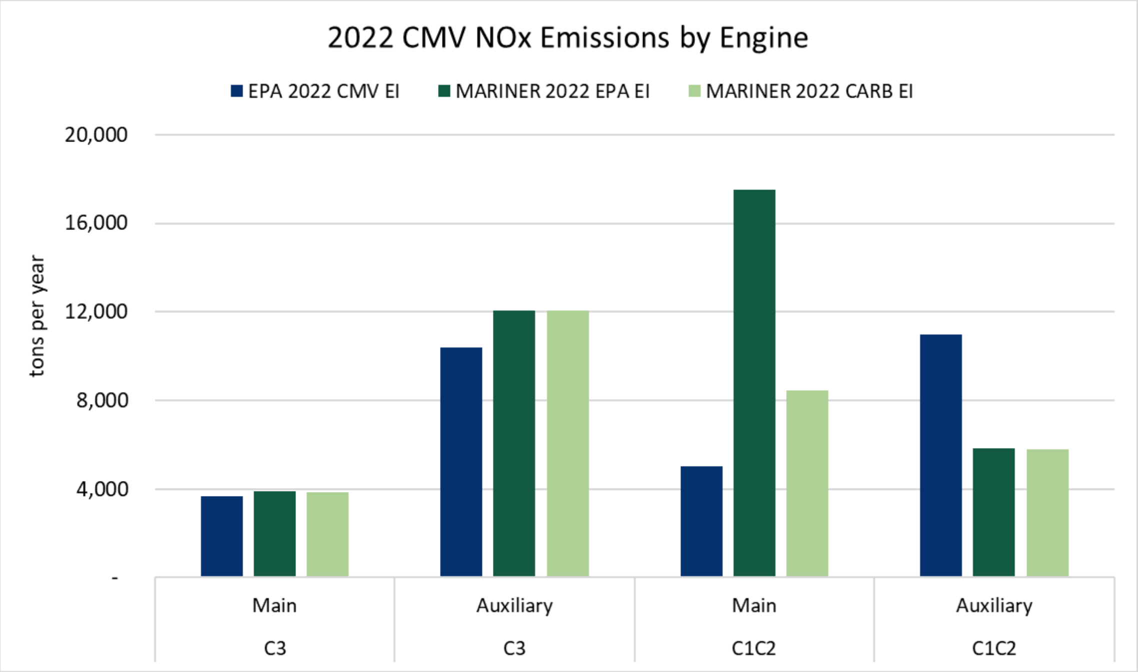


Figure 3-9. **EPA 2022 CMV NO_X and MARINER 2022 CMV NO_X emissions by engine.**

4.0 RECOMMENDATIONS

The following recommendations are presented to further improve the accuracy of MARINER EIs in future projects:

- Gap-filling vessel characteristic data is necessary because the S&P Global Ships database is not comprehensive. To address this, one approach is to develop a Texas-specific gap-fill dataset for vessel characteristics, using the latest S&P Global Ships database and most recent AIS data (e.g., 2022, 2023, and 2024).
- Improving memory management to allow MARINER to run for longer periods in the TX domain including all vessels, i.e., more than two months. Currently, memory issues can occur when processing vessel type 31 (Towboat/Pushboat) because this vessel type has the most activity records and thus large memory requirements that make MARINER stop execution occasionally.
- Leveraging Artificial Intelligence (AI) and Machine Learning (ML) techniques to enhance the quality and utility of AIS data, thereby improving the accuracy and precision of marine emission estimates. For instance, AI can perform quality assurance (QA) on large datasets, detecting anomalies and inconsistencies more efficiently and in greater detail than a person, ensuring higher data integrity for emission modeling.

5.0 REFERENCES

CARB 2020. "WEBINAR: Overview of Proposed Concepts for Amendments to the Commercial Harbor Craft Regulation," March 2020. https://ww2.arb.ca.gov/sites/default/files/2020-03/CHC%20Webinar%20Presentation%20March%202020_1.pdf

CARB 2021. "Appendix H 2021 Update to the Emission Inventory for Commercial Harbor Craft: Methodology and Results," September 21, 2021. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/chc2021/apph.pdf

Community Collaborative Rain, Hail & Snow Network. (n.d.). View data map: Texas. Retrieved June 21, 2024, from https://www.cocorahs.org/Maps/ViewMap.aspx?state=TX

EPA 2024. 2022v1 Emissions Modeling Platform. https://www.epa.gov/air-emissions-modeling/2022v1-emissions-modeling-platform

NOAA 2022. "May 22, 2022 0730 UTC Day 3 Severe Thunderstorm Outlook," May 2022. https://www.spc.noaa.gov/products/outlook/archive/2022/day3otlk_20220522_0730.html

Ramboll 2020. Automation of Commercial Marine Vessel Emissions Inventory Development. Work Order No. 582-20-12636-017 (texas.gov)

Ramboll 2021. 2020 Texas CMV Emissions Inventory and 2011 through 2050 Trend Inventories. Work Order No. 582-21-11294-001 (texas.gov)

Ramboll 2022a. Commercial Marine Vessel Research - Shore Power and/or Alternative Emissions Controls. Work Order No. 582-22-31436-031 (texas.gov)

Ramboll 2022b. Enhance MARINER Tool for Commercial Marine Emission Inventories. Work Order No. 582-22-31220-030 Enhance MARINER Tool (texas.gov)

Ramboll 2023. Updating the Marine Emissions Resolver. Work Order No. 582-23-42629-035 Updating the Marine Emissions Resolver (texas.gov)