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Commercial Marine Vessel Research - Shore Power and/or Alternative Emissions Controls

Final Report

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RAMBOLL

Commercial Marine Vessel Research - Shore Power and/or Alternative Emissions Controls
Final Report

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List of Acronyms and Abbreviations

AERR	Air Emissions Reporting Requirements
AIS	Automatic Identification System
CO	Carbon Monoxide
CCL	Carnival Cruise Lines
CMV	Commercial Marine Vessels
EI	Emission Inventory
EPA	Environmental Protection Agency
IMO	International Maritime Organization
MARINER	MARINe Emissions Resolver
MARAD	Maritime Administration
MMSI	Maritime Mobile Service Identity
NOx	Nitrogen Oxides
PM_{10}	Particulate Matter with diameter smaller than 10 μm
$PM_{2.5}$	Particulate Matter with diameter smaller than 2.5 μm
ROS	Reduced Operating Status
RORO	Roll On/Roll Off
RCL	Royal Caribbean lines
SO_2	Sulfur Dioxide
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality
tpy	Tons Per Year
TRU	Transportation Refrigeration Units
VOC	Volatile Organic Compounds

EXECUTIVE SUMMARY

The purpose of this study is to 1) determine to what extent shore power or alternative emissions control technology (such as barge or shore-based capture and control) is currently implemented or will be implemented at eight Texas ports (Houston, Beaumont, Corpus Christi, Texas City, Port Arthur, Freeport, Brownsville, and Galveston) and 2) estimate realized and potential at berth hoteling emissions reduction potential where applicable.

To achieve study objectives, Ramboll performed the following tasks:

1. Conducted survey efforts to collect data from the eight Texas ports to determine to what extent shore power or alternative emissions control technology (such as barge or shore-based capture and control) is currently implemented or will be implemented in the future at each port.
2. Estimated realized and potential hoteling emissions reductions and compared the potential reduction estimates to the Texas Commission on Environmental Quality's (TCEQ) most recent commercial marine vessel (CMV) emission inventory (EI) for each port by vessel type. Additionally, the analysis provided perspective on the number of ships and types of ships that may need refitting to allow for shore power use in order to reach significant control levels.

A summary of the study findings is as follows:

- **Current Use of Shore Power at Surveyed Ports:** Most Ports and private terminals surveyed as part of this study are not currently using shore power. Maritime Administration (MARAD) Ready Reserve fleets at the Port of Beaumont and Texas A&M training vessels at the Port of Galveston do use shore power. The emissions for the MARAD Ready Reserve fleets and Texas A&M training vessels should not include hoteling emissions when shore power is being used.
- **Planned Future Use of Shore Power at Surveyed Ports:** The Port of Galveston is beginning an evaluation on the potential use of shore power for one of their main cruise ship customers and may also consider shore power infrastructure for additional cruise, container and refrigerated ship operations.
- **Shore Power Cost Effectiveness and Emissions Reduction Considerations:**
  - **Container ships** produced larger annual at berth emissions compared to cruise ships, but emissions are smaller on an average per call and per vessel basis compared to cruise ships.
  - **Cruise ships** produced close to the same magnitude of annual emissions as container ships at the Port of Galveston. Cruise ship emissions are larger on an average per call and per vessel basis compared to container ships. Many cruise ships are currently equipped to make use of shore power.
  - **Refrigerated (reefer) ships:** Targeted use of shore power for frequently calling reefer ships may produce cost effective emission reductions at the Port of Galveston.
- **Distinguishing At Berth from At Anchor Hoteling Emissions:** Ramboll's MARINe Emissions Resolver (MARINER) estimates of in-Port and 'Underway' hoteling emissions are based on port geographic areas defined by the United States Environmental Protection Agency (US EPA). The EPA-defined port geographic areas do not allow for accurate distinction of at berth hoteling emissions (which can be reduced by shore power) and at anchor hoteling emissions (which cannot be reduced by shore power) mainly because EPA's port boundaries are overly specific, frequently excluding private terminals. TCEQ may consider redrawing port boundaries such that at berth, hoteling emissions that can be reduced by shore power can be more accurately defined and estimated.

1.0 INTRODUCTION

The TCEQ regularly develops statewide emission inventories (EI) for non-road mobile sources in Texas, including the commercial marine vessel (CMV) source category. These EIs are needed to fulfill federal Air Emissions Reporting Requirements and to support state implementation plan development and other air quality planning efforts. Ramboll recently developed statewide 2019 and 2020 county-level CMV EIs for the TCEQ using the MARINER tool with year-specific Automatic Identification System (AIS)[1] vessel location data and vessel characteristics data from the Sea-web Ships database following the latest applicable EPA guidance and methodologies (Ramboll, 2021; TCEQ WO 582-21-11294-001).

While anchoring (hoteling) at berth, vessels typically use auxiliary engines and/or boilers to provide power which results in emissions of criteria pollutants. However, a vessel could potentially mitigate emissions at berth by making use of shore power (if suitably equipped) or, alternatively, an exhaust capture and control system could be employed. The current CMV EI does not account for the possible use of shore power and/or alternative emissions control technologies.

Ramboll investigated the presence and possible use of shore power and/or alternative emissions control technologies for CMV sources while at ports in Texas waterways. Identifying the presence and potential use of such technology will help to improve the accuracy of TCEQ's CMV EI.

Chapter 2 of this report describes the survey efforts performed to collect data from eight Texas ports (Houston, Beaumont, Corpus Christi, Texas City, Port Arthur, Freeport, Brownsville, and Galveston) to determine to what extent shore power and alternative emissions control technology is implemented at each port and the ports' plans for use of at berth emission controls. The information collected may be used to supplement activity data used in MARINER to ensure a higher level of accuracy for future CMV EI development.

Chapter 3 of this report describes 1) use of data collected during the ports' survey to estimate realized and potential emissions reductions. Estimated emission reductions were compared with TCEQ's most recent CMV inventory for each port for container and cruise ships which typically have higher berthing loads and are the strongest candidates for at berth emission reductions. Some ships may already be shore power compatible, but others need refitting to receive shore power. Therefore, the number of ships by ship type that may need refitting to obtain substantial emission reductions was estimated.

Chapter 3 also includes a quality assurance comparison of 2020 berthing times from 1) MARINER and 2) the Port of Galveston provided berth report. The results of this review confirmed that MARINER includes accurate estimates of container, refrigerated cargo, and cruise ship activity at the Port of Galveston. The quality assurance comparison also highlighted discrepancies in the Port of Galveston geographic region used by MARINER (at the time of this report) and can help inform improvements to Port spatial definitions to better characterize in-port activity.

Chapter 4 includes study conclusions and recommendations.

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

2.0 SURVEY EFFORT AND RESULTS

This chapter describes the survey of eight Texas ports which was performed to understand the operation and plans for the installation of shore power at berth. For each port, Ramboll 1) reached out to port staff and selected fleets, initially by phone call and subsequently via emails, to gauge current shore power operations, interest in/plans for future shore power installation, and 2) collected vessel calls for fleet vessels that use shore power at berth. The data collected, which is discussed in more detail below, includes the following components:

- Vessel calls from the port (collected data was limited to the Port of Galveston)
- Recorded shore power electricity consumption or alternative emission control descriptions and operations (data collected from the Maritime Administration (MARAD) and University of Texas A&M Training Vessels)
- Details for any future plans to implement shore power or other at berth emissions control technology (collected data was limited to the Port of Galveston)

The following summary findings are discussed:

- Time horizons for potential planned shore power or at berth emissions controls: Galveston is beginning a feasibility analysis (timeline currently unspecified) but has at least one interested partner fleet.
- Recommended sources for surrogate data: Port data is often unavailable, limited in geographic scope, and does not include private berth facilities. Besides freely available historical[2] AIS data used in the MARINER tool, the Greater Houston Port Bureau[3] offers port call data for many Texas ports for a fee.
- Survey administration and documentation procedures including survey questions and survey delivery formats.
- Survey response gap-filling and validation procedures and subsequent data processing were performed on the Port of Galveston vessel calls data. Ramboll reviewed the Port of Galveston call data, compared the Port of Galveston call data to AIS data, and highlighted data gaps and quality assurance concerns.

2.1 Survey Approach

Ramboll identified relevant port contacts at each port to discuss the current and planned approach to using and providing shore power capability or alternative at-berth emission controls. Once a knowledgeable port staff member was contacted, a phone call was arranged and a phone interview was conducted to understand the ports' operations, service to its terminals, and fleets calling to those terminals.

Ramboll previously developed EIs for TCEQ using historical AIS data (Ramboll, 2021). The MARINER EI program assumes that if the AIS system was providing a signal, auxiliary engines were operating. In the case that AIS was operating, but the auxiliary engines were turned off (such as when using

[2] availability is usually within several months after year's end

[3] https://www.txgulf.org/products/marine-exchange-reports-inquiry##

shore power), MARINER would overestimate emissions. Ramboll contacted ports and knowledgeable fleets about whether they knew of any vessels using shore power or alternative emission controls while at berth.

2.2 Survey Results

The public ports encompass only a fraction of the activity at all the terminals in Texas. There are a substantial number of private terminals near or along the same waterways as the public ports. The most significant marine freight category is liquid and gas bulk associated with the petroleum industry. The petroleum industry is served by vessels with unique characteristics and freight handling systems to transport flammable cargo via ships and push boat barges.

The eight public ports contacted reported that they were not (and knew of no other terminals that were) using shore power or alternative at-berth emission controls. The ports were aware of shore power and alternative at-berth emission control options but could not justify the capital cost of installing the associated infrastructure until their tenants and fleets were interested and willing to commit to its long-term use. Ramboll also spot-surveyed a tug fleet and tug base who responded that they did not use shore power, nor did they know of any other fleet in their industry in Texas that did.

MARAD ready-reserve ships were identified as a fleet that uses shore power. MARAD ready-reserve ships were primarily berthed at the Port of Beaumont and along the Neches River at the Beaumont Reserve Fleet Layberth Facility at the McFadden Bend Cutoff on the border of Jefferson and Orange counties as shown in Figure 1. These MARAD ships layberth (berthing for a longer time than is typical when in ready status) under reduced operating status (ROS) and use shore power for reduced operating loads. MARAD ships must occasionally start generators and other motors as part of routine maintenance and the main engines are started on a periodic basis as part of a "dock trial," and during any sea trials. The MARINER tool identifies underway operations for ship speeds exceeding 1 knot during any trials away from berth.

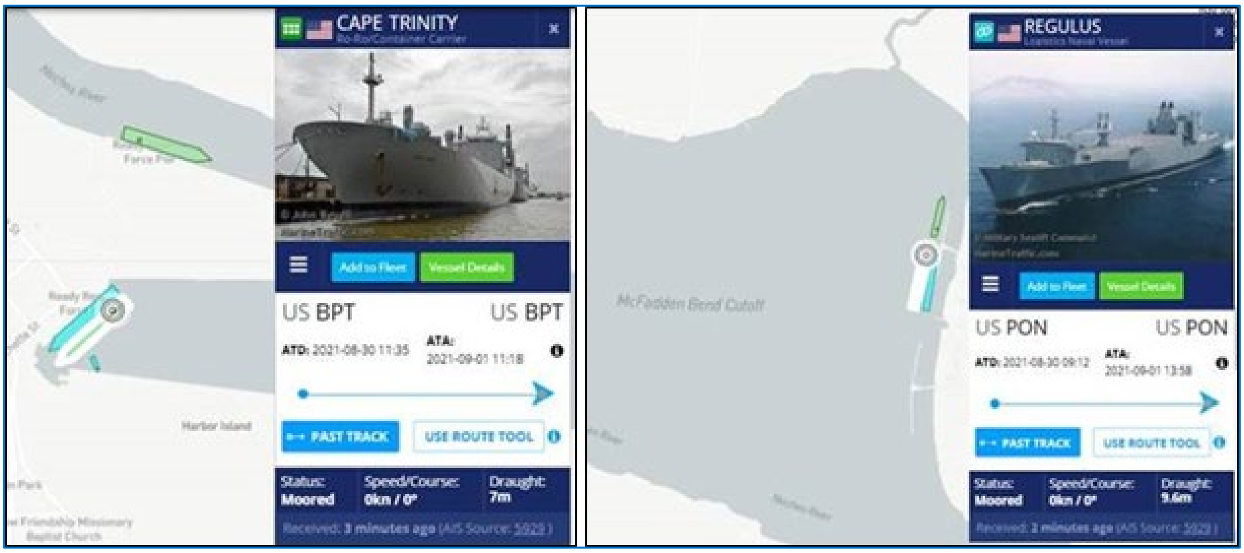

Figure 1. MARAD Ready-Reserve ships example, March 2022 (Beaumont, left panel; McFadden Bend Cutoff, right panel).[4]

Additional vessels which were identified as using shore power are training vessels berthed at the Texas A&M campus on Pelican Island, Galveston. These are smaller vessels with a unique training or research purpose. The Texas A&M and MARAD vessels are listed in Appendix A.

MARINER estimates of 2019 and 2020 hoteling emissions at berth for those vessels reported to use shore power are summarized in Table 1. MARINER does not include shore power assumptions; therefore, the emissions reported in Table 1 represent the maximum emissions reductions from the use of shore power by these MARAD and Texas A&M vessels.

The MARAD fleet also includes other vessels (such as Cape Farewell and Cape Flattery) that are anchored in the McFadden Bend Cutoff. These vessels are not in ready status and engines are turned off. Because the engines are turned off, there are no associated AIS records and MARINER does not estimate any emissions for these vessels at anchor. The Texas A&M training and research vessels are smaller and have lower auxiliary power demands than typical cargo vessels.

[4] https://www.marinetraffic.com/en/ais/home/centerx:-94.057/centery:30.042/zoom:13

Table 1. MARINER 2019 and 2020 hoteling activity (hours) and emissions (tons per year[5]) estimated for vessels reported to use shore power.

Vessel	Year	Hoteling (hours) [a]	VOC [b] (tpy)	CO [b] (tpy)	NOx [b] (tpy)	PM_{10} [b] (tpy)	$PM_{2.5}$ [b] (tpy)	SO_2 [b] (tpy)
MARAD Ready-Reserve Ships								
Cape Taylor (Hoteling)	2019	5,551	3.29	8.45	83.72	1.76	1.62	4.19
Cape Taylor (All Modes)	2019	---	3.35	8.58	84.95	1.76	1.64	4.25
Cape Taylor	2020	7,860	4.65	11.96	118.53	2.49	2.29	5.94
Cape Taylor (All Modes)	2020	---	4.66	11.96	118.60	2.49	2.29	5.94
Cape Texas (Hoteling)	2019	8,555	0.75	1.97	19.53	0.34	0.31	0.76
Cape Texas (All Modes)	2019	---	0.80	2.04	20.16	0.35	0.32	0.80
Cape Texas (Hoteling)	2020	8,776	0.77	2.02	20.04	0.35	0.32	0.78
Cape Texas (All Modes)	2020	---	0.77	2.02	20.04	0.35	0.32	0.78
Cape Trinity (Hoteling)	2019	4,508	2.67	6.86	67.98	1.43	1.31	3.40
Cape Trinity (All Modes)	2019	---	2.72	6.96	68.88	1.44	1.33	3.44
Cape Trinity (Hoteling)	2020	5,227	3.09	7.95	78.82	1.65	1.52	3.95
Cape Trinity (All Modes)	2020	---	3.11	7.99	79.14	1.66	1.53	3.96
Cape Victory (Hoteling)	2019	4,830	2.86	7.35	72.84	1.53	1.41	3.65
Cape Victory (All Modes)	2019	---	2.90	7.44	73.68	1.54	1.42	3.68
Cape Victory (Hoteling)	2020	6,819	4.04	10.37	102.83	2.16	1.98	5.15
Cape Victory (All Modes)	2020	---	4.04	10.37	102.83	2.16	1.98	5.15
Cape Vincent (Hoteling)	2019	4,072	2.41	6.19	61.40	1.29	1.18	3.07
Cape Vincent (All Modes)	2019	---	2.45	6.27	62.11	1.30	1.20	3.11
Cape Vincent (Hoteling)	2020	7,804	4.62	11.87	117.69	2.47	2.27	5.89
Cape Vincent (All Modes)	2020	---	4.63	11.89	117.89	2.47	2.27	5.90
Regulus (Hoteling)	2019	6,436	0.57	1.48	14.69	0.25	0.23	0.57
Regulus (All Modes)	2019	---	0.57	1.48	14.69	0.25	0.23	0.57
Regulus (Hoteling)	2020	7,466	0.66	1.72	17.04	0.29	0.27	0.66
Regulus (All Modes)	2020	---	0.67	1.73	17.09	0.30	0.27	0.68
Pollux (Hoteling)	2019	2,241	0.20	0.52	5.12	0.09	0.08	0.20
Pollux (All Modes)	2019	---	0.23	0.56	5.45	0.09	0.08	0.20
Pollux (Hoteling)	2020	2,338	0.21	0.54	5.34	0.09	0.08	0.21
Pollux (All Modes)	2020	---	0.23	0.56	5.45	0.10	0.10	0.26
Cape Farewell (Hoteling)	all	0	0.00	0.00	0.00	0.00	0.00	0.00
Cape Flattery (Hoteling)	all	0	0.00	0.00	0.00	0.00	0.00	0.00
MARAD Subtotal (Hoteling)	**2019**		**12.75**	**32.81**	**325.28**	**6.68**	**6.14**	**15.85**
MARAD Subtotal (Hoteling)	**2020**		**18.04**	**46.43**	**460.29**	**9.50**	**8.74**	**22.58**
Texas A&M University at Galveston (Pelican Island) Training Vessels								
General Rudder (Hoteling)	2019	1,289	0.22	1.16	7.75	0.16	0.16	0.00
General Rudder (All Modes)	2019	---	0.24	1.26	8.34	0.17	0.17	0.01
General Rudder (Hoteling)	2020	5,069	0.87	4.57	30.49	0.64	0.62	0.02
General Rudder (All Modes)	2020	---	0.90	4.75	31.63	0.66	0.64	0.02
Trident (Hoteling)	2019	527	0.00	0.01	0.08	0.00	0.00	0.00
Trident (All Modes)	2019	---	0.05	0.27	1.55	0.03	0.03	0.00

[5] Tons per year

Vessel	Year	Hoteling (hours) [a]	VOC [b] (tpy)	CO [b] (tpy)	NOx [b] (tpy)	PM_{10} [b] (tpy)	$PM_{2.5}$ [b] (tpy)	SO_2 [b] (tpy)
Texas A&M University at Galveston (Pelican Island) Training Vessels								
Trident (Hoteling)	2020	680	0.00	0.01	0.10	0.00	0.00	0.00
Trident (All Modes)	2020	---	0.02	0.09	0.55	0.01	0.01	0.00
Earl L. Milan (Hoteling)	2019	194	0.00	0.00	0.03	0.00	0.00	0.00
Earl L. Milan (All Modes)	2019	---	0.04	0.21	1.23	0.03	0.03	0.00
Earl L. Milan (Hoteling)	2020	29	0.00	0.00	0.00	0.00	0.00	0.00
Earl L. Milan (All Modes)	2020	---	0.01	0.05	0.28	0.01	0.01	0.00
Texas A&M Subtotal (Hoteling)	**2019**		**0.22**	**1.18**	**7.86**	**0.17**	**0.16**	**0.00**
Texas A&M Subtotal (Hoteling)	**2020**		**0.87**	**4.59**	**30.59**	**0.64**	**0.62**	**0.02**

[a] *2020 was a leap year with 8784 total hours*

[b] *VOC, volatile organic compounds; CO, carbon monoxide; NOx, nitrogen oxides; PM_{10}, particulate matter less than 10 microns; $PM_{2.5}$, particulate matter less than 2.5 microns; SO_2, sulfur dioxide.*

The Port of Galveston indicated in the survey that it is seriously considering shore power for cruise ships and has issued press releases to that effect.[6] The Port will investigate shore power for a variety of ship types focusing on Royal Caribbean lines (RCL) and other cruise ships. Because the Port has RCL tenant interest, it increases the chances that a shore power system may be a near-term possibility. Carnival Cruise lines (CCL) reported[7] in 2021 that 42 of their 93 ships had been equipped for shore power and had plans for 16 more. The Port has not committed to a timeline for shore power installation and use. Potential shore power emission reductions for Port Galveston are discussed in Chapter 3.

[6] https://www.portofgalveston.com/CivicAlerts.aspx?AID=180, https://www.galvnews.com/news/article_55000634-1738-5456-90b2-7dc553718f0f.html

[7] https://www.cruiseindustrynews.com/cruise-news/25456-renewed-interest-in-shore-power-for-cruise-lines-and-ports.html

3.0 SHORE POWER POTENTIAL ANALYSIS

Ramboll collected the data for vessel calls from the Port of Galveston and supplemented the collected ship calls data with AIS recorded data for hoteling time within and near the ports of Houston and Freeport for container, reefer, and cruise ships. Ramboll used this data to estimate the shore power emissions reduction potential for these three ship types. In Chapter 2 Table 1, Ramboll provided realized shore power emissions reductions from the vessels that used shore power in 2019 and 2020.

The MARINER tool assumes that if the AIS system was providing a signal, auxiliary engines were operating. In the case that AIS was operating, but the auxiliary engines were turned off (such as when using shore power), MARINER would overestimate emissions. Ships also operate boilers at berth, but boiler emissions were not included in this analysis because it is difficult to use shore power to create the steam and hot water supplied by the on-board boilers.

In California, under a 2007 rulemaking[8,9], the State required shore power initially for container ships, passenger (cruise) ships, and refrigerated-cargo (reefer) ships, with the requirement phase-in starting in 2014. California considered these three vessel types to be the most suitable for shore power and these were the ship types first required to use shore power. Fleets with five cruise ship or 25 container and reefer ship calls were required to reduce their at-berth emissions by 80% by 2020; some exemptions were allowed including Coast Guard requirements for ship maintenance or other reasons and at the Governor's discretion (e.g., during grid power outages experienced in 2020). Under a normal year without exemptions, an emissions reduction of 72% was expected for the Port of Oakland[10] (based on full 80% compliance for the more frequently calling container ships), but, given the unusual Governor exemptions in 2020, a 65% emissions reduction was achieved. California[11] is expanding its at-berth rule to include more vessel types and more strict coverage of container, reefer, and cruise ship calls.

Ramboll investigated the potential shore power emissions benefits for cruise, container, and reefer ship types at the ports of Houston, Galveston, and Freeport because Houston and Freeport are the two busiest container ports in Texas[12], and Galveston[13] experiences routine container, reefer, and cruise ship activity. The Port of Galveston is investigating shore power for cruise ships and will also consider providing shore power for container and reefer ships. Port Houston has physical infrastructure available (concrete boxes and conduits) at Bayport to install electrical power systems but has not yet implemented shore power. Port Freeport does not have shore power for ships but has installed shore plugs for refrigerated containers to avoid using diesel transportation refrigeration units while awaiting delivery at the terminal.

[8] https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation/about

[9] https://ww3.arb.ca.gov/regact/2007/shorepwr07/shorepwr07.htm

[10] https://www.portofoakland.com/community/environmental-stewardship/seaport-air-emissions-inventory-2005/

[11] https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation

[12] https://www.logisticsmgmt.com/article/top_30_u.s._ports_big_ports_got_bigger_in_2020

[13] https://www.joc.com/port-news/us-ports/port-galveston/galveston-roll-roll-project-reefer-focus-working_20180207.html

In this chapter, the following items are discussed:

- **Shore power emission reduction potential:** Container, reefer, and cruise ships have the most cost-effective potential emission reductions.
- **Port of Galveston:** Potential emission reductions estimated by MARINER (based on AIS vessel calls activity) were compared to emission reductions estimated based on activity from the Port's berthing reports.
- **Houston, Freeport, Galveston:** MARINER hoteling emissions estimates were used to estimate potential shore power emission reduction benefits.
- **Fleet Analysis**: Frequently calling vessels are the most suitable and cost effective for using shore power.
- **Recommended data sources**: Port data is often unavailable, limited in geographic scope, and does not include adjacent private berth facilities. Besides freely available historical AIS data used in MARINER, the Greater Houston Port Bureau[14] offers port call data for many Texas ports for a fee, which first requires a membership fee followed by cost fee that depends on the time period and how many berths are included in the request.
- **Port shape files**: Port areas could be delineated more accurately by redrawing the port shape files. More accurate port shape files would allow MARINER to estimate at-berth emissions and shore power emission reduction potential more accurately based on better delineation of emissions from (i) hoteling activity outside of ports and (ii) hoteling activity at berth.

3.1 Port of Galveston Analysis

3.1.1 Vessel Calls Comparisons

The Port of Galveston provided vessel call data for calendar years 2017 to 2021. The Port of Galveston recorded about 828 calls during 2020 of which more than 90 were tug and barge calls including some construction, dredge and other barges. There were only 91 cruise ship calls in 2020 because of the pandemic. Cruise ship service is scheduled[15] to return to 320 calls in 2022; RCL and CCL will make up 303 of those calls. Notably, Port of Galveston has a small (16 calls annually) container ship business, but two ships identified as refrigerated (reefer) ships call weekly (52 calls in 2020) carrying refrigerated containers and perhaps also carrying refrigerated noncontainerized break bulk cargo. The remaining vessels calling to the Port include a wide variety of liquid tankers, solid bulk, general cargo, roll on/roll off (RORO) freight ships, and research/offshore support vessels.

Ramboll compared the Port calls data with the 2020 MARINER hoteling activity estimates within Galveston County. Overall, the hoteling time estimated from the AIS data used in MARINER for large ships (i.e., excluding tugs) was within 1% including offsetting positive (AIS hoteling>Port berth time) and negative (AIS time<Port berth time) bias. Negative bias alone was under 10% when accounting for errors in vessel identification and date and time in/out of berth in the Port activity tables. Tugs (and other smaller vessels including research and offshore support vessels) often shut

[14] https://www.txgulf.org/products/marine-exchange-reports-inquiry##

[15] https://www.portofgalveston.com/80/Cruise-Lines-Schedules

off their propulsion and auxiliary engines at berth, turning off the power to the AIS signal. Therefore, AIS data more accurately identifies engine activity than Port berthing time.

MARINER identifies vessel activity by either county total or 'in Port' where the 'in Port' activity is geographically defined using EPA 'shape files' that describe the boundaries for each port. The EPA shape file is of unknown origin for the Port of Galveston and is limited to public Port of Galveston berths and potentially excludes some berths which are included in the Port's vessel calls data. Including all ship hoteling within Galveston County results in identifying more vessels than are listed by the Port of Galveston calls because the county boundary encompasses the Ports of Galveston and Texas City along with private marine terminals and anchorages at the entrance to Galveston Bay and offshore (but within 9 nautical miles of shore). The two databases (Port calls and AIS hoteling) cover mismatched geographic scopes and must be aligned before a detailed accounting of differences can be determined.

The Port berthing times are not always comparable with AIS hoteling for a variety of reasons listed in Table 2.

Table 2. Comparison of 2020 Port of Galveston calls with 2020 AIS calls for Galveston County.

"Positive Bias" (AIS Hoteling Hours > Port Berthing hours)	"Negative Bias" (AIS Hoteling Hours < Port hours)
Vessels at private berths within county	Tugs or small ship AIS off at berth such as when engines are shut off
At Anchorage away from berth	Dry dock or other maintenance AIS off at berth
Texas City calls of the same vessels that also call to the Port of Galveston	Incorrect vessel ID in Port data
Tug layover not counted in Port's call list such as without barge	Vessel MMSI[a] can change from one year to the next such as transferring vessel ownership
Incorrect vessel ID in Port data	Typos (IMO[b] number, MMSI, dates) in Port data
Typos (IMO number, MMSI, dates) in Port data	

[a] *Maritime Mobile Service Identity*

[b] *International Maritime Organization*

To remedy the positive bias (i.e., when AIS has recorded activity that the Port did not), Port areas should be redrawn by creating new 'shape files' in MARINER to include all berths for which calls are reported by the Ports. A tug or other vessel may temporarily layover at a port berth but not be counted as a port berthing, creating positive bias, though these vessel types often power down their auxiliary engines and therefore the AIS signals at berth. The port call list must be quality assured to correct vessel identification and precise dates.

Negative bias refers to instances in which the Port calls list included activity when the AIS system records did not. Some situations, such as when the AIS was off, but the vessel was at berth, cannot be resolved. The AIS can be off due to no vessel power (engines off) or the AIS system itself has been disabled, such as for maintenance. In other cases, the MMSI (AIS signals use MMSI as the vessel identifier) for the vessel may have changed from one year to the next, such as from change of ownership, while the IMO number stays the same. In such a case, the AIS records would have had a different MMSI than the available cross reference of MMSI to IMO number used by MARINER and so misidentified that vessel. For the 2020 Galveston calls, there were many errors where the vessel was misidentified (incorrect IMO number), or the date or time in and out of berth was incorrect; correction of these errors resolved many differences between the Port calls and AIS records.

In summary, the AIS vessel hoteling records largely matched the Port's calls in both number and hoteling/berthing time. Careful review of each vessel's identification and operation (date and time stamps) can explain much of the small remaining difference.

3.1.2 Shore Power Emissions Reduction Potential

In California, under a 2007 rulemaking[16], the State required shore power initially for container ships, passenger ships, and refrigerated-cargo ships, with the requirement phased-in starting in 2014. California considered these vessel types to be the most suitable for shore power and were the ship types first required to use shore power. Likewise, the Port of Galveston is investigating shore power for cruise ships and may also consider container and reefer ships. For these reasons, the Galveston hoteling activity and emissions are presented for these vessel types.

For the 159 cruise, reefer, and container ship calls to Galveston, the MARINER AIS hoteling time matched all the Port recorded calls and berthing time (no missing calls or significant time at berth bias). Compared to the Port calls data, MARINER AIS records indicated a slightly higher average (about +10 minutes or 0.6%) berthing time of 26.25 hours compared to the Port average of 26.10 hours. In MARINER, the AIS records hoteling when the vessel is moving at less than 1 knot, so the small high bias probably reflects near dock time before tying up and after casting off at very slow speeds. In the second half of 2019[17], the average berthing time was much lower at about 9.6 hours per call reflecting vessel berthing activity in a typical year.

The shore power emissions reduction potential for Galveston is expected to be a fraction of the auxiliary engine emissions shown in Table 3 because shore power would not be available for all ships, calls, and hours at berth. Cruise ship hoteling emissions are higher than other vessel types due to higher auxiliary loads and repeat calls at the Port. Cruise ship activity is expected to rebound to 320 cruise ship calls in 2022 (there were only 91 calls during 2020)[18], indicated in the last row in Table 3. Ramboll estimated that cruise ship calls could be responsible for up to 400 tons of NOx during 2022 while at berth without the use of shore power.

[16] https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation/about

[17] The Port provided berthing time for only the second half of 2019.

[18] https://www.portofgalveston.com/80/Cruise-Lines-Schedules

Table 3. MARINER Galveston County cruise and container/reefer ships activity and hoteling auxiliary engine emissions (tons per year).

Ship Type	Calls	No. of Vessels	Average Hoteling Time (hours/call)	VOC (tpy)	CO (tpy)	NOx (tpy)	PM_{10} (tpy)	$PM_{2.5}$ (tpy)	SO_2 (tpy)
Refrigerated (2020)	52	2	24.4	0.70	1.81	16.19	0.38	0.35	0.90
Container (2020)	16	6	68.7	0.54	1.37	12.31	0.33	0.30	0.81
Cruise (2020)	91	7	26.1	12.98	33.79	303.28	6.02	5.54	13.71
Cruise (2019)	*297*	*8*	*9.6*	*15.39*	*40.07*	*353.40*	*7.13*	*6.56*	*16.25*
Estimated Cruise (2022)	*Adjusted to 320*	[a]	*9.6*	*17*	*43*	*381*	*8*	*7*	*18*

[a] *The number of vessels that will call in 2022 is unavailable.*

Shore power cost considerations include port infrastructure and operating costs as well as the cost required to refit ships to accept shore power. It may be easier to justify or encourage fleets to make their ships shore power-ready when a small number of ships make frequent calls to and have substantial berthing times at Port. Two refrigerated ships made 52 calls and seven cruise ships made 91 calls in 2020. Regular calls by a limited fleet would also facilitate scheduling for the shore power equipped berth. The cruise ship fleets that call to Galveston (RCL and CCL) are largely equipped to use shore power making this approach attractive for Galveston.

3.2 Port Houston and Port Freeport Analysis

3.2.1 Shore Power Emissions Reduction Potential

For Houston and Freeport, Ramboll relied on the 2019 and 2020 MARINER output to estimate the emissions reduction potential of container and reefer ships. MARINER bins emissions as either 'Port' or 'Underway' based on the AIS position relative to areas defined for each port by shape files. As currently programmed in MARINER, the 'Hoteling' mode refers to all vessel activity at <1 knot speeds, which could occur in 'Port' or 'Underway' based on the vessel position relative to port shape files.

The definition of the port area shape file can be overly specific leading to misidentification of berthing hoteling as 'Underway.' 'Underway' hoteling is intended to describe hoteling activity while the vessel is at anchor or maneuvering in a ship channel rather than at berth. An inaccurate or overly specific 'Port' shape file misidentifies vessels as outside the 'Port' area when they were within a widely accepted port area. Therefore, some 'Underway' hoteling (<1 knot speed) may be at-berth activity that is misidentified. Ramboll also notes that in certain cases, recorded position[19] may be different than actual position.

Table 4 shows the MARINER calculated hoteling auxiliary engine emissions for container and reefer ships by 'Port' and other ('Underway') positions. Most of the at-berth container ships emissions were for calls to the Port of Houston. The 'Underway' hoteling emissions, representing about 15% of

[19] https://www.hindawi.com/journals/wcmc/2022/5954483/

container ship hoteling NOx emissions, may be at berth given potentially inaccurate or overly specific port shape files used in MARINER.

Table 4. MARINER container and refrigerated ship hoteling auxiliary engine emissions (tons per year)

Ship Type	Mode	Port	VOC (tpy)	CO (tpy)	NOx (tpy)	PM_{10} (tpy)	$PM_{2.5}$ (tpy)	SO_2 (tpy)
2019								
Container	Port	Freeport, TX	0.72	1.83	16.74	0.43	0.40	1.06
Container	Port	Houston, TX	13.61	34.51	305.15	8.24	7.58	20.37
Container	Underway	N/A	2.83	7.17	63.91	1.71	1.57	4.23
Container	*Subtotal*	*All*	*17.16*	*43.51*	*385.79*	*10.38*	*9.55*	*25.66*
Reefer	Port	Galveston, TX	0.15	0.39	3.54	0.08	0.07	0.19
Reefer	Port	Houston, TX	0.00	0.00	0.0003	0.00	0.00	0.00
Reefer	Port	Texas City, TX	0.04	0.10	1.01	0.02	0.02	0.05
Reefer	Underway	N/A	0.74	1.89	17.34	0.39	0.36	0.94
Reefer	*Subtotal*	*All*	*0.93*	*2.39*	*21.89*	*0.50*	*0.46*	*1.18*
Both	**Total**	**All**	**18.09**	**45.89**	**407.68**	**10.87**	**10.00**	**26.84**
2020								
Container	Port	Freeport, TX	0.73	1.86	16.93	0.44	0.40	1.08
Container	Port	Galveston, TX	0.29	0.73	6.55	0.17	0.16	0.43
Container	Port	Houston, TX	14.24	36.10	316.76	8.64	7.95	21.37
Container	Underway	N/A	2.55	6.47	57.35	1.54	1.42	3.81
Container	Subtotal	*All*	*17.81*	*45.16*	*397.59*	*10.79*	*9.93*	*26.69*
Reefer	Port	Galveston, TX	0.10	0.25	2.21	0.05	0.05	0.12
Reefer	Underway	N/A	0.68	1.74	15.76	0.36	0.33	0.86
Reefer	Subtotal	*All*	*0.77*	*1.99*	*17.97*	*0.41*	*0.38*	*0.99*
Both	**Total**	**All**	**18.59**	**47.15**	**415.56**	**11.20**	**10.31**	**27.68**

Port of Galveston 2020 'Port' hoteling NOx emissions in Table 4 represent 53% (for container ships) and 14% (for reefer ships) of the results in Table 3. Table 4 includes 'Port' emissions for hoteling activity occurring within inaccurate or overly specific port shape file boundaries and therefore misidentifies a substantial amount of hoteling that occurred at the Port of Galveston berths as 'Underway'. Table 3 results were based on the container and reefer calls date and time stamps provided by the Port of Galveston which Ramboll was able to use to correctly identify all 'Port' hoteling emissions. About half of the container and most of the reefer ship call hoteling emissions at Galveston were misidentified as 'Underway' for 2020. For example, Table 3 shows 16.19 tons of NOx for 2020 reefer ships hoteling at the Port of Galveston (based on Port of Galveston vessel berthing data). Table 4 shows only 2.21 tons of NOx for 2020 reefer ships hoteling at the Port of Galveston at 'Port' (i.e., within EPA port shape file boundaries); 15.76 tons of NOx were estimated for hoteling activities that occurred outside of the EPA shape file port boundaries and were therefore included as 'Underway' hoteling. The at-berth 'Port' emissions which were misidentified as 'Underway', highlight the need to better represent port area boundaries in MARINER.

3.2.2 Fleet Analysis of Potential At-berth Reductions

The potential for emission reductions from shore power is heavily dependent on vessel berthing time. For each vessel call, time is required to connect and disconnect the shore power unit and take the vessels' auxiliary engines off-line (limited to no more than 3 hours per call as required by California). In addition, it is most cost effective to apply shore power to the most frequently calling vessels which spend substantial time at berth.

Table 5 shows the relative activity by vessel frequency and average at berth duration. The vessels that had hoteling times greater than 240 hours (10 days) in 2019 and 2020 together represented 73% of total hoteling time while also representing a minority of vessels calling to Houston-Galveston area ports. Targeting ships which call more often and have longer berthing times will result in more cost-effective shore power emission reductions.

Table 5. 2019 and 2020 vessel call hoteling time for container and reefer ships.

Vessels	Minimum Hoteling Hours	Fraction of Hours	Total Hoteling Hours	Hoteling Hours per Vessel
384	>1	100%	86,130	224
285	>60	96%	82,898	291
205	>120	88%	75,949	370
131	>240	73%	62,737	479
65	>360	50%	42,935	661
30	>480	33%	28,741	958

Overall, Galveston cruise ship shore power will have the largest impact on emissions because in a normal year (unaffected by the pandemic) up to 400 tons of NOx are emitted at a limited number of berths by few ships which are largely already capable of using shore power. Container ships produce about 400 tons of NOx per year, primarily at Houston's Barbours Cut and Bayport container terminals but a lower fraction of container ships will be shore power capable. Reefer ships produced a minority of emissions, but the two frequently calling reefers at Galveston produced more emissions on average than most container ships.

The at-berth auxiliary engine emissions represent the emissions reduction potential for shore power, but shore power cannot reduce 100% of at berth emissions because of (i) time required to connect shore power upon arrival and disconnect shore power prior to disembarkation and (ii) not all ships will be able to use shore power.

3.3 MARINER Input Improvements

One suggestion to improve the distinction in MARINER between in-port hoteling and away from port ('Underway') hoteling is to redraw the port boundaries to be more inclusive of all at-berth activity. The port boundaries used by MARINER to estimate at-berth hoteling emissions presented in Table 2 are GIS 'shape files' created by EPA and may not include all port activity.

There may be hoteling activity away from a port for short-term maneuvering or while at anchor. Hoteling activity away from a port needs to be distinguished from at-berth hoteling because at-berth hoteling emissions may be reduced by shore power, but away from port hoteling emissions cannot be reduced by shore power. Bolivar Roads (see Figure 2) is an anchorage location at the entrance to

Galveston Bay (additional offshore anchorage locations are not shown in Figure 2). Vessels that anchor at Bolivar Roads would be accurately considered by MARINER to be hoteling in 'Underway' mode because the location is outside any port boundary.

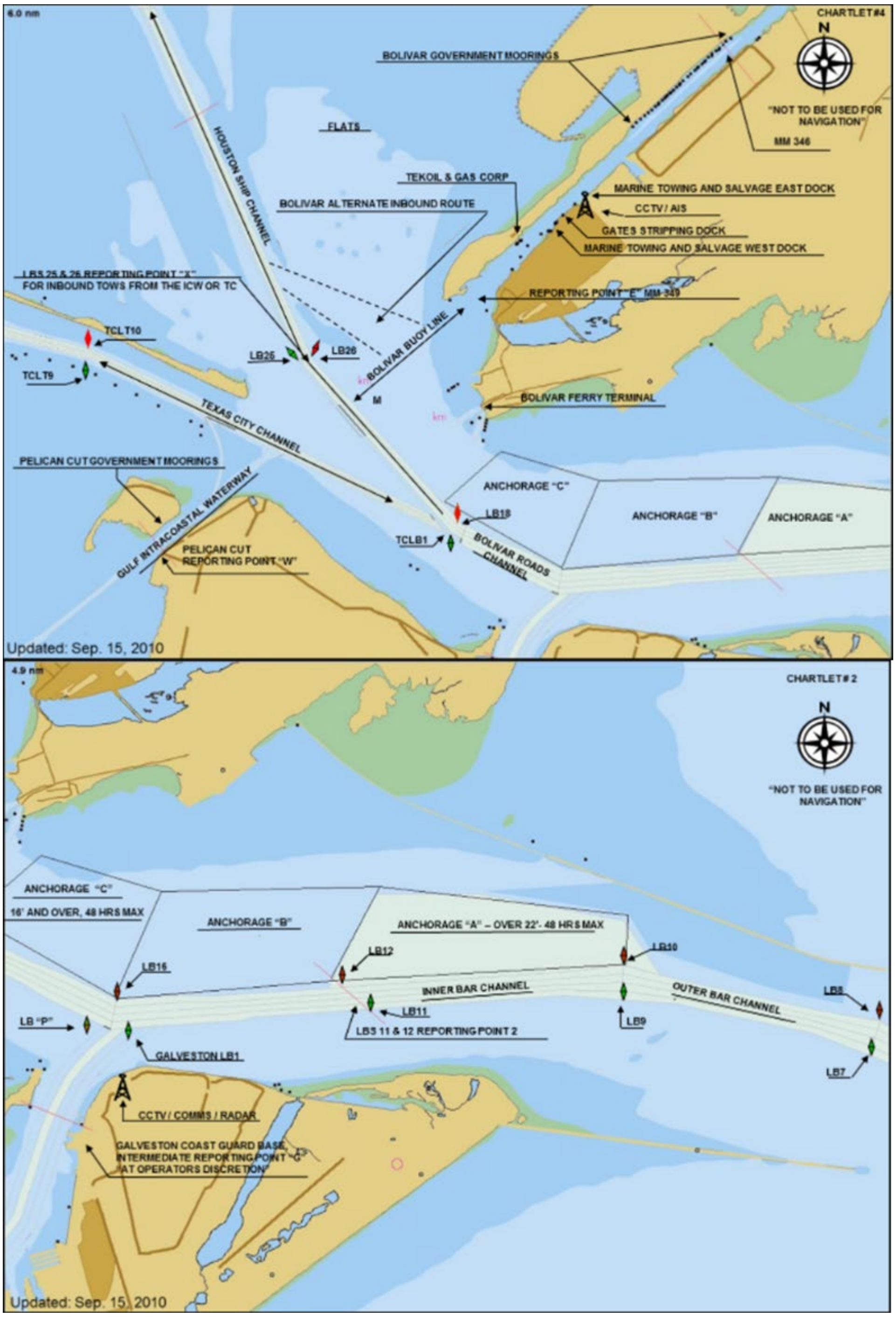

Figure 2. Bolivar Roads Anchorage[20] (same anchorages; west view (top panel) and east view (bottom panel)).

Many private berths and terminals lie adjacent to or some distance from public ports. EPA shape files are largely consistent with only public port domains. For Galveston however, the EPA shape file

[20] http://www.galvestonpilots.com/Charlets.aspx

shown in Figure 3 is somewhat different than the Port-owned property and berths[21] including some and excluding other adjacent private berths and terminals. It would be more inclusive to have the port boundary encompass the entire water area between urban Galveston and Pelican Island. This would eliminate 'Underway' and 'Port'' location identification errors when vessel positions are marginally outside of the port boundary. In Figure 3, the port boundary could encompass more of the land mass to avoid small precision errors in ship position that lead to misidentification of in-port activity as 'Underway'.

Figure 3. Port of Galveston with EPA shape file redlined (Pelican Island at top).

Figure 4 and Figure 5 show the EPA port boundaries for Port Houston, and Figure 6 shows the EPA Port Freeport boundary. In these figures, the EPA shape files boundaries are discontinuous with many additional (likely private facilities) berths and terminals clearly visible between and adjacent to the defined port boundaries. Figure 7 highlights the EPA Port Arthur definition with busy nearby private terminals excluded.

[21] https://www.portofgalveston.com/DocumentCenter/View/2607/Strategic-Master-Plan-Preliminary-Draft-Presentation-Website

Figure 4. Port Houston with EPA shape file redlined.

Figure 5. Port Houston Ship Channel with EPA shape file redlined.

Figure 6. Port Freeport with EPA shape file redlined.

Figure 7. Port Arthur with EPA shape file redlined (nearby private terminals highlighted).

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

A summary of the findings of this study is as follows:

- Most Ports and private terminals are not using shore power currently.
- Based on a more limited survey (input from a single operator), smaller harbor craft tug and towboats do not currently use shore power.
- MARAD Ready Reserve fleets and Texas A&M Galveston training vessels do use shore power. The emissions for these ships should not include hoteling emissions when shore power is being used.
- The Port of Galveston is beginning an evaluation of shore power for at least one of their main cruise ship customers and may consider shore power for additional cruise, container and refrigerated ship (reefer) operations.
- The following factors are important to consider when assessing potential cost effectiveness and emission reductions for cruise, container, and reefer ships:
  - **Container ships** produced larger annual at berth emissions compared to cruise ships in both 2019 and 2020, but emissions are smaller on an average per call and per vessel basis compared to cruise ships.
  - **Cruise ships** produced close to the same magnitude of annual emissions as container ships at the Port of Galveston. Emissions are larger on an average per call and per vessel basis compared to container ships. Many cruise ships are currently equipped to make use of shore power.
  - **Reefer ships:** Targeted use of shore power for frequently calling reefer ships may produce cost effective emission reductions at the Port of Galveston.

MARINER provides emission estimates by vessel and by location and can also aggregate emissions by vessel types and by area. The cruise, container, and reefer ships that called to Port of Galveston were all found to be accurately characterized by MARINER. Therefore, large ocean-going vessel types which use Category 3 propulsion engines appear to be well characterized by the IHS Markit Sea-web Ships database. However, MARINER estimates of in-Port and 'Underway' hoteling emissions, which are based on EPA defined port geographic areas, do not accurately distinguish at berth hoteling emissions that could be reduced by shore power from away from berth hoteling emissions (typically at anchor) that cannot be reduced by shore power.

4.2 Recommendations

MARINER relies on EPA GIS shape files to describe port areas for emissions reporting purposes. The EPA shape files do not match port areas; in particular, private terminals are generally not included though they may be near or adjacent to the public ports. The ports boundaries should be redrawn to better distinguish at berth and at anchor hoteling emissions. When redrawing the port boundaries, TCEQ should consider whether public port and private at berth areas should be distinguished or not. Additionally, the port boundaries should include more land mass area directly adjacent to waterways to avoid AIS position precision errors.

5.0 REFERENCES

Ramboll. (2021). 2020 Texas CMV Emissions Inventory and 2011 through 2050 Trend Inventories. Prepared for the Texas Commission on Environmental Quality. June 2021.

APPENDIX A

Vessels that Shore Power during Layberthing at Base

Appendix A Vessels that Shore Power during Layberthing at Base

A.1 MARAD Ready Reserve

The Ready Reserve Force (RRF) is a subset of vessels within MARAD's National Defense Reserve Fleet (NDRF)[22] ready to support the rapid worldwide deployment of U.S. military forces. Ships in priority readiness have Reduced Operating Status (ROS) maintenance crews of about 10 commercial merchant mariners that are then supplemented by additional mariners on a situational basis once activated. Some RRF ships are anchored with the NDRF homeport in Beaumont, Texas or at the nearby McFadden Bend Cutoff base and are listed in Table A-1.

Table A-1. MARAD (Beaumont and McFadden Bend Cutoff) Jefferson and Orange County: Reduced Operating Status (ROS) Vessels.

Vessel Name	IMO Number	MMSI
McFadden Bend Cutoff Primarily		
MV Cape Victory	8211306	303923000
MV Cape Vincent	8211291	303924000
Regulus	7302897	366987000
Pollux	7319632	368989000
Port of Beaumont Primarily		
MV Cape Taylor	7603497	365729424
MV Cape Texas	7602247	368952000
MV Cape Trinity	7602259	366838000
Beaumont Reserve Fleet		
SS Cape Farewell	7304792	366059000
SS Cape Flattery	7320411	366058000

A.2 Texas A&M Training Ships

Founded in 1962, The Texas A&M University at Galveston Maritime Academy (TAMUG) is one of six maritime academies in the United States. They maintain and operate state training ships to gain practical experience in seamanship, navigation, and engineering operations.[23] The TS General Rudder uses shore power for all its electricity needs while in port as do all the vessels at TAMUG. Table A-2 shows the TAMUG vessels.

Table A-2. Texas A&M Galveston (Pelican Island) Galveston County Vessels.

Vessel Name	IMO Number	MMSI
General Rudder	8835463	367604000
Trident		367670750
Earl L. Milan		367516630

[22] https://www.maritime.dot.gov/national-defense-reserve-fleet
[23] https://www.tamug.edu/corps/pages/About/About.html