Work Order No. 582-17-72097-24
Contract No. 582-15-50417
Tracking No. 2017-24

Final Report
Ocean-Going Tanker Vessel Lightering Emissions in the Gulf of Mexico

PREPARED UNDER A CONTRACT FROM THE
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

The preparation of this report was financed through a contract from the State of Texas through the Texas Commission on Environmental Quality. The content, findings, opinions and conclusions are the work of the author(s) and do not necessarily represent findings, opinions or conclusions of the TCEQ.

Prepared for:
Jim MacKay
Texas Commission on Environmental Quality
121 Park 35 Circle MC 164
Austin, TX 78753

Prepared by:
Timothy Sturtz, Maria Zatko, Chris Lindhjem,
and Greg Yarwood
Ramboll Environ US Corporation
773 San Marin Drive, Suite 2115
Novato, California, 94998
www.ramboll-environ.com
P-415-899-0700
F-415-899-0707

June 2017

06-35854X

RAMBOLL ENVIRON

CONTENTS

TABLES

FIGURES

GLOSSARY OF TERMS

Adjustment factors: Used to adjust emission factors or engine load factors or other situations for non-standard conditions.

Anchorage: Vessels anchored off-shore waiting for berth or next assignment.

Assist mode: Period when a tugboat is engaged in assisting a ship to/from its berth or maneuvering in the harbor.

Automatic Identification System (AIS): AIS is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites.

Auxiliary engine: Used to drive on-board electrical generators to provide electric power or to operate equipment on board the vessel.

Auxiliary power: Typically electric power generated via the auxiliary engine.

Berth: A location alongside a pier to moor vessels.

Bulk: Vessels designed to transport dry bulk (e.g. grain, potash, sand and gravel, etc.).

CAMx: The Comprehensive Air Quality Model with Extensions

Cargo: Vessels designed to transport break bulk too big to fit into containers (e.g. machinery, parts, etc.)

Container: Vessels designed to carry freight containers.

Cruise mode: The vessel mode while traveling in the open ocean or in an area without speed restrictions.

Gross tonnage (GT): The internal volume of tween-decks and deck space used for cargo and is a measurement of volume of all enclosed spaces on a ship with 100 cubic feet = to one ton.

Diesel-electric: Ship propulsion designs where sets of diesel engines generate electric power to drive propellers and primarily used on most cruise ships.

Emission Control Areas (ECAs): These areas must comply with international regulations on fuel sulfur and engine NOx emission standards, and applies to most U.S. and Canadian waters.

Emission factor: The average emission rate of a given pollutant for a given source, relative to a unit of activity. Typical examples are grams per kilowatt of actual power or grams per hour of engine operation.

Emissions inventory: An accounting of emissions of several pollutants from the sources included in the study.

Gas turbines: An alternative engine type to internal combustion diesel engines used on some cruise ships.

Gross Tonnage (GT): Defined by the volume of space within the hull and enclosed space above the deck of a merchant ship which are available for cargo, stores, fuel, passengers and crew with units of 100 cubic feet of capacity equivalent to one gross ton.

g/kW-hr: This is the unit for reporting emission or fuel consumption factors, and means the grams per kilowatt-hour of work performed. Work and energy are used synonymously in this context.

Harbor Craft: The smaller vessels conducting business in the bay, including excursion vessels, pilot boats, assist tugs, and towing tugs.

Hotelling: On-board activities while a ship is in port and at its berth or at anchor.

IHS Fairplay: Database of vessel characteristics including speed, engine power, and other information and is cross referenced with IMO or MMSI number.

Installed power: The engine power available on the vessel. The term most often refers only to the propulsion power available on the vessel, but could incorporate auxiliary engine power as well.

IMO ship identification number: The International Maritime Organization (IMO) number is made of the three letters "IMO" followed by the seven-digit number assigned to all ships by IHS Fairplay (formerly known as Lloyd's Register-Fairplay) when constructed.

Knot: A nautical unit of speed meaning one nautical mile per hour and is equal to about 1.15 statute miles per hour.

Link: A defined portion of a vessel's travel. For example a link was established extending from Ports out to the ocean. A series of links defines all of the movements within a defined area or a trip.

LNG: Liquefied natural gas, mostly methane

Load: The actual power output of the vessel's engines or generator. The load is typically the rated maximum power of the engine multiplied by the load factor if not measured directly.

Load factor: Average engine load expressed as a fraction or percentage of rated power.

LPG: Liquid petroleum gas, mostly propane.

Maneuvering: Very slow transiting to position the ship.

Maritime Mobile Service Identity (MMSI): is a series of nine digits which are sent in digital form over a radio frequency channel in order to uniquely identify ship stations, ship earth stations, coast stations, coast earth stations, and group calls.

Maximum power: A power rating usually provided by the engine manufacturer that states the maximum continuous power available for an engine.

Medium speed engine: A 4-stroke engine used for auxiliary power and rarely, for propulsion. Medium speed engines typically have rated speeds of greater than 130 revolutions per minute.

Mode: Defines a specific set of activities, for example, a tug's transit mode includes travel time to/from a port berth while escorting a vessel.

NOx: Nitrogen oxides, mostly nitric oxide (NO) with some nitrogen dioxide (NO_2). By convention, the mass of NOx emissions is reported assuming the composition is 100% NO_2.

Ocean-going vessels (OGV): Vessels equipped for travel across the open oceans. These do not include the vessels used exclusively in the harbor, which are covered in this report under commercial harbor craft. In this report, OGV are restricted to the deep draft vessels.

Operation mode: the current mode of operation for a ship – for example, cruising, maneuvering, or hotelling.

PM_{10}: Particulate matter emissions less than 10 micrometers in diameter.

$PM_{2.5}$: Particulate matter emissions less than 2.5 micrometers in diameter

Port of Call: A specified port where a ship docks.

Propulsion engine: Shipboard engine used to propel the ship.

Propulsion power demand: Power used to drive the propeller and the ship.

Rated power: A guideline set by the manufacturer as a maximum power that the engine can produce continuously.

Reduce Speed Zone (RSZ): Mode where ship transit at slower speeds due to traffic or speed limits.

RoRo: Roll on/Roll off vessel usually designed to carry new vehicles but could include other rolling freight

SOx: Oxides of sulfur. Mostly sulfur dioxide but may include some other sulfur oxides.

Spatial allocation: Areas on a map allocating a specific set of activities.

Spatial scope: A specified area on a map that defines the area covered in study.

Slow speed engine: Typically a 2-stroke engine or an engine that runs below 130 rpm.

Steam boiler: Boiler used to create steam or hot water using external combustion.

Time in mode: The amount of time a vessel remains in a specified mode, for example the amount of time a ship spends in the reduced speed zone.

Tons: Short tons (2,000 lbs) unless otherwise noted.

Tonnes: Metric tons (1,000 kg)

Two-stroke engine: Engine designed so that it completes the four processes of internal combustion (intake, compression, power, exhaust) in only two strokes of the piston.

VOCs: Pollutant containing compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, that has been determined to have photochemical reactivity. Includes any such organic compound except for those which have been determined to have negligible photochemical reactivity. For mobile source engine emissions, the significant organic compounds excluded from VOC as nonreactive are methane; ethane; and acetone.

1.0 INTRODUCTION

1.1 Background

Accurate emissions estimates for marine vessels are critical to understanding air quality for coastal urban areas in Texas. For the Houston-Galveston-Brazoria (HGB) nonattainment area, the ocean-going vessel (OGV) emissions inventories included port and transit emissions supplied by the Port of Houston Authority for the Ports of Freeport, Galveston, and Texas City; and the Environmental Protection Agency (EPA) emissions for vessels transiting the Gulf of Mexico. Emission inventories for the Galveston Bay and other Texas ports (ERG 2012, ENVIRON 2010, Port of Houston 2009) included vessel transit activity inshore of approximately 9 nautical miles, activity within the waterways through the Galveston-Bolivar jetties, and anchorage activity located near the Bolivar Peninsula, but did not include vessels anchoring beyond 3 nm from shore. A significant number of vessels also anchor beyond 3 nm from shore, and those vessels were not previously estimated in either the EPA's (EPA, 2007) or the Galveston Bay ports' inventories.

Vessels anchoring offshore include very large tankers, associated shuttle tankers that lighter the large tanker's cargo, and tankers receiving oil from off-shore platforms. Lightering occurs during the import or export of cargo when a smaller tanker vessel is needed to navigate nearshore waters and into ports. Lightering volatile liquids produces volatile organic compound (VOC) emissions when vapor is displaced during the transfer process. If these VOC emissions are uncontrolled they can approach 20 tons per million barrels of oil transferred or, in other words, more than 40 tons of VOCs per large tanker lightered.

Thousands of tankers transit and anchor in the western Gulf of Mexico each year. Lightering of crude oil from super tankers to vessels small enough to navigate the Houston Ship Channel may be a significant source of volatile organic compound (VOC) emissions. Additionally, most tankers use steam-driven pumps to off-load liquids. Providing steam to the pumps requires an increased boiler load (approaching 3,000 kW) and results in higher boiler VOC, NOx, and particulate matter emissions during the lightering period. Currently, there is no reliable estimate for these emissions beyond Texas' coastal waters. Since these emissions may contribute to ozone formation in the HGB nonattainment area, accurately accounting for them will both enhance the accuracy of Texas' ozone modeling and quantify ozone precursors emanating from areas beyond Texas' jurisdiction.

1.2 Purpose and Objectives

The purpose of this project was to estimate the lightering emissions from offshore ocean-going vessels (OGV) during 2014 and include these emissions in the existing OGV emission inventory. The addition of these emissions to the Texas Commission on Environmental Quality's (TCEQ) existing inventory will help improve the performance of the Comprehensive Air Quality Model with Extensions (CAMx) simulations. Estimating lightering emissions in the western Gulf of Mexico requires a thorough understanding of where lightering operations occur, how a lightering event is performed, and the associated emission rates. This memorandum describes the findings from a review of lightering emission factors and describes lightering operations in the western Gulf of Mexico as discerned via communications with lightering operators and the U.S. Coast Guard.

The lightering emission factors and logistics of operations presented in this technical memorandum were used to estimate lightering emissions from 2014 western Gulf of Mexico Automatic Identification System (AIS) data. Data from AIS records describe a vessel's Maritime Mobile Service Identity (MMSI), date, time, position, speed, and direction of travel. The lightering emissions estimates will supplement the TCEQ offshore ocean-going vessel (OGV) emission inventory that was developed in 2015 using AIS records (Ramboll Environ, 2015). The lightering emissions were prepared for the Emission Processing System (EPS3) and will complement the OGV emission inventory in future CAMx modeling by the TCEQ.

2.0 LIGHTERING OPERATIONS AND EMISSION FACTORS

2.1 Lightering Operations

Lightering operation emissions were derived from AIS data by identifying operational modes that help discern where and when two vessels rendezvous and lighter. To determine these spatial and temporal components, Ramboll Environ reviewed existing lightering regulations and contacted numerous lightering support companies and the U.S. Coast Guard to better understand the processes associated with lightering. The industries contacted include International Seaways, Inc. (INSW), Wilhelmsen Ships Services, AET Tankers, and Inchcape Shipping Services.

2.1.1 Designated Lightering Locations

Lightering generally occurs 30 to 40 nautical miles from shore (Danus 2017) and may not occur within 1 nm of any offshore structure and Mobile Offshore Drilling Units (MODU). Most lightering activities occur near designated lightering rendezvous areas, as identified in 33 CFR Part 156, subpart C (Federal Register 2010). The names and coordinates of the 9 designated lightering points are provided in Table 1, which has been adapted from 33 CFR Part 156 (Federal Register 2010). Figure 1 shows the lightering rendezvous points along with the designated lightering zones, lightering prohibited areas, and fairways within the Gulf of Mexico region.

The designated lightering zones were established to provide a region for single hull oil tankers to transfer oil within the U.S. Economic Exclusive Zone, although as of January 1, 2015, single hull tank vessels are prohibited from transferring oil. This prohibition is why the majority of lightering activity occurs at designated lightering points rather than within the larger specified lightering zones labelled as Southtex, South Sabine, Gulfmex, and Pascagoula.

Table 1. Designated lightering rendezvous locations

Lightering Rendezvous Points	Latitude (N)	Longitude (W)
Offshore Corpus Christi No. 1	27.28	96.49
Offshore Corpus Christi No. 2	27.28	95.31
Offshore Freeport	28.45	95.03
Offshore Galveston No. 1	28.27	94.30
Offshore Galveston No. 2	28.40	94.08
South Sabine Point	28.30	93.40
South West Point	28.27	90.42
Gulfmex	28.00	89.30
Offshore Pascagoula	29.27	88.13

Source: Adapted from 33 CFR Part 156

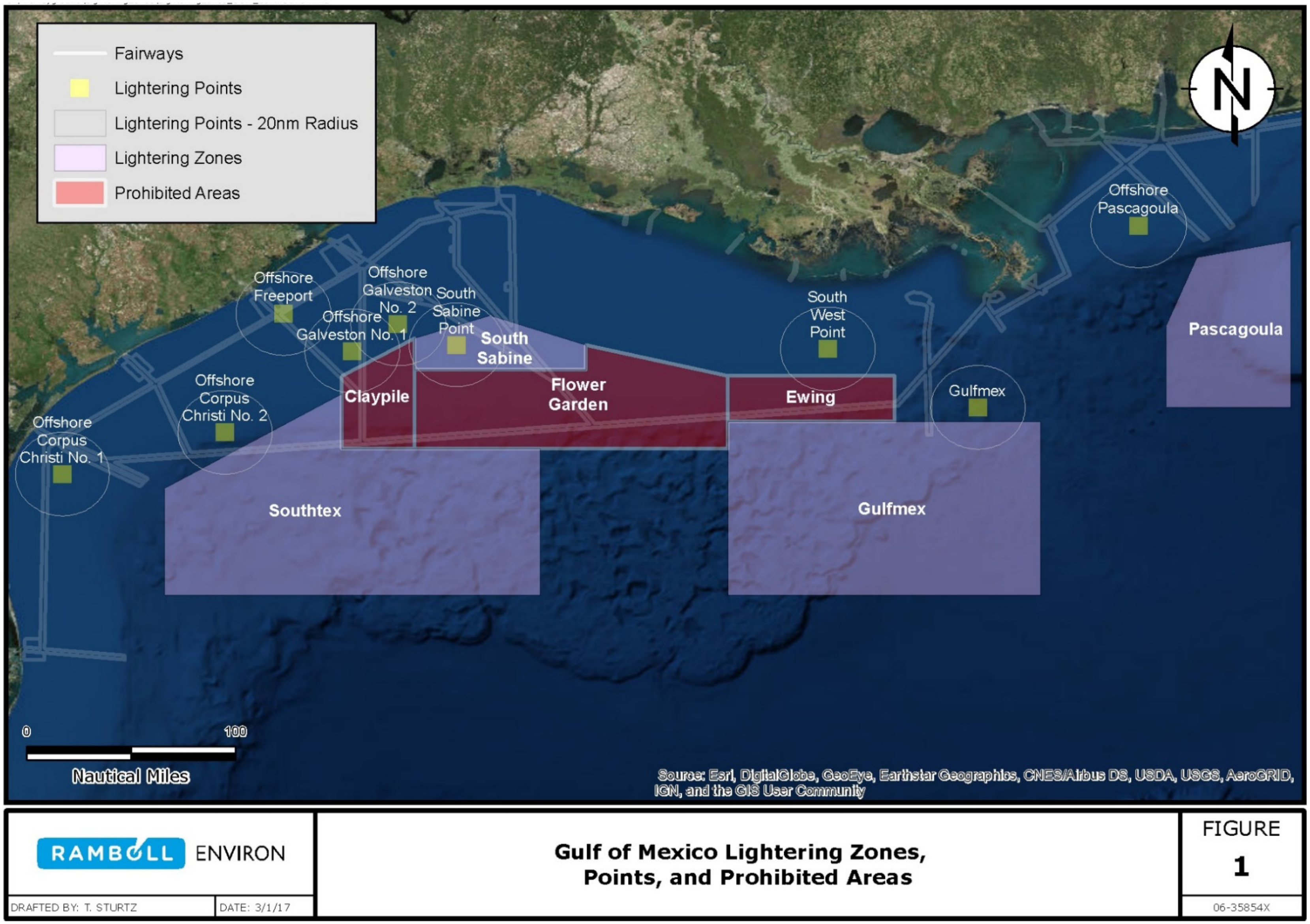

Figure 1. Gulf of Mexico Lightering Zones, Points, and Prohibited Areas

Discussions with the Coast Guard and private industry revealed that the most popular lightering rendezvous points are near Offshore Galveston No. 1 and No. 2, followed by Corpus Christi Points and South Sabine Point (AET 2017; Danus 2017; Inchcape 2017; Wilhelmsen 2017). The ship to be lightered (STBL) and lightering service vessel (the receiving vessel) determine a rendezvous point that is generally in the vicinity of the points listed in Table 1, although the exact location may vary between operations (Inchcape 2017).

Lightering can occur while the service vessel and STBL are anchored, drifting, or underway. While the service vessel is approaching the STBL, it may not exceed speeds greater than 8 knots while towing its lightering fenders (Ternus, Buetzow, and Selle 1990). When lightering occurs underway, the STBL and service vessel typically transit at speeds between 3 and 5 knots (Ternus, Buetzow, and Selle 1990).

2.1.2 Timing of Lightering Operations

Individual lightering jobs are typically completed within 24 hours (INSW 2017), but may last longer during inclement weather (Federal Register 2010). While the entire lightering process may take up to 24 hours, the material transfer period typically ranges from 12 to 16 hours (AET 2017; Inchcape 2017), depending on the STBL size, pumping capacity, product viscosity, receiving vessel size, and product characteristics.

The most common material transferred by lightering in the Gulf of Mexico (AET 2017; Inchcape 2017) is crude oil, although other oil/petroleum products are also transferred (Danus 2017, Wilhemson 2017). During each lightering job, between 50,000 and 500,000 barrels of product is transferred, with an average of 350,000 to 375,000 barrels of crude oil (INSW 2017). Hazardous material may be lightered in accordance to 33 CFR 156.400-420, but this is infrequent and requires approval by Coast Guard Headquarters (Federal Register 2010).

In addition to lightering operations in the Gulf of Mexico, refueling (bunkering) of ships may occur for ships at anchor beyond 3 nm from shore. Bunkering activity may lead to additional release of VOCs into the atmosphere, however, refueling is not subject to the offshore lightering regulations stated in 33 CFR 156.400 (Danus 2017). This study did not estimate VOC emissions from bunkering operations.

2.1.3 Characteristics of Vessels involved in Lightering

STBL are generally either very large crude oil carriers (VLCC), ranging from 165,000 to 320,000 DWT or ultra large crude oil carries (ULCC) range from 320,000 up to 550,000 DWT (National Research Council 1998, EIA 2017). The larger STBL can be 1500 feet long, 225 feet wide, and have a cargo capacity up to 4 million barrels (National Research Council 1998, EIA 2017). Regulations prohibit single hull tankers (STBL or the lightering service vessel) from lightering and allow only double hull tankers (National Research Council 1998). Due to their size, VLCC and ULCC vessels cannot transit to shore in the western Gulf of Mexico (Wilhelmsen 2017).

In the Gulf of Mexico, lightering service vessels are generally tankers, such as Handymax, Aframax, and Suezmax (AET, 2017; Colman, J., Solomon, M., Coralie 2010; Inchcape, 2017;

Wilhelmsen, 2017). Aframax vessels are used most commonly because fully-loaded Suezmax vessels may not be able to approach the shoreline (Wilhelmsen 2017). Service vessels typically range from 80,000 to 120,000 DWT and have a cargo capacity between 375,000 and 1.1 million barrels. Suezmax vessels do not service STBLs as frequently as Aframax and are often only partially filled when used (Wilhelmsen 2017). Approximately 4 service vessel jobs are required to fully lighter 1 VLCC and 6 service vessel jobs are needed to fully lighter 1 ULCC (Inchcape 2017; Wilhelmsen 2017). Generally, service vessels transit toward the STBL in a staggered fashion, with a several hour overlap at the lightering rendezvous location.

2.1.4 Emission Control Technologies

There are no state or federal-level regulations that address emission controls associated with lightering operations in the Gulf of Mexico region beyond 12 nm from shore (Danus 2017).

In contrast, California and Delaware have imposed regulations related to lightering emissions. In California, no more than three drops of liquid material and 1000 ppm (expressed as methane) of gaseous material may leak during lightering (Bay Area Air Quality Management District 2005). In Delaware, any new lightering service company must use vapor balancing technology during lightering such that at least 95% of its annual total volume of crude oil is lightered in a controlled fashion (Colman, Solomon, and Coralie 2010). Given the expense associated with retrofitting ships with lightering control technology, older ships are held to a less stringent standard, although the uncontrolled lightering percentage will continue to reduce with time (from 80% in 2008 to 43% in 2012).

2.2 Emission Factor Review

The lightering process produces emissions from vessel engines, boilers, and vapor losses associated with the lightering and ballasting processes. The engine approach emissions and emissions from idle activity were captured in TCEQ’s offshore OGV emission inventory, but the VOC emissions from ballasting and product evaporation were not assessed. Additionally, 33 CFR 156.330 states that the main propulsion system may not be disabled at any time during the lightering operation (Federal Register 2010), indicating that propulsion idle emission occur during the lightering process. A review of the emission factors that are available in current literature are presented here.

On behalf of BOEM, ERG developed an offshore, gulfwide emission inventory for 2011, which included emission estimates for vessel lightering (Wilson et al. 2014). In the inventory, lightering emissions included emissions from primary propulsion engines of STBL and service vessels, secondary engines, and emissions tied to ballasting. In the study, emission estimates were based upon emission factors from the USEPA.

2.2.1 EPA

The USEPA discusses lightering emissions for crude oil within the Compilation of Air Pollutant Emission Factors (AP-42). The emission rates for typical crude oil lightering transfers and ballasting are presented in Table 2 (EPA 2008). Additional emission factors for transit have been reported by Bhatia and Danwoodie (2004) that were used in Ramboll's assessment of the emission factor sensitivity.

Table 2. Lightering Emission Factors for Crude Oil

Source[a]	TOG Emission Factor	Emission Factor Units
Loading	0.61	Lb/10^3 gal of product transferred
Ballasting[b]	1.1	Lb/10^3 gal of ballast water

Source: Adapted from AP-42 Tables 5.2-4 and 5.2-6

[a] Assumes crude oil at 60°F and RVP of 5 psia. Represents typical value based on observations of fully loaded and partially loaded vessels.

[b] Typically, individual cargo tanks are ballasted about 80%, and a total vessel 15% to 40%, of total capacity.

The AP-42 documentation indicates that vessels are required to displace vapors into tanks that are being unloaded if conducting ballasting at a terminal that resides in an ozone nonattainment area. Displaced vapors that occur in areas other than nonattainment areas are expected to emit the displaced vapors directly to the atmosphere.

In addition, most often steam boilers are used to power the pumps and result in increased emissions during lightering operations. The 2014 OGV emission inventory reported emission estimates using a lower boiler load of 371 kW for tankers during anchorage because lightering operations were specifically excluded. EPA (2009) indicated that tankers hotelling have higher boiler loads of 3000 kW presumably to account for the extra power required to pump product from the tanker. These additional boiler loads and resulting emissions were calculated and included for those tankers being lightered.

Additional main or auxiliary engine operations due to positioning during lightering operations not previously captured by the Ramboll Environ (2015) report were included in the emissions estimates for lightering.

3.0 EMISSION ESTIMATION METHODOLOGY

The information distilled during the literature review and discussions with the lightering community were used to inform the AIS analysis-based estimate of lightering emissions in the Gulf of Mexico in 2014. In particular, the assessment identified the lightering events in the AIS data, use the EPA emission factors to estimate lightering-related VOC emissions, and prepare the lightering emissions for use in EPS3.

To obtain an estimate of the number of lightering events that occurred in 2014, Ramboll Environ performed additional analysis on the 2014 AIS activity and IHS/Lloyd's Register Fairplay ship characteristic data that were previously used to develop an offshore OGV emission inventory in the Gulf of Mexico on behalf of TCEQ (Ramboll Environ 2015). In this analysis, records of vessel pairs within 250 meters of each other and within 20 minutes of each other were identified. Dead weight tonnage (DWT), liquid capacity of each vessel, and minimum vessel separation distance were used to qualitatively assess whether the vessel pair was likely participating in lightering operations. The vessel pairs were considered to be lightering when one vessel is noticeably larger than the other (in terms of both DWT and liquid capacity), since service vessels are generally at least 3 times smaller than VLCC and ULCC vessels.

Ramboll Environ correspondence with industry and government agencies suggests that the majority of material lightered in the Gulf of Mexico region is crude oil. Therefore, unless explicitly stated otherwise, the crude oil emission factor equations used to develop the values reported in Table 2 were used to estimate lightering emissions in this study. Ramboll Environ may recalculate, or assess the sensitivity, of the emission factors identified in Table 2 based on Gulf-specific temperatures and anticipated product vapor pressure.

3.1 AIS Processing

Ramboll Environ explored the AIS data records by creating a subset of the AIS data associated with lightering regions, assessing spatial and temporal proximity between vessel records, and by requiring specific relationships between vessel characteristics for pairs of lightering vessels.

3.1.1 Identifying Lightering Occurrences

The AIS records that did not reside in the lightering zones, prohibited zones, or within 20 nautical miles of a lightering point were removed from the data set (see Figure 1). Using the remaining 1.2 million records, the distance and time differences between each point and all other points were calculated and only record pairs that were within 250 meters and 20 minutes of each other were kept. The resulting data set contained the vessel MMSI, unique voyage ID, the matched MMSI and voyage ID, and the spatial and temporal differences.

These records were then cross referenced with the IHS/Lloyd's Register Fairplay vessel characteristic database. The deadweight tonnage (DWT) and liquid capacity (LC) were determined for each pair of MMSI's and added to the dataset. Ramboll Environ calculated the ratio of DWTs and a ratio of LCs for matched vessel pairs and explored lower-bound cut-points to identify lightering occurrences.

The vessel characteristic criteria used to extract lightering events included: 1) the vessel pair was required to have one vessel exceeding a DWT of 200,000; 2) both vessel pairs were required to have a capacity exceeding 100,000 U.S. barrels; and 3) the DWT ratio of the pair was required to exceed a value of 3.

Prior discussions with industry representatives suggested that service vessels may have a DWT as low as 80,000 and typical VLCCs have a minimum DWT of 200,000. Using the ratio of these DWT estimates as a lower limit and rounding up, a lower-bound cut-point of 3 for the DWT ratio was selected (i.e., a lightering occurrence is assumed to correspond with a STBL that has a DWT at least three times larger than the DWT of a lightering support vessel).

After limiting the data set using the DWT ratio criteria, the remaining data, representing 279 lightering events, were used to estimate emissions. The LC ratio was reviewed for this data set to ensure the results were consistent with our understanding of lightering practices. The LC ratios had an average of 3.97, a minimum of 2.18 and a maximum of 8.37 which generally bounds the industry suggestion that a VLCC often requires 4 support vessels and a ULCC may require 6 support vessels. As an additional validation check, the duration of lightering events were averaged (12 hours, 40 minute average) and corresponded well with industry estimates of approximately 12 hours for product transfers.

3.1.2 Estimating Emissions

Emissions were estimated from the AIS records by assuming complete product transfer from the STBL to supply vessels. Ramboll Environ identified the liquid capacity of the STBL to calculate the loading VOC emissions and ballasting VOC emissions for each lightering event. The water ballasting was assumed to have a capacity equal to 40% of a vessel's capacity. For each lightering event, these emissions were distributed equally across the associated records to capture the spatial variability of the lightering events.

Emissions from propulsion engine exhaust and pump-use were calculated for all records where the speed over ground was less than 1 knot. Ramboll Environ's previous AIS-driven emission inventory included propulsion engine emissions when vessels exceeded 1 knot, negating the need to recalculate those emissions. However, during the previous effort, propulsion engines were assumed to be disabled during activity less than 1 knot. Emissions from these propulsion engines were tabulated here because propulsion engines are not permitted to be disabled during lightering operations (33 CFR 156.330). The STBL and support vessel propulsion engines were taken from the Fairplay database and used to estimate the propulsion emissions by applying the emission estimation methodology described in (Ramboll Environ 2015). The propulsion engine low-load adjustment factors during lightering events was assumed to be 2%; the minimum load for emission estimation suggested by the EPA (2009). The boiler pump emissions were modeled using a loaded rating of 3,000 kW and steam turbine emission factors (EPA, 2009).

3.2 Forecast Considerations

The industry contacts spoken with during this study were not able to provide an exact estimate for the number of lightering jobs that occurred in the Gulf of Mexico 2014. The Coast Guard (Danus 2017) indicated that STBLs are required to provide the Coast Guard with a notice of arrival, but the Coast Guard has only retained a subset of these records that TCEQ and Ramboll Environ obtained from a Freedom of Information Act request. The notice of arrivals records that were available (2014 and 2016 offshore of Port Arthur) were used to broadly confirm the lightering estimates and served as a data point of trends between 2014 and 2016. International Seaways mentioned that the frequency of lightering jobs can vary dramatically; from 3 jobs a day to 3 jobs a week (International Seaways (INSW) 2017). Wilhelmsen, Inchcape, and AET noted that lightering activity has declined sharply since 2014; reduced by a factor of 15 according to Wilhelmsen (AET 2017; Inchcape 2017; Wilhelmsen 2017).

4.0 RESULTS

The lightering analysis identified 279 lightering events within the TCEQ modeling domain. The Lightering activity primarily produced VOC emissions, but the propulsion engines and the boilers contributed to the wider collection of criteria pollutants. The emission totals from each source are provided in Table 3.

Table 3. Lightering emissions

Emission Source	2014 Lightering Emissions (tons/day)					
	NO_x	VOC	CO	PM_{10}	$PM_{2.5}$	SO_x
Lightering Product Transfer	--	19.7	--	--	--	--
Lightering Ballasting	--	14.2	--	--	--	--
Propulsion Engine Exhaust	0.35	0.07	0.08	0.02	0.02	0.10
Boilers	0.06	0.003	0.01	0.02	0.01	0.16
Total	**0.41**	**34.06**	**0.08**	**0.04**	**0.04**	**0.25**

Spatially, the emissions were dispersed outside of the Houston-Galveston region near the lightering points named "Offshore Galveston No.1" and "Offshore Galveston No. 2." The emissions were summed by 4km grid cell; the method was identical to the process employed for the prior offshore emission inventory. Figure 2 depicts the spatial variability of the emissions. As anticipated, the emissions that intersect the vessel traffic fairways are notably lower than adjacent regions.

There are no comparisons to total emissions or lightering events that Ramboll Environ was able to obtain during the course of the project. However, an order-of-magnitude comparison can be made from the results of a Freedom of Information Act (FOIA) request and a previous estimate of Gulf-wide lightering emissions. Ramboll Environ and TCEQ submitted a FOIA request for lightering records, but only received total counts of lightering events registered off the coast of Port Arthur. The FOIA response indicated that in 2014 there were 116 lightering events. While a directly comparison cannot be made to this count, we can conclude that the estimated lightering events exceeds this minimum value. Further, more lightering events are expected from the Houston-Galveston region, which agrees with our estimate if we assume the events not associated with Port Arthur are destined for Houston-Galveston.

Additionally, lightering emissions were estimated in the Gulf-wide Emission Inventory in 2011 (Wilson et. al., 2014). The estimate for these emissions relied solely upon industry reported lightering events and volume of products transferred. The 2011 gulf-wide estimate was 17,113 tons of VOCs (approximately 47 tons per day). Again, we cannot directly compare our emission estimate because the TCEQ domain is a subset of the gulf-wide emission inventory domain. However, based on the density of lightering points and zones in the TCEQ domain, we would expect that more lightering occurs near the Texas coast than in other regions.

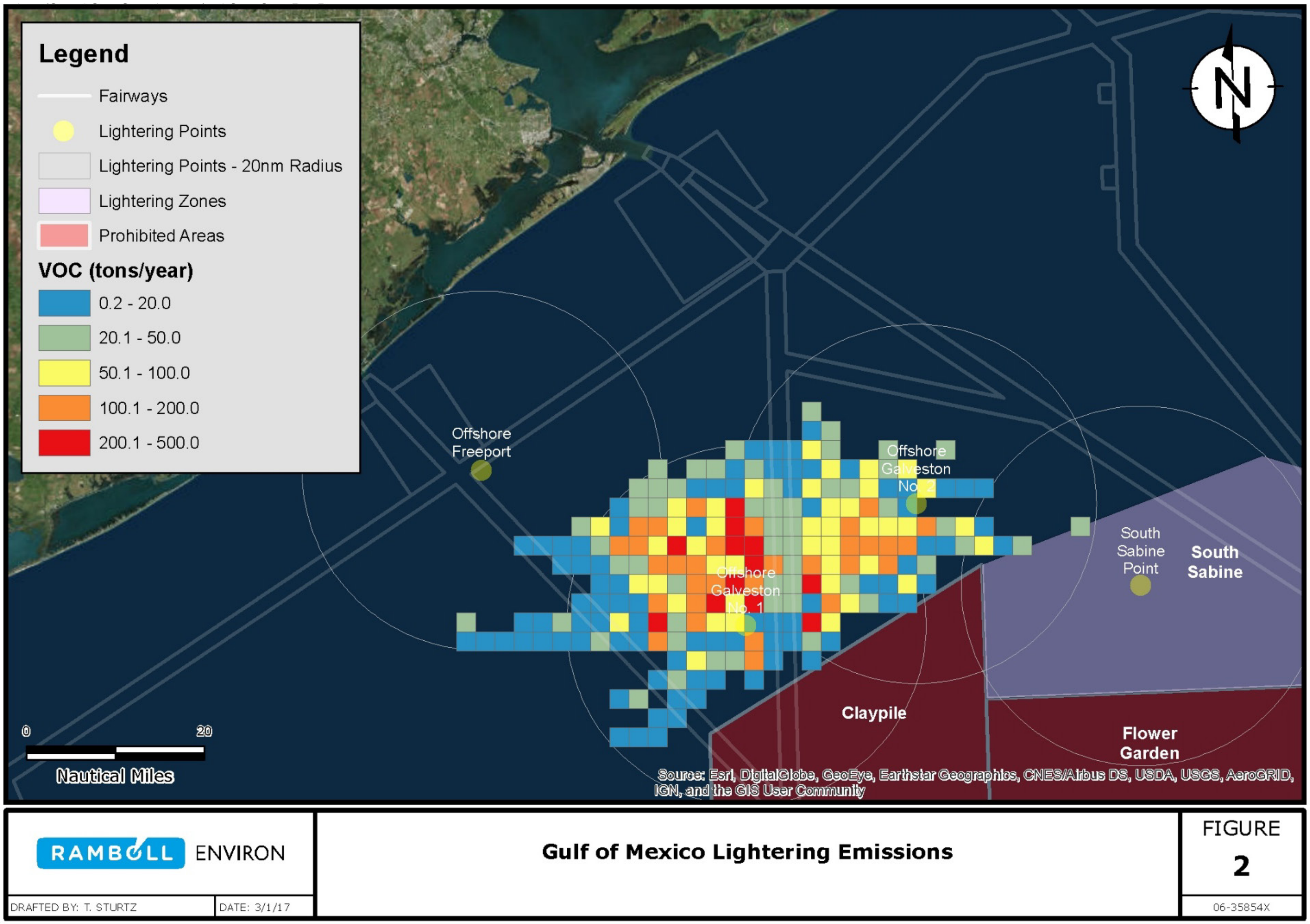

Figure 2. Gridded Lightering Emissions

5.0 CONCLUSIONS & RECOMMENDATIONS

Ramboll Environ assessed the lightering emissions within TCEQ's CAMx modeling domain for the Gulf of Mexico by analyzing vessel AIS records. The lightering emissions were developed to help improve the modeling emission inventories by capturing a large, albeit removed from nonattainment areas, source of VOCs previously not specifically accounted or spatially defined. The emissions were tabulated and produced as EPS-ready emission files. While these emission estimates can be back-cast or forecast using the scaling factors derived in the previous offshore emission inventory, caution should be exercised because of changes in crude oil export and import balances and the marked decline reported by the lightering industry between 2014 and 2016.

This work demonstrated how AIS records can be used to assess detailed offshore activities for the benefit of emission inventory development. However, in 2015, regulations for AIS use changed to require that near universal coverage of commercially active vessels install AIS transponders by March of 2016. An increased use of AIS transponders by harbor craft (including off-shore support vessels, tug and barge, and bunkering tankers) provides a new expanded data set for use to determine more highly resolved near-port and/or near-platform emission inventories. More detailed estimates of VOC and vessel engine emissions at off-shore facilities, or otherwise operating off-shore, are possible with the more detailed AIS records becoming available.

6.0 REFERENCES

AET 2017. Personal communication with AET employee (name withheld) by T. Sturtz, C. Lindhjem, M. Zatko of Ramboll Environ. March 1, 2017.

Bay Area Air Quality Management District. 2005. “Organic Compounds Marine Tank Vessel Operations; Regulation 8, Rule 44.”

Colman, J., M. Solomon, and C. Coralie. 2010. “Potential NOx and VOC Emissions Controls,” 1–19.

Danus, S. 2017. Personal communication with S. Danus of U.S. Coast Guard by C. Lindhjem of Ramboll Environ. March 9, 2017

EIA 2017, Oil Tanker Definitions. Energy Information Administration. U.S. Department of Energy https://www.eia.gov/todayinenergy/detail.php?id=17991

ENVIRON 2010, "Implement Port of Houston’s Current Inventory and Harmonize the Remaining 8-county Shipping Inventory for TCEQ Modeling" August 18, 2010

EPA 2007, Emission Inventories for Ocean-Going Vessels Using Category 3 Propulsion Engines In or Near the United States; EPA420-D-07-007, December 2007.

EPA. 2008. “Transportation and Marketing of Petroleum Liquids.” *AP-42*.

ERG 2012. “Development of 2011 Staewide Toxics and Actual Annual and Ozone Season Weekday Emissions Inventories for Commercial Marine Vessels," August 17, 2012.

Federal Register 2010. *Part 156 — Subpart A — Oil and Hazardous Material Transfer Operations*.

Federal Register 2010. *Part 156 — Subpart C — Lightering Zones and Operational Requirements for the Gulf of Mexico*.

ICF 2009. "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories." Prepared for U.S. Environmental Protection Agency, April 2009.

Inchcape. 2017. Personal communication with Inchscape employee (name withheld) by T. Sturtz, C. Lindhjam, and M. Zatko . March 1, 2017.

INSW 2017. Personal communication with International Seaways employee (name withheld) by T. Sturtz, C. Lindhjem, M. Zatko of Ramboll Environ. March 1, 2017.

National Research Council. 1998. *Oil Spill Risks From Tank Vessel Lightering*. National Academies Press.

Port of Houston. 2009. “2007 Goods Movement Air Emissions Inventory.” Port of Houston Authority, January 2009 prepared by Starcrest Consulting Group.

Ramboll Environ. 2015. “Link-Based Modeling Emissions Inventory of Marine Vessels (Ocean Going Vessels) in Transit and at Anchor in the Gulf of Mexico." Prepared by Ramboll Environ for the Texas Commission on Environmental Quality, 2015.

Ternus, R.A., M.R. Buetzow, and E.D. Selle. 1990. “Chevron’s 78 000-DWT Lightering Tankers.” *Marine Technology* 27 (1): 1–9.

Wilhelmsen. 2017. Personal communication with employee Wilhelmsen Group employee (name withheld) by T. Sturtz, C. Lindhjem, M. Zatko of Ramboll Environ. March 1, 2017.

Wilson, D., R. Billings, R. Chang, H. Perez, and J. Sellers. 2014. “Year 2011 Gulfwide Emission Inventory Study Year 2011 Gulfwide Emissions Inventory Study.” *OCS Study BOEM 2014-666*. New Orleans, LA.