

**UPDATE TO THE COMMERCIAL MARINE INVENTORY FOR  
TEXAS TO REVIEW EMISSIONS FACTORS,  
CONSIDER A TON-MILE EI METHOD, AND  
REVISE EMISSIONS FOR THE BEAUMONT-PORT ARTHUR  
NON-ATTAINMENT AREA**

**FINAL REPORT**

**Submitted to the Houston Advanced Research Center  
Prepared by Eastern Research Group and Starcrest Consulting Group, LLC**

**January 2004**



---

**TABLE OF CONTENTS**

<b>Executive Summary .....</b>	<b>ES-1</b>
<b>Introduction .....</b>	<b>1</b>
<b>Task 1: Investigation of CMV Emissions Factors.....</b>	<b>1</b>
<b>ENTEC Emission Factors .....</b>	<b>4</b>
<b>Development of CMV Emission Rates.....</b>	<b>6</b>
<b>Selected Bibliography of Emission Factor Research .....</b>	<b>7</b>
<b>Task 2: Consideration of the Ton-Mile Method.....</b>	<b>8</b>
<b>Task 3: CMV Emissions in the Sabine-Neches Waterway .....</b>	<b>10</b>
<b>Local Geography and Sources Considered.....</b>	<b>11</b>
<b>Data Acquisition and Survey Methods .....</b>	<b>11</b>
<b>Ocean-Going Vessels .....</b>	<b>13</b>
<b>General Approach for Estimating Emissions.....</b>	<b>16</b>
<b>Application of Main Engine Load Factors .....</b>	<b>20</b>
<b>Emission Factors .....</b>	<b>22</b>
<b>Consideration of Auxiliary Engine Emissions .....</b>	<b>23</b>
<b>Use of GIS .....</b>	<b>23</b>
<b>Ship Emission Calculations .....</b>	<b>26</b>
<b>Assist Tugboats.....</b>	<b>27</b>
<b>Towboats.....</b>	<b>30</b>
<b>Other Harbor Vessels .....</b>	<b>35</b>
<b>Discussion &amp; Conclusion .....</b>	<b>40</b>
<b>Appendix A – Trip and Supporting Data .....</b>	<b>A-1</b>

---

---

LIST OF TABLES

Table ES-1: Report Findings, Tons per Day, 2000 .....	ES-1
Table 1: Comparison of ENTEC and EPA Studies, Number of Main Engines Tested .....	3
Table 2: Main Engine Emission Factors, g/kW-hr .....	4
Table 3: Auxiliary Engine Emission Factors, g/kW-hr .....	5
Table 4: Refinement of PM Emission Factors .....	6
Table 5: Ton-Mile Emission Factors for 1996 .....	8
Table 6: Sabine-Neches Summary Ship Calls in 2000 .....	13
Table 7: Inbound Ship Calls by Ship Grouping .....	14
Table 8: Trip Segments Defined.....	15
Table 9: Distances from Sabine Bar (S.B.) Buoy .....	16
Table 10: Ship Trip Travel Times .....	18
Table 11: Ship Categories by Deadweight Tonnage .....	19
Table 12: Weighted Average Main Engine Power by Ship Type .....	19
Table 13: Ship Speeds and Load Factors at 12, 6.5, and 3 Knots.....	21
Table 14: Emission Adjustment Factors.....	22
Table 15: Waypoints in Latitude in Longitude.....	24
Table 16: Comparison of Model versus GIS Map Distances.....	24
Table 17: Annual Results, Short Tons per Year, 2000.....	26
Table 18: Seasonal Allocation of Ship Trips (Normal Month = 365) .....	27
Table 19: Average Daily Emissions for August, 2000 .....	27
Table 20: Assist Towboat Power Converted to kW .....	28
Table 21: Estimation of Average Assist Tug Load Factor .....	29
Table 22: Assist Vessel Emissions.....	30
Table 23: In-Port Towboat Trips, 2000.....	31
Table 24: Allocated Towboat Trips, 2000 .....	31
Table 25: Method to Determine Towboat Main Power .....	33
Table 26: Towboat Main Engine Activity .....	33
Table 27: Towboat Main Engine Emissions.....	34
Table 28: Towboat Auxiliary Engine Activity .....	34
Table 29: Towboat Auxiliary Engine Emissions.....	34
Table 30: Major Dredge Projects (2000) .....	35
Table 31: Estimation of Dredging Days .....	36
Table 32: Estimated Dredging Power .....	36
Table 33: Dredge Emissions (TPY, 2000) .....	36
Table 34: Dredge Tender Activity, 2000 .....	37
Table 35: Tender Emissions, Tons per Year, 2000.....	37
Table 36: Fishing Vessel Activity.....	38
Table 37: Annual Shrimp Boat Emissions.....	38
Table 38: Average July-September Daily Emissions .....	38
Table 39: Government Vessels, Annual Emissions .....	39
Table 40: Government Vessels, Average Daily Emissions.....	39
Table 41: Previous TCEQ CMV Emissions Baseline, 1996.....	40
Table 42: Report Findings, Tons per Average Day, 2000.....	40

---

---

**LIST OF FIGURES**

**Figure 1: Sabine-Neches Waterway ..... 12**  
**Figure 2: Lower Sabine Area..... 17**  
**Figure 3: Emissions and Low Maneuvering Loads ..... 22**  
**Figure 4: GIS Overlay of Trip Segments ..... 25**

Special thanks to Dr. James Corbett for his review of this report.

---

---

**UPDATE TO THE COMMERCIAL MARINE INVENTORY FOR  
TEXAS TO REVIEW EMISSIONS FACTORS, CONSIDER A TON-  
MILE EI METHOD, AND REVISE EMISSIONS FOR THE  
BEAUMONT-PORT ARTHUR  
NON-ATTAINMENT AREA**

**FINAL REPORT**

Submitted to the Houston Advanced Research Center  
Prepared by Eastern Research Group and Starcrest Consulting Group, LLC

January 2004

**EXECUTIVE SUMMARY**

Air emissions estimates were prepared for commercial marine vessels in the vicinity of Beaumont and Port Arthur, Texas. Only in-port emissions were included; the furthest seaward waypoint was approximately 14 nautical miles offshore. The evaluation year was 2000, which is consistent with the requirements of the base photochemical modeling efforts for the Houston/Beaumont region currently underway at the Texas Commission on Environmental Quality. The estimates were based on further research into emission factors as well as an improved suite of engine load factors.

**Table ES-1: Report Findings, Tons per Day, 2000**

<b>All Vessels - TPD</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Ships	5.45	0.63	0.24	0.42	2.62
Towboats	3.73	0.56	0.10	0.11	0.41
Harbor Vessels	1.57	0.19	0.06	0.07	0.13
	10.75	1.38	0.40	0.61	3.15

---

## INTRODUCTION

This study is part of a continuing effort to improve upon the understanding of commercial marine vessel air emissions in the Houston/Beaumont area photochemical modeling domain. Commercial marine vessels (CMV) comprise a wide spectrum of sources ranging from small workboats under 25 tons to ultra-large cargo carriers over 200,000 tons. The goal of this study is to refine CMV emissions in the vicinity of Beaumont, Texas. The main objective is to provide emissions data for the ozone modelers at the Texas Commission for Environmental Quality, although as discussed later, there is increasing national attention to CMV as a source of particulate emissions.

Three tasks were authorized by the Houston Advanced Research Center (HARC) regarding CMV air emissions in Texas:

- Task 1 – Investigation of CMV Emission Factors
- Task 2 – Consideration of Ton-Mile Emissions Inventory (EI) Method
- Task 3 – Update Emissions Estimates for the Sabine-Neches Waterway

The first two tasks re-examine emission factors. The third task is a major overhaul of CMV emissions in the region of Port Arthur and Beaumont. These tasks seek to clarify air emissions of pollutants such as hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and particulate matter (PM). Emissions of NO<sub>x</sub> are important for modeling impacts relating to the ozone standard; PM emissions have more of a health effect even though the mass is by comparison very low. Mass emissions are usually expressed in grams converted into short tons (2,000 pounds). The emission rates developed by engineers were estimated by evaluating the concentration of a pollutant in the exhaust stream against the volume of exhaust emitted. The tonnages presented in the sections below are based on the atomic weight of the compounds of concern.

### **TASK 1: INVESTIGATION OF CMV EMISSIONS FACTORS**

There is considerable uncertainty regarding emission rates from CMV engines, since few have been tested. The first high-quality emission factors were produced by Lloyds' Engineering Services and included only 50 ships (62 engines) tested by using portable equipment, as compared to over 30,000 ocean-going ships in the world. Most authorities augment their studies to include additional testing (usually no more than a few dozen more measurements) but the fact remains that there are a very small number of test observations, and the level of uncertainty could be as high as +/- 50 percent based on the variability of the fleet in question.

---

There are several ways to categorize CMV engines. The U.S. Environmental Protection Agency (EPA)<sup>1</sup> has defined three groupings based on per-cylinder displacement, regardless of whether the engine is a main propulsion engine or an auxiliary engine:

- Category 1: 1-5 liters/cylinder
- Category 2: 5-30 liters/cylinder
- Category 3: over 30 liters/cylinder

While broad assumptions with regard to the horsepower ranges included in each group can be made, the emission factors are based on engine speed (revolutions per minute, RPM). The categories are based on international MARPOL<sup>2</sup> regulations that include:

- High speed: over 2,000 RPM
- Medium speed: 130-2,000 RPM
- Slow speed: below 130 RPM

It is possible to combine the lists together, although it should be noted that Category 2 is a transitional grouping based on total displacement divided by the number of cylinders; thus the same horsepower engine could be an 8-cylinder Category 2, medium speed engine or a 16-cylinder Category 1, high speed engine. Engine power groupings, expressed in kilowatts (kW) can also be used to help predict the emission factors for the different engines:

- Category 1 / high speed: below 2,000 kW
- Category 2 / medium speed: 2,000-7,000 kW
- Category 3 / slow speed: over 7,000 kW

Category 1 and high speed diesel CMV engine emission rates are based on existing EPA emission factors which are reported in summary tables in a later section. In the following sections Category 2 and 3 are treated together as being “ships” that can be slow-speed or medium-speed.

There are two means of estimating ship engine emissions. The first is based on power, where an engine has a potential to emit emissions based on maximum continuous rated (MCR) power, usually expressed in either horsepower or kilowatts. The second is based on energy consumption, which is especially useful if one has reliable fuel information on a fleet-wide or worldwide basis. The two methods are theoretically equivalent, with an average of 195 grams per kilowatt-hour (g/kW-hr) of fuel as the means to translate one unit of measurement to another.

---

<sup>1</sup> EPA 1999. ‘Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines.’ EPA420-R-99-026.

<sup>2</sup> Ibid at Table 1-1.

A report compiled by ENTEC<sup>3</sup> contains a thorough review of CMV emission factor data. This study included 114 engines tested by a Swedish company named IVL (a leader in examining selective catalyst reduction for ships). By comparison, the 2002 EPA rulemaking for Category 3 engines<sup>4</sup> issued just prior to the ENTEC study averaged together emission factors from a smaller pool of data. Table 1-1 compares the number of test scores used to estimate average emission rates.

**Table 1: Comparison of ENTEC and EPA Studies, Number of Main Engines Tested**

Study	Engine Years	Slow Speed*	Medium Speed	Total
Lloyds (1995)	1963-1990	15	41	56
IVL (2002)	1972-2000	11	75	86
ENTEC (2002)	1963-2000	26	116	142
EPA (2002)	1980-1999	15	17	32

\*Slow speed engines are below 300 RPM; medium speed engines are faster (300 to ~1,500 RPM).

Table 1 shows that ENTEC combines the number of Lloyds and IVL tests; this sample frame resulted in a larger population than any other single study. ENTEC was very careful to note that only the Lloyds dataset was prepared with the goal of having a representative fleet sample, and that there was considerable variation in the scientific controls and measurement protocols. The newer IVL dataset complied with international testing standards (ISO 8178) that were adopted by the EPA and International Maritime Organization (IMO), whereas the older Lloyds data used non-standard methods (e.g., use of non-dispersive infrared [NDIR] optical monitors for NO<sub>x</sub> as opposed to chemiluminescence). All studies seem to have a major problem with identifying the fractional load on the ship's engine, or if the load was identified, it was not consistent, and fuel consumption as reported by on-board instruments was often questionable at best, when compared to laboratory instrumentation. This is a main source of uncertainty, understandable because large ship engines cannot be removed from the ship for testing in laboratory-controlled test cells.

Despite these in-use testing issues, average emission factors appear to be in fair agreement. HC and CO are generally below 2 g/kW-hr. SO<sub>2</sub> and PM emissions are often a function of fuel sulfur (% weight). The variability is most pronounced in NO<sub>x</sub> emissions, which may range from 2 to 26 g/kW-hr, depending on engine technology and fuel type (e.g., steamship versus diesel motor ship), thus spanning an order of magnitude.

<sup>3</sup> ENTEC (2002), *Quantification of emissions from ships associated with ship movements between ports in the European Community*, prepared for the European Commission.

<sup>4</sup> E.H. Pechan & Associates (2002), *Commercial Marine Emission Inventory Development*, prepared for the EPA by ENVIRON International Corporation.

---

### **ENTEC EMISSION FACTORS**

Ship emission factors for main and auxiliary engines are presented in Tables 2 and 3, respectively. Main engine emission rates are defined for five engine types and three fuel types. Auxiliary engines are assumed to be medium or high speed diesel engines; steam boiler auxiliary emission rates were not included in the ENTEC study. (Even on a diesel powered ship, hot water or steam is required for heating the residual fuel and providing hot water for the crew).

**Table 2: Main Engine Emission Factors, g/kW-hr**

<b>Engine</b>	<b>Fuel</b>	<b>NOx</b>	<b>SO2</b>	<b>HC</b>
Slow speed diesel	Residual oil	18.10	10.50	0.60
Slow speed diesel	Diesel oil	17.00	3.70	0.60
Slow speed diesel	Gas oil	17.00	0.90	0.60
Medium speed diesel	Residual oil	14.00	11.50	0.50
Medium speed diesel	Diesel oil	13.20	4.10	0.50
Medium speed diesel	Gas oil	13.20	1.00	0.50
High speed diesel	Residual oil	12.70	11.50	0.20
High speed diesel	Diesel oil	12.00	4.10	0.20
High speed diesel	Gas oil	12.00	1.00	0.20
Gas turbine	Residual oil	6.10	16.50	0.10
Gas turbine	Diesel oil	5.70	5.80	0.10
Gas turbine	Gas oil	5.70	1.50	0.10
Steam turbine	Residual oil	2.10	16.50	0.10
Steam turbine	Diesel oil	2.00	5.80	0.10
Steam turbine	Gas oil	2.00	1.50	0.10

Note that ENTEC did not publish PM or CO emission rates for main propulsion engines, for reasons not completely understood. These two pollutants will be discussed at length in the following sections. ENTEC provided detailed NOx emission rates, which vary according to the nitrogen content of the fuel as well as the lower heating value and fuel consumption levels. Sulfur dioxide is directly proportional to the sulfur content of the fuel, which varies as follows:

- Marine gas oil – 0.25% sulfur (similar to U.S. off-road diesel, mostly used in domestic ships)
- Marine diesel oil – 1.0% sulfur (more common in Europe)
- Residual oil – 2.7% sulfur

The carbon content of the three fuels is the same (86.7%), so one would expect carbon dioxide, CO, and HC to be fairly consistent across fuel types (ENTEC). The most common type of technology and fuel combination found on large ships are slow speed engines using residual oil; most domestic US ships found in coastwise traffic (e.g., large ferryboats, towboats, and dredges) would be medium speed diesels operating on marine gas oil.

Auxiliary engine emission factors found in the ENTEC report are discussed next. Auxiliary engines are used mainly for generating electricity and tend to be Category 1 or Category 2 engines although ENTEC only discriminates between medium and high speed diesels. Larger, Category 3 slow-speed auxiliary engines are thought to be very rare; they are more common in diesel-electric engines that produce auxiliary power as well as main propulsion power (and thus are not true auxiliary engines). As was noted in the ENTEC study, there were difficulties in differentiating between marine diesel and marine gas oil emission factors, which are identical with the exception of SO<sub>2</sub>.

**Table 3: Auxiliary Engine Emission Factors, g/kW-hr**

<b>Engine</b>	<b>Fuel</b>	<b>NOx</b>	<b>SO<sub>2</sub></b>	<b>HC</b>	<b>PM-10</b>
Medium speed diesel	Residual oil	14.70	12.30	0.40	0.30
Medium speed diesel	Diesel oil	13.90	4.30	0.40	0.30
Medium speed diesel	Gas oil	13.90	1.10	0.40	0.30
High speed diesel	Residual oil	11.80	12.30	0.40	0.30
High speed diesel	Diesel oil	10.90	4.30	0.40	0.30
High speed diesel	Gas oil	10.90	1.10	0.40	0.30

PM emission rates are included in Table 3 although CO is not. The omission may reflect the concerns of the European Commission, which was much more interested in NO<sub>x</sub> and SO<sub>2</sub> emissions. (The study authors could not be contacted in this regard, so this statement is purely hypothetical). In contrast, the contiguous U.S. is more interested in ozone and PM emissions.

The process of comparing and completing the suite of emission factors is addressed in the next section, which includes a discussion of:

- Completing the suite of emission factors for ships
- Augmenting a suite of emission factors for domestic harbor vessels
- Adding emission factors for auxiliary boilers
- Addressing other sources of emission factors
- Estimating composite emission factors
- Considering emission factor uncertainties
- Clarifying future emission factor projection issues

---

### ***DEVELOPMENT OF CMV EMISSION RATES***

As mentioned above, ENTEC omitted CO and PM emission factors for main ship engines, although the report suggests that the authors had partial data including these pollutants plus speciated contaminants such as polycyclic aromatic hydrocarbon (PAH) in some cases. Most authorities cited in the ENTEC report (EPA<sup>5</sup>, Lloyds, TECHNE, Intergovernmental Panel on Climate Change) suggest a factor of 1.6 g/kW-hr for CO emission rates on marine diesel engines, whereas ENVIRON (EPA 2002) suggests using a lower factor of 1.1 g/kW-hr for slow-speed diesel engines, after careful screening of the data. To be conservative we recommend the former factor be used for all diesel engines.

The selection of PM emission factors is complicated because these emissions are affected by fuel sulfur, engine type (diesel, steamship), engine load, engine lubrication oil ashing, in-stack residence time, engine stroke (2- versus 4-stroke), engine timing (degrees off top dead center), and engine maintenance. Measurement of PM is also difficult because the exhaust must be sampled under steady-state operations of several hours so as to be collected on a Teflon filter, whereas the gases can be measured on an instantaneous basis. Then the sample must be carefully recorded and sent to a laboratory for micro-balance weighing, during which the sample might undergo secondary chemical changes (e.g., neutralization of sulfuric acid particles).<sup>6</sup> Thus available PM measurements show a considerable range, spanning an order of magnitude between 0.2 g/kW-hr and 2.4 g/kW-hr, with steamships and high-speed diesels running on low-sulfur fuel having the lowest values.

As with CO, it was deemed prudent to use the higher value when there was more than one estimate found in the literature, as opposed to using an average. After careful inspection, it was found that ENTEC estimated that approximately 80 percent of the total particulate matter (TPM) was below ten microns (PM-10 -- in theory, a PM-10 sampler can accommodate particles up to 30 microns, mainly fuel ash in this range). Table 4 compares the results of this application to work previously done by Starcrest Consulting Group (SCG) and ENVIRON.

**Table 4: Refinement of PM Emission Factors**

<b>Engine</b>	<b>Fuel</b>	<b>TPM</b>	<b>PM-10</b>	<b>SCG</b>	<b>ENVIRON</b>
Slow speed	Residual	2.4	1.9	1.6	1.8
Medium speed	Diesel oil	0.9	0.7	1.8	0.7
High speed	Gas oil	0.9	0.7	0.3	N/A
Steamship	All	0.9	0.7	N/A	N/A

---

<sup>5</sup> EPA 1999. 'Final Regulatory Impact Analysis: Control of Emissions from Compression-Ignition Marine Engines,' EPA420-R-026.

<sup>6</sup> It was suggested by Peer Reviewers that the International Standards Organization (ISO) 8178 and report-specific measurement protocols be further investigated in the future, for the sake of clarity.

---

Further research was conducted to clarify Lloyds' PM numbers as well as to estimate the particle size distribution. The 1995 Lloyds report<sup>7</sup> contains an excellent discussion of its PM monitoring effort, which recommended using somewhat lower emission factors (1.5 g/kW-hr for residual and 0.2 g/kW-hr for the lighter fuel oils). These emission factors were developed based upon an average of 33 test scores based on 50% and 85% MCR power; given that "cruise speed" emission factors were desired at about 80% MCR, somewhat higher emission factors could be justified.

Next, particle sizes were evaluated in studies such as one by a group in Finland<sup>8</sup>, which suggested that a surprising amount of the mass was in the coarse mode between 1 and 10 microns. The distribution was bimodal, as expected, with most of the mass in the 6 to 9 nm (0.06 to 0.09µm) range and a secondary mode at 7 to 10µm: "it was found that the fine mode [below 0.4µm] includes nearly 60% of the total particulate mass concentration." This was a surprising finding because the EPA and California Air Resources Board tend to use a PM-fine factor of 92 percent; that is, nearly all diesel exhaust PM is considered to be below a 2.5 micron cutpoint. While the raw data was not available from the study authors, it lends credence to using a lower PM-2.5/PM-10 split such as 80 percent. However, future studies should be conducted to properly evaluate the fine and coarse fractions of marine diesel engine exhaust TPM in accordance with more recent EPA guidance.

#### ***SELECTED BIBLIOGRAPHY OF EMISSION FACTOR RESEARCH***

The following list represents a non-exhaustive bibliography of literature on CMV emission factor research:

- Corbett, J. and Fischbeck, P. (2000), *Emissions for Waterborne Commerce Vessels in United States Continental and Inland Waterways*. Environmental Science and Technology: volume 34.
- Corbett, J. and Fischbeck, P. (1998), *Commercial Marine Emissions Inventory for EPA Category 2 and 3 Compression Ignition Marine Engines in the United States*. Prepared for the EPA. EPA420-R-98-020.
- E.H. Pechan & Associates (2002), *Commercial Marine Emission Inventory Development*, prepared for the EPA by ENVIRON International Corporation.
- ENTEC (2002), *Quantification of emissions from ships associated with ship movements between ports in the European Community*, prepared for the European Commission.
- Environment Canada (1997), *Port of Vancouver Marine Vessel Emissions Test Report*, ERMD Report #97-04.

---

<sup>7</sup> Lloyds 1995. 'Marine Exhaust Research Programme,' courtesy of the EPA and University of Delaware.

<sup>8</sup> Lyyranen et al 1999. 'Aerosol Characterization in Medium-Speed Diesel Engines Operating with Heavy Fuel Oils,' *Journal of Aerosol Science* 30:6.

- 
- EPA (2000), *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data*, prepared for EPA by Energy and Environmental Analysis, Inc.
  - EPA (1995), *Compilation of Emission Factors*, AP-42.
  - EPA (1992), *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA450/4-81-026d (Revised).
  - Lloyds Register Engineering Services (1995), *Marine Exhaust Emissions Research Programme*. Several similar reports prepared by Lloyds are also available.
  - TECHNE (1997), *Methodologies for estimating air pollutant emissions from ships*. Prepared by Trozzi, C. and Vaccaro, R. for the European Commission. Several similar studies were published by EMEP in the 1996-2001 timeframe under EMEP/CORINAIR *Atmospheric Emission Inventory Guidebook*.

## **TASK 2: CONSIDERATION OF THE TON-MILE METHOD**

As an alternative to Task 1, further investigation was warranted so as to express ship emission factors in terms of ton-miles. The method was devised by Corbett and Fischbeck<sup>9</sup> so as to link ship emissions to tonnages compiled by the U.S. Army Corps of Engineers and other reliable sources. As is discussed below, the method works best in describing offshore ship emissions, especially in the context of imported commodities.

The initial method developed by Corbett and Fischbeck was updated in 2000 by the authors; in 2002 ENVIRON also refined the approach for the purposes of an EPA rulemaking regarding Category 3 ship engines. Average emission factors in grams per ton-mile are reported in Table 5.

**Table 5: Ton-Mile Emission Factors for 1996**

<b>Source</b>	<b>HC</b>	<b>CO</b>	<b>NOx</b>	<b>PM</b>	<b>SO<sub>2</sub></b>
Corbett et al	0.0105	0.0323	0.3625	0.0295	-
ENVIRON	0.0122	0.0251	0.5301	0.0475	0.3568

---

<sup>9</sup> EPA. 1998. 'Commercial Marine Emissions Inventory for Category 2 and 3 Compression Ignition Marine Engines in the United States Continental and Inland Waterways.' EPA420-R-98-020.

---

Such an approach would be extremely useful for port planners who desire a “snapshot” estimate of emissions without having to consider a myriad of complex factors. For example, if one had 6.3 million tons of imported steel, with a trip distance of approximately 50 miles, the NO<sub>x</sub> emissions would be very simple to estimate (184 short tons using the ENVIRON factor). The strength of the method is its ability to compare different scenarios (e.g., multiple years) that might have four or ten million tons of shipments, since many import economies are subject to wild fluctuations on the world market.

The procedure to generate new ton-mile emission factors, however, is not clear from the source documentation. Presumably, ships were profiled into different categories having different cargo capacities; emissions were estimated using the complex method and then emissions were divided by the tonnage capacity for each ship. A capacity factor of 70% was suggested by Corbett and Fischbeck for estimating the gross tonnage available in a ship’s cargo hold, although it is not known if ENVIRON followed the same rule of thumb. Obviously, the resulting ton-mile emission factor would depend not only on the capacity factor but also the type of ship activity (e.g., bulk, general cargo, tanker, containership, and whether the ship was big, large or small, and if it was equipped with a diesel engine or a steam or gas turbine, and what the effect of slower in-port speeds might be).

Unfortunately several developments limited our ability to complete this task. The Port of Houston Authority was contacted to obtain freight tonnage by terminal and ship, but this request was beyond their data collection capabilities, with the exception of containerships at Barbours Cut. Containers are recorded in twenty-foot equivalent units (TEU), not weight, which presented yet another difficulty. Additionally, containerships do not load or unload all containers on the vessel but are constantly adding and removing them in each port of call. It soon became evident that the ton-mile method would work best for non-containerized import or export traffic in which the entire vessel was loaded or unloaded, without any partial or “light loading” trips. While it is true that the Port of Houston is heavily involved in such foreign trade, there is a large domestic component that confounds the process, especially with regards to the chemical tankers.

Therefore the ton-mile method works well on a global scale for foreign trade but not very well within ports on a microscale basis. If the purpose of this project was to estimate oceanic ship emissions between the Houston-Beaumont area and the rest of the world, starting at perhaps 25 miles seaward, and not counting domestic trade, the method might work quite satisfactorily. However, in a recent request for proposal, it was discussed that the ton-mile method would no longer be used by the EPA. Instead, the power method involving energy (kW), time (hours) and an emission factor (g/kW-hr) would be used to estimate commercial marine vessel emissions for domestic emission inventory efforts in the future.

Based on these limitations it was decided that investing resources in developing such a tool for local usage would not be beneficial.

---

### **TASK 3: CMV EMISSIONS IN THE SABINE-NECHES WATERWAY**

Two major ports, Port Arthur and Beaumont, reside in the Sabine-Neches waterway system. Deepwater ship access was made possible by construction of the Sabine-Neches Canal. A brief overview of the Port's history begins in 1835, when a customs house was authorized at the mouth of the Sabine River. After years of construction, mainly by the Port Arthur Canal and Dock Company, the Sabine-Neches canal was opened for ship traffic. In 1901 the Spindletop oilfield was discovered, creating a huge demand for additional shipping. In 1916 the U.S. Congress authorized construction of a deepwater channel to Beaumont, which was followed by similar plans to allow access to Orange. By 1972 the three waterways were dredged to a depth of 40 feet and a width of 400 feet.<sup>10</sup> Most of the current CMV activity in Beaumont is related to the large petroleum presence, although military and agricultural shipping interests are also significant.

If the entire Sabine-Neches-Orange waterway were considered as a single port, it would be the fourth largest in the U.S. following the ports of Los Angeles, Houston, and New York (source: MARAD tonnage cargo statistics). Inbound ships enter the fairway a relatively long way out to sea, approximately 16 miles south of the Sabine jetty (by comparison, most ships enter the Houston fairway a few miles south of the Galveston jetty). The reason for the longer trip out at sea is the hazardous Sabine Bar, a shallow water area located approximately 14 miles off the coast. Once inside Sabine Pass the vessels typically go to Port Arthur (33 miles from the fairway entrance) or Beaumont (56 miles from the fairway).

The Sabine Pilots operate the piloting service in the entire waterway. Their office is located in Groves, Texas and the pilot station is at Sabine Pass. The pilots meet the inbound ships at the fairway entrance, which is defined as buoy "S.B." on the nautical charts. All ships and barge tows are required to have a pilot on board to navigate the vessel from the fairway to the dock; large vessels over 875 feet or 85,000 metric tons are required to have two pilots on board.<sup>11</sup> Use of pilot data was critical to this project because they control all CMV movements except for harbor craft less than 160 feet in length, recreational vessels, and tugboats not having a tow (i.e., barge or offshore oil platform).

---

<sup>10</sup> "Sabine-Neches Waterway And Sabine Pass Ship Channel." The Handbook of Texas Online. <<http://www.tsha.utexas.edu/handbook/online/articles/view/SS/rrs2.html>> [Accessed Thu Sep 25 10:14:40 US/Central 2003 ].

<sup>11</sup> See: <http://www.businessintexas.com/sabinepilots/pilots.htm>

---

### ***LOCAL GEOGRAPHY AND SOURCES CONSIDERED***

The Sabine Neches Waterway can be divided into four segments or sections. The first section, Sabine Pass Harbor, is from the Gulf of Mexico to the upper end of Sabine Pass and it is about 28.4 miles long. Approximately 12% of the total freight traffic in the Sabine Neches Waterway is attributed to the Sabine Pass Harbor section.

The second section, Port Arthur, is from Sabine Pass Harbor to the Neches River and it is about 27.7 miles long. Thirty percent of the total freight traffic in the Sabine Neches Waterway is attributed to the various docks in this section which include the Port of Port Arthur, Premcor, Great Lakes Carbon Corp, and Motiva Port Arthur among others.

Another section, Orange which is in the Sabine River, is from the mouth of the Neches River to the mouth of the Sabine River and then upstream to the Old U.S. Highway 90. The Orange section also includes Adams and Cow Bayou. The Orange section has one percent of the total freight traffic.

The last section, Beaumont, is along the Neches River from the mouth of the Neches River to Bethlehem Steel Company about 20 miles upstream. Over 57% of the freight traffic in the Sabine Neches Waterway is attributed to the various docks in this section which include Huntsman, Sun Oil, Unocal –Beaumont Terminal, Dupont Beaumont, Exxon Mobil Chemical and Oil docks, Motiva Port Neches, and Port of Beaumont. A general area nautical chart shows the general layout of the area.

Figure 1 also shows the Intracoastal Waterway (ICW) extending to the southwest of Port Arthur. The northern extension of the ICW follows the Sabine River through Orange and then heads east towards the Mississippi River delta.

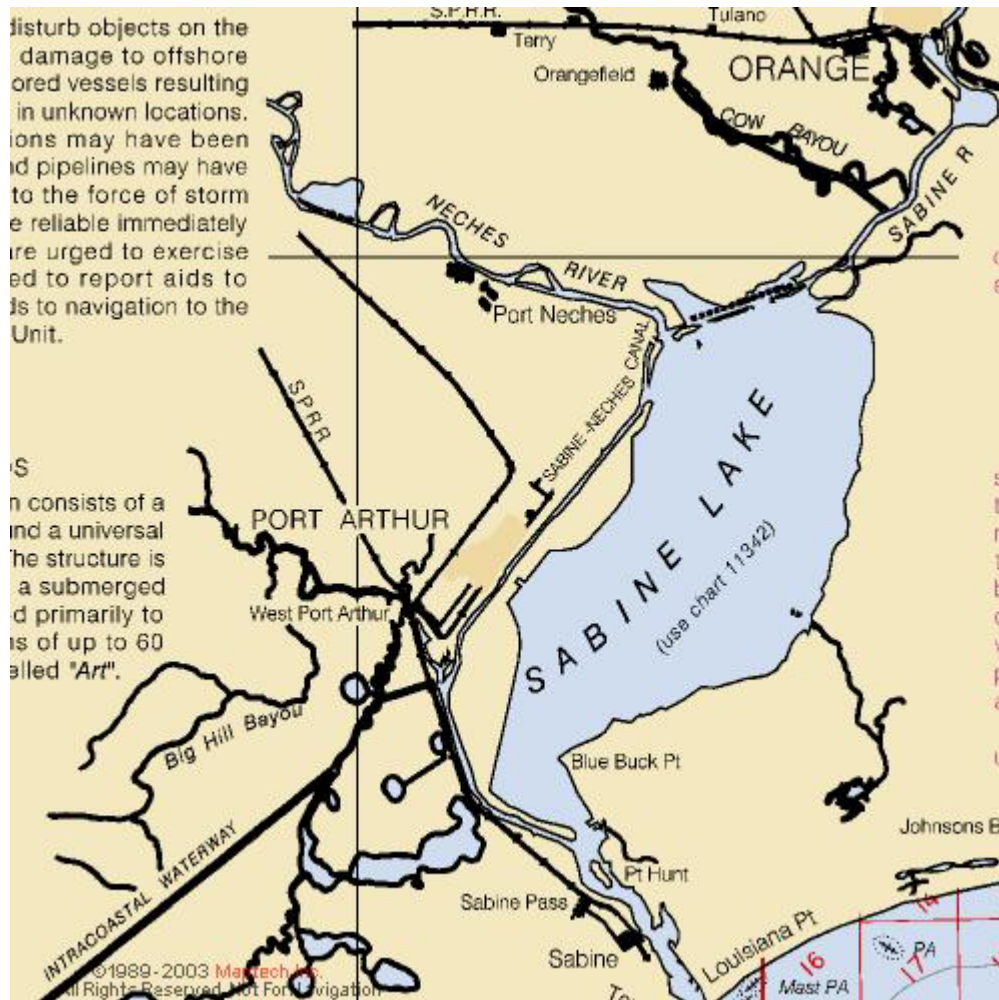
### ***DATA ACQUISITION AND SURVEY METHODS***

The Sabine Pilots, who serve the shipping industry, the public ports of Beaumont, Port Arthur and Orange, the private oil terminals and the industrial facilities of Southeast Texas, were initially contacted for local knowledge and pilot data. The president of the Sabine Pilots met with Starcrest representatives to discuss the project and agreed to provide the data. Up to this year, the pilot data has been stored in an old DOS database. The data was output into a text file and then loaded into a database and converted into a Microsoft™ Excel file. The data was then checked for accuracy and clarification was sought from the dispatcher on such items as vessel type abbreviations.

For dredging projects, the local Army Corps of Engineers and the Jefferson County Waterway and Navigation District were contacted. A list of dredging projects in the area for 2000 was compiled from the Corps' dredge database and local interviews. The dredging companies that completed these projects were contacted for detailed information on the projects.

The two local assist tug companies were contacted for information on their boat engine profiles and operations. Local marine fuel and towing companies were also contacted initially by phone and followed with a letter summarizing the information requested.

**Figure 1: Sabine-Neches Waterway**



Source: Maptech Mapserver

Local oil terminals, refineries and shipping companies were contacted for information on the loading/unloading of the tankers. The Port of Beaumont was also visited to discuss their operations and obtain their support for the project.

Information was obtained on the pilot boats owned and operated by the Sabine Pilots. Information was also obtained from the U.S. Coast Guard on their boats in the area after a request was submitted through the Freedom of Information Act (FOIA).

---

The owner of the main local fish houses was contacted to gain knowledge on the local fishing industry. An estimate on the number of commercial fishing boats was obtained, including how far and how often they go offshore, and the average engine size.

Local information was also acquired from tanker loading terminal operators in site visits and telephone interviews.

The sections below are divided into discussions of ocean-going vessels, tugboats, dredges, and other harbor vessels. Most people are familiar with large ships, which are typically over 300 feet in length. Tugboats can be more complex, with some being oceanic vessels but most being inland push-boats. Dredges usually are large barges or even ships, and their operation involves significant amounts of tugboat and crew-boat activity. The “other” category can include oil and gas support vessels, fishing boats, small government vessels, and the like. The larger ocean-going vessels are discussed first because of their large impact on regional emission levels.

### ***OCEAN-GOING VESSELS***

In the year 2000 there were about 1,868 ship calls to the Sabine-Neches. A ship call is defined as a ship that enters and exits a port, on a two-way basis. There are a variety of definitions for a “ship” but for the purposes of this study if a vessel needs a pilot, according to the local laws and regulations, it is a ship; this can include some ocean-going tugboats that might otherwise be considered as harbor vessels. Table 6 reports inbound and outbound ship calls for 2000, which are roughly equal, along with internal movements called “shifts.”

**Table 6: Sabine-Neches Summary Ship Calls in 2000**

<b>Trips</b>	<b>Event</b>
1,868	Inbound
1,872	Outbound
208	Shift In Zone
162	Shift Out Zone
4,110	

A significant number of ships moved within the ports. Some are shifts within a restricted area (“Shift In Zone”), usually no more than a few miles, and some are shifts across major portions of the waterway (“Shift Out Zone”). These kinds of trips will be important when the emission calculations are performed. Inbound trips are usually used to estimate the main portion of what we call transit emissions, when the main engines are used. This is the same as a “ship call” but only considers the ship trip from the outer sea buoy to the terminal dock.

An important concept in planning an emissions inventory is to first differentiate between the different kinds of vessels. Table 7 shows inbound ship calls by ship type.

As expected given the huge petrochemical presence, tankers dominate the number of ship calls. Bulk and general cargo vessels are also present. The “Tug” category includes only ocean-going towboats that had pilot trips out the Sabine Pass, mainly related to the oil and gas industry (e.g., towing large offshore drilling platforms, etc.). There are several other things of note in Table 7:

**Table 7: Inbound Ship Calls by Ship Grouping**

<b>Trips</b>	<b>Category</b>	<b>Steam</b>	<b>Diesel</b>	<b>St_PCNT</b>
214	Bulk	0	214	0.00%
347	Chemical Tanker	21	326	6.44%
3	Containership	0	3	0.00%
153	General Cargo	0	153	0.00%
48	LPG	0	48	0.00%
6	Military	0	6	0.00%
12	Misc	0	12	0.00%
58	Not assigned	0	58	0.00%
7	Roro	0	7	0.00%
897	Tanker	14	883	1.59%
123	Tug	0	123	0.00%
1,868		35	1,833	1.91%

- Diesel motor ships (98%) dominate steamships, suggesting that use of diesel emission factors would be an economical approach for this study. The column “ST\_PCNT” reports the fraction of steam versus motor vessels for each grouping and overall. No gas turbine-powered vessels were found (these would be more common in certain military attack vessels; most of the military vessels found in this study were military support vessels).
- Boats involved in 58 trips could not be identified through Sabine Pilots or Lloyds data, possibly indicating military vessels from visiting nations. The only military vessels identified were those having names beginning with USS, USN, or USNS.
- Miscellaneous (MISC) boats included heavy-lift ships, light-on-ship (LASH) vessels, and dive boats.

Of the 1,868 two-way ship calls (based on inbound trips from Sabine Pilot data) 123 of them were ocean-going tugboats (6%). This category of ocean-going ship was not estimated in the previous section because there were no matches with the Lloyds' registry data, and therefore must be profiled separately. This kind of tugboat is usually larger than the ordinary river towboat, having between 4,000 and 8,000 HP (most riverboats have less than 1,000 HP) and includes types such as:

- Integrated tugboat (ITB) that looks more like a ship but the tractor tugboat can be separated from the barge
- Oceanic barge unit tow – barges over 200 feet in length towed out at sea
- Crane barges
- Offshore drill rig; e.g., jack-up rig (JU)
- Specialty barge (pontoon, semi-submersible, etc.)

The Beaumont-Sabine-Orange area is noted as a major constructor of offshore drill rigs over the last 30 years (Bethlehem Steel, Levingston Shipbuilding, Texas Dry Dock, US Steel, Marathon LeTourneau). According to local knowledge gained through interviews, most of the rig pulling activities out to the Gulf of Mexico was contracted to towboat companies located in southern Louisiana.

Next, trips were summarized by location on the Sabine-Neches waterway. Since inbound trips were used to simulate a majority of the ship emissions, the trips start at the outer sea buoy and proceed inland. Table 8 shows the general areas of interest, some named after major industries, cities, or geographic features.

**Table 8: Trip Segments Defined**

<b>Trips</b>	<b>Segment</b>	<b>Order</b>
47	Sabine Pass	1
220	Port Arthur	2
89	N. Port Arthur	3
178	Fina	4
250	Huntsman	5
502	Smiths Bluff	6
156	Stanolind	7
395	Beaumont	8
31	Orange	9
1,868		

Detailed trips by trip type, ship type, and channel segment are presented in the Appendix A. For the sake of comparison, the Port of Houston, including Galveston, Freeport, and Texas City, had approximately 9,500 inbound ship calls; the Sabine-Neches waterway had 1,868 calls, or about 20 percent of the port traffic of Houston.

---

**GENERAL APPROACH FOR ESTIMATING EMISSIONS**

The overall approach was similar to that used in the preceding report (ERG, 'Improvements to the Commercial Marine Vessel Emission Inventory in the Vicinity of Houston, Texas', August 29, 2003, prepared for HARC). Once the geographic scope was established, CMV categories of interest were defined. Vessel trips were then estimated from activity data, which in turn was used to estimate emissions. Unlike the recent Houston update, tugboats and towboats would be included as a critical vessel category.

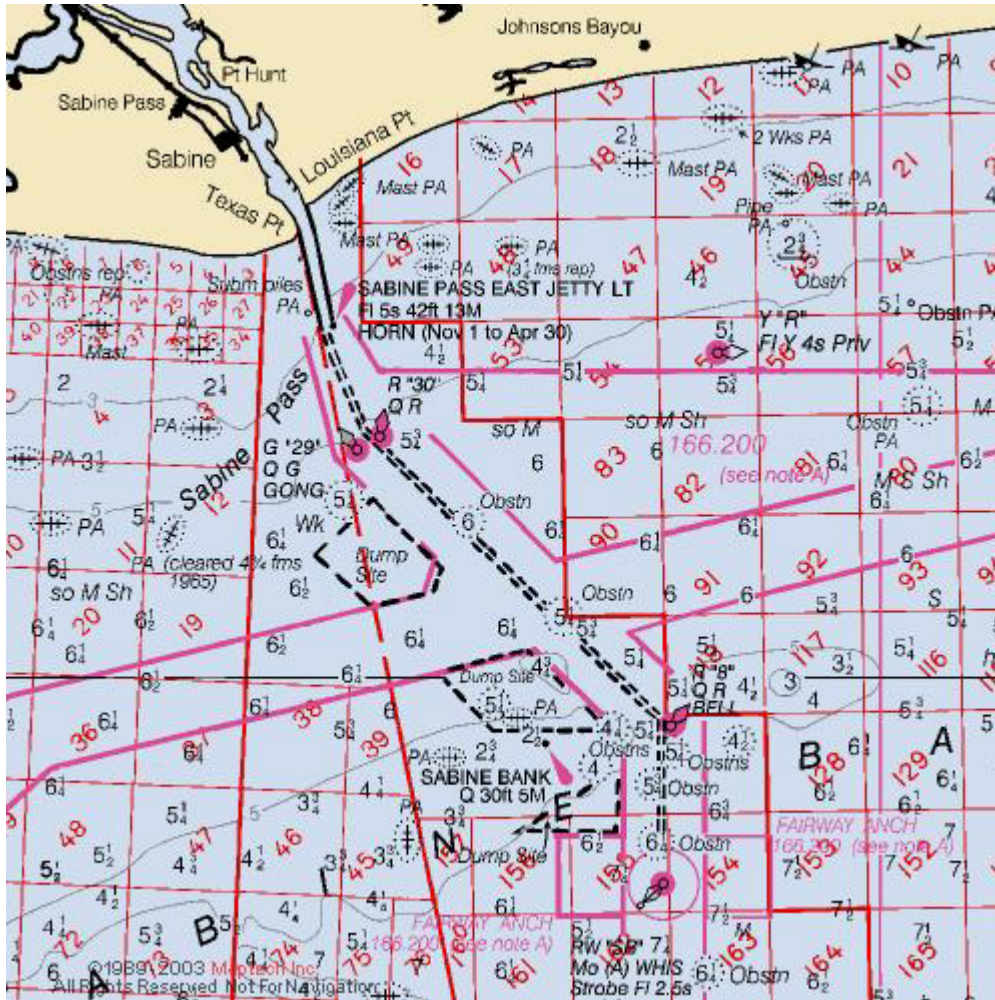
A horsepower-hour (HP-hr, expressed as kW-hr) method was used to estimate emissions, as opposed to using the ton-mile or fuel consumption methods discussed previously in Task 2. The hours are estimated by dividing the trip distance by the ship speed. Based on an October 6, 2003 interview with Sabine Pilot officers, ships approach the Sabine Pass at approximately 12 knots but then slow to about 6 to 7 knots for the inland portion starting at the Port Arthur Canal. Table 9 reports channel distances in nautical miles from the Sabine Bar (S.B.) Buoy.

**Table 9: Distances from Sabine Bar (S.B.) Buoy**

<b>Location</b>	<b>County</b>	<b>Naut_Miles</b>
S.B. Buoy	Offshore	0
Sabine, Fort Point (Pilot Sta)	Jefferson	21.6
Port of Port Arthur	Jefferson	32.6
North Port Arthur	Jefferson	36.8
Petro Fina (ATOFINA)	Jefferson	41.7
Huntsman	Jefferson	44.8
Smith's Bluff / SUN OIL	Jefferson	47.6
Stanolind	Jefferson	51.9
Municipal Docks Beaumont	Jefferson	56.1
Municipal Docks Orange	Orange	50.2

The Sabine Bar, where inbound trips begin, is located a considerable distance off the coastline, approximately 15 miles. By comparison, the Galveston Sea Buoy is approximately 8 miles off the coast. The Sabine Pilots may pick up inbound ships at any place between the Sabine Bar buoy and the East Jetty, as is shown in Figure 2.

Figure 2: Lower Sabine Area



Source: Maptech Mapserver.

Note that the “SB” Buoy marking the beginning or end of the passage is towards the lower right side indicated by a red circle in Figure 2.

Not all piloted trips go all the way to the Sabine Bar Buoy, but this location is used for the purposes of estimating travel times from distance and speed in a uniform manner. Table 10 lists the trip times.

---

**Table 10: Ship Trip Travel Times**

<b>Location</b>	<b>Distance</b>	<b>Speed</b>	<b>Time</b>
Sabine Pass	21.6	11	2.0
Port of Port Arthur	11	6.5	1.7
N. Port Arthur	4.2	6.5	0.6
Petro Fina (ATOFINA)	4.9	6.5	0.8
Huntsman	3.1	6.5	0.5
Smith's Bluff / SUN OIL	2.8	6.5	0.4
Stanolind	4.3	6.5	0.7
Municipal Docks Beaumont	4.2	6.5	0.6
Municipal Docks Orange	10.2	6.5	1.6

Travel time was computed as distance divided by speed, with speeds provided by the Sabine Pilot Association. Maneuvering time was to include an additional 45 minutes (.75 hour), during which the ship engines were almost at idle but tugboats were used to help position the vessel against the dock.

Next a process was developed to assign average horsepower to each vessel type. The preferred method is to divide the ships into different deadweight ton (DWT) categories. The approach used in this study relied on three categories:

- Small – below 50,000 tons
- Large – between 50,000 and 100,000 tons
- Super – over 100,000 tons

Deadweight tonnage is available from the Lloyds' ship registry data and reflects the design capacity of the vessel fully loaded (other metrics such as gross or net weight estimate ship tonnage with or without a full load). Table 10 lists the new vessel categories stratified by DWT.

Note that in Table 11 not all ships had valid DWT tonnage numbers in the Lloyds database, so there were somewhat fewer than the 1,868 ship calls. The "Unknown" and military vessels were assigned an average tonnage of almost 53,000 tons. Use of average tonnage may be acceptable in that it would err on the high side of true vessel displacement when the true values were not listed by Lloyds. Also, towboats are missing from the list because Lloyds does not include many of them in their registry of ships – they are more likely to be engaged in domestic travel and would not appear in the Lloyds' *Registry of Ships*.

**Table 11: Ship Categories by Deadweight Tonnage**

<b>Category</b>	<b>Size</b>	<b>Number</b>	<b>DWT</b>
Bulk	Small	153	32,499
Bulk	Large	42	80,943
Bulk	Super	19	112,035
Chemical Tanker	Small	347	32,720
Containership	Small	3	11,293
General Cargo	Small	151	24,528
General Cargo	Large	2	67,563
LPG	Small	47	17,882
LPG	Large	1	94,890
Military	Small	6	52,682
Misc	Small	12	12,800
Roro	Small	7	7,309
Tanker	Small	187	43,445
Tanker	Large	518	90,215
Tanker	Super	192	109,426
Unknown	Small	58	52,682
		1,745	52,682

Using these categories based on ship type and deadweight tonnage, horsepower was then averaged, with weighting factors used for each tonnage subcategory. The weighting factors were based on the number of incoming trips for each vessel subcategory (as an average of small, large, and super sizes). Table 12 shows the results of this weighting.

**Table 12: Weighted Average Main Engine Power by Ship Type**

<b>Category</b>	<b>kW</b>
Bulk	8,321
Chemical Tanker	7,738
Containership	7,302
General Cargo	7,207
LPG	7,709
Misc	7,355
Roro	5,291
Tanker	10,151
<i>Average</i>	7,634

---

These power levels are roughly consistent with those used in the previous Houston studies with the exception that containerships were much smaller in Beaumont – Beaumont is not a container port and the few containership trips were probably associated with military activity (Beaumont and Orange have significant military facilities including a Ready Reserve Fleet). The following calculations were then performed:

- Power (kW) was adjusted by load factor (see next section)
- Adjusted power for cruise, in-port, and maneuvering were multiplied by hours in each mode resulting in kilowatt-hours (kW-hr)
- Kilowatt-hours were multiplied by the emission factors (g/kW-hr) contained in Task 1, adjusted for low-speed correction factors
- Resulting grams were then converted to short tons by dividing by 907,200 (253.6 grams per pound, 2,000 pounds per ton)

#### ***APPLICATION OF MAIN ENGINE LOAD FACTORS***

Table 12 reports a weighted average for what is known as “maximum continuous rated” (MCR) power. This would be the full throttle available to the engine that would result in a full cruise speed. Using the Propeller Law, actual horsepower is adjusted by a load factor that is the cube root of cruise speed according to the following equation:

$$\text{Load factor} = (\text{actual speed} / \text{cruise speed})^3$$

Equation 1

This is a slight variation from the load equation used in the Houston Study, which assumed that no load factors would be below ten percent. New evidence collected from interviews with over 70 ship engineers suggests that load factors could be as low as two to three percent. The solution was to use the “natural” form of the equation but restrict low-speed loads to no less than three percent. Table 13 is a result of the application of Equation 1 to speeds that were obtained from Lloyds’ registry data.

**Table 13: Ship Speeds and Load Factors at 12, 6.5, and 3 Knots**

<b>Category</b>	<b>Size</b>	<b>Number</b>	<b>Speed</b>	<b>Twelve</b>	<b>Six_Half</b>	<b>Three</b>
Unknown	Small	58	15.2	49.2%	7.8%	0.8%
Bulk	Large	42	14.5	56.5%	9.0%	0.9%
Bulk	Small	153	14.4	58.0%	9.2%	0.9%
Bulk	Super	19	14.5	56.5%	9.0%	0.9%
Bulk Ship Average			14.5	57.0%	9.1%	0.9%
Chemical Tanker	Small	347	14.8	53.5%	8.5%	0.8%
Containership	Small	3	17.8	30.8%	4.9%	0.5%
General Cargo	Large	2	15.8	44.2%	7.0%	0.7%
General Cargo	Small	151	15.0	51.7%	8.2%	0.8%
LPG	Large	1	14.9	52.2%	8.3%	0.8%
LPG	Small	47	16.1	41.3%	6.6%	0.6%
Military	Small	6	15.2	49.2%	7.8%	0.8%
Misc	Small	12	16.0	42.2%	6.7%	0.7%
Roro	Small	7	16.0	42.2%	6.7%	0.7%
Tanker	Large	518	14.5	57.1%	9.1%	0.9%
Tanker	Small	187	14.6	55.7%	8.9%	0.9%
Tanker	Super	192	14.4	58.2%	9.2%	0.9%
Tanker Average			14.5	57.0%	9.1%	0.9%
		1,745	15.2			

The “Speed” column refers to maximum design speed of the ship, averaged for each ship type. The “Twelve” column refers to the cruise speed in knots as the ships cross the Sabine Bar to the entry jetty; the “Six-Half” columns refers to the average in-port speed of the ships as they proceed up the canals and rivers, showing a load of a little less than 10 percent. As is also shown in Table 13, the slow-speed maneuvering mode that is used to simulate docking activities is below one percent, which is considered to be too low for a diesel engine to operate.<sup>12</sup> Therefore, the estimates for the maneuvering mode were all reset and corrected to three percent (3%) in further computations. Given that load factors are directly applied to the MCR power, the difference between one and three percent is very small, however.

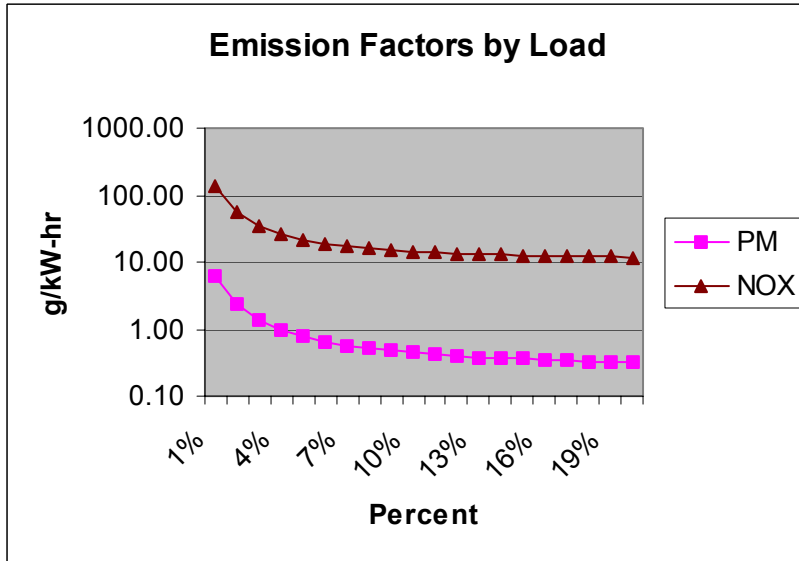
A large spreadsheet was constructed to estimate inbound, outbound, and shift horsepower-hours for each vessel type and each port terminal area. Emissions would then be estimated by applying an emission factor (g/kW-hr) to the accumulated power (kW-hr).

<sup>12</sup> This can be confusing because the Propeller Law predicts loads that are lower than what a typical slow-speed, direct-drive diesel ship engine can output. Most ships of this type operate at about 100 RPM (80% load) at cruise and 25 RPM (2-3% load) during maneuvering. Below this minimum the engine is simply turned off (0% load).

**EMISSION FACTORS**

Emission factors used in this study were developed under Task 1. It is a well-known fact that emissions from diesel engines can increase at low loads when using the power method, since fuel consumption is increased.<sup>13</sup> An analysis was conducted from an EPA report.<sup>14</sup> The factors apply to cruise speeds above 20% load factor, as are graphed for two pollutants in Figure 3.

**Figure 3: Emissions and Low Maneuvering Loads**



Since all maneuvering loads were capped at three percent, one can compare the cruise and maneuvering mode so as to generate adjustment factors, which are summarized in Table 14.

**Table 14: Emission Adjustment Factors**

<b>Mode and Engine Load</b>	<b>PM</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>
Maneuvering - 3%	4.33	2.92	6.67	17.21
In-Port Transit - 9%	1.48	1.27	2.22	3.31

Thus, the cruise mode was assumed to be equal to the Task 1 emission factors but the Table 14 factors were used to adjust the default emission rates upwards for loads less than 20%. For example, diesel/residual engines with a default emission factor of 18.1 g/kW-hr were adjusted to 2.92 times higher for the maneuvering mode, equivalent to 52.8 g/kW-hr.

<sup>13</sup> As correctly noted by Corbett, emission factors expressed in terms of kg/tonne of fuel remain constant, so using g/kW-hr “power method” results in higher emissions due to increased fuel consumption.

<sup>14</sup> EF&EE, 2000. 'Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data.' EPA420-R-00-002

---

### ***CONSIDERATION OF AUXILIARY ENGINE EMISSIONS***

Auxiliary emissions were added to the main engine emissions. There are three modes of auxiliary usage:

- Ocean cruise and channel transit
- Loading/unloading
- Hotelling

Through interviews with terminal operators and data from the Sabine Pilots, the average time taken to discharge a ship and idling time was taken into consideration since the auxiliary engines would be in use in transit and at berth.

A typical ocean-going tanker can take 24 to 40 hours to unload, with the ship using its own pumps to unload liquid material. When loading a vessel, the terminal uses its own terminal pumps. Due to the night time restriction on vessel moves by the Sabine Pilots<sup>15</sup>, vessels over 85,000 metric tons or greater than 875 feet in length (the ocean going tankers) must wait at berth until daylight for a pilot to board for the departure. So, after loading, a vessel may stay an additional 12-18 hours at berth. Discharge rates for product ships vary considerably. The loading rate depends on the diameter of the pipeline, the distance to the tank, pump used, and capacity. Some terminals estimated 22-32 hours to load a tanker product ship. Since there was no hard data to rely upon, all ships were profiled via the surveys to have a 34-hour dwell time at the dock:

- 34 hours of hotelling using one auxiliary engine
- 20 hours tanker discharging using an additional auxiliary engines

As was mentioned in the previous Houston study, ships have unique characteristics regarding the number of auxiliary engines, their average power output, and on-board electrical power requirements, and thus were difficult to model. During ship transits, one auxiliary engine operating for the entire trip time was assumed to be in use. During maneuvering, which was usually modeled as one hour docking or undocking, two auxiliary engines were modeled because power is needed for winches, thrusters, and blowers (additional air is required for the main engine to exhaust its smoke).

### ***USE OF GIS***

In order to estimate emissions for the purposes of dispersion modeling (e.g., CAM-x ozone model), emissions had to be represented in terms of channel segments (lines) and terminal dwelling (points). The Army Corps of Engineers database for port characteristics was used to extract terminal locations that would match the waypoints identified by the Sabine Pilots. Table 15 shows these points:

---

<sup>15</sup> <http://www.businessintexas.com/sabinepilots/guidelines.htm>

---

**Table 15: Waypoints in Latitude in Longitude**

<b>Zone</b>	<b>Location</b>	<b>LATITUDE</b>	<b>LONGITUDE</b>
BMT00	Sabine Bar Buoy	29.41666667	-93.66666667
BMT01	Sabine Pass	29.7375	-93.8825
BMT02	Port of Port Arthur	29.858889	-93.940278
BMT03	North Port Arthur	29.930278	-93.875278
BMT04	Fina	29.980278	-93.877778
BMT05	Huntsman	29.993611	-93.9425
BMT06	Smith's Bluff	30.01	-93.9925
BMT07	Stanolind	30.031389	-94.033611
BMT08	Municipal Docks Beaumont	30.078056	-94.088056
BMT09	Municipal Docks Orange	30.066944	-93.723056
BMT10	Jefferson County Line	29.60972222	-94.35333333

Quality assurance comprised of comparing distances from these waypoints using a geographic information system (GIS), as well as ensuring that the waypoints were located in expected places along the waterway system. Table 16 shows the results of this comparison.

**Table 16: Comparison of Model versus GIS Map Distances**

<b>Trip</b>	<b>Name</b>	<b>Actual</b>	<b>GIS</b>
BMT01	Sabine Bar to Sabine Pass	21.6	22.0
BMT02	Sabine Pass to Port Arthur	11.0	7.8
BMT03	Port Arthur to N. Port Arthur	4.2	5.4
BMT04	N. Port Arthur to Fina	4.9	3.0
BMT05	Fina to Huntsman	3.1	3.3
BMT06	Huntsman to Smith's Bluff	2.8	2.7
BMT07	Smith's Bluff to Stanolind	4.3	2.4
BMT08	Stanolind to Beaumont	4.2	3.9
BMT09	Fina to Orange	10.2	9.3
BMT10	Jefferson County Line to Port Arthur	25.5	25.5
		91.8	85.3

The GIS performance was very good, considering that exact locations of the Sabine Pilot waypoints was not known (with 93 percent of distances accounted for). Figure 4 shows the links. While not perfect, they are adequate for the purposes of spatial allocation in a dispersion model.

Figure 4: GIS Overlay of Trip Segments



There are several aspects of Figure 4 to discuss. The link from Jefferson County Line to Port Arthur is meant for towboats in sections that fall below – no ships take this route because the depth of the water is only about 12 feet, whilst most ships require at least 25 feet. Second, there is considerable curve-straightening that causes boats to look like they are traveling over land; it should be noted that the resolution of most dispersion models is 1-2 kilometer grids, so this is not a significant issue from an air quality modeling perspective. Finally, it should be noted that all the emissions are within the State of Texas, since the Louisiana border runs down the middle of the Sabine River.

---

### **SHIP EMISSION CALCULATIONS**

A spreadsheet was devised to accommodate the following types of emissions:

- Transiting emissions (line sources)
  - Main Engines underway
  - Main engine when maneuvering
  - Auxiliary engines during transit
  - Auxiliary engines during maneuvering
  - Auxiliary boilers
- Dwelling Emissions (point sources)
  - Auxiliary dwelling
  - Tanker auxiliary unloading
  - Auxiliary boilers

Detailed results are appended in electronic format. Table 17 estimates annual emissions for the year 2000.

**Table 17: Annual Results, Short Tons per Year, 2000**

<b>Transit Emissions</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	987.92	105.57	47.45	109.44	538.55
Main Engines - Maneuvering	46.68	9.42	9.12	7.35	9.28
Auxiliary Engines Transit	92.32	10.63	2.66	1.99	28.56
Auxiliary Engines - Maneuvering	20.04	2.31	0.58	0.43	6.20
Auxiliary Boilers Underway	3.88	1.45	0.12	0.41	17.01
	1,150.84	129.37	59.93	119.62	599.60
<b>Dockside Emissions</b>					
Auxiliary Dwelling	429.16	49.40	12.35	9.26	132.76
Auxiliary Tanker Unloading	124.08	14.28	3.57	2.68	38.39
Auxiliary Dockside Boilers	12.12	4.53	0.37	1.28	53.23
	565.37	68.22	16.30	13.22	224.37
<b>Total</b>	1,716.21	197.59	76.22	132.84	823.98

Temporal allocation is also very important because photochemical modeling evaluates daily as opposed to annual emissions. Table 18 shows the distribution of ship trips (including shifts) by month, as obtained from the Pilots data. The seasonal adjustment factor (SAF) is a divisor used to convert annual emissions to daily emissions.

Table 18: Seasonal Allocation of Ship Trips (Normal Month = 365)

Month	Trips	Percentage	SAF
January	321	7.81%	389
February	292	7.10%	428
March	347	8.44%	360
April	316	7.69%	396
May	342	8.32%	366
June	331	8.05%	378
July	352	8.56%	355
August	397	9.66%	315
September	346	8.42%	361
October	353	8.59%	354
November	356	8.66%	351
December	357	8.69%	350
	4,110	100.00%	

This table indicates that August is the peak month for ship activity, which coincides with the period of interest for modeling the 1-hour and 8-hour ozone standards. Some of the ozone episodes used by the TCEQ spillover into the month of September, but to use an August SAF would err conservatively on the high side. Using a SAF value of 315 days as opposed to the normal 365 would increase the average daily emissions. Results of this analysis are shown in Table 19.

Table 19: Average Daily Emissions for August, 2000

Transit Emissions	NOx	CO	HC	PM-10	SO2
Main Engines - Transit	3.14	0.34	0.15	0.35	1.71
Main Engines - Maneuvering	0.15	0.03	0.03	0.02	0.03
Auxiliary Engines Transit	0.29	0.03	0.01	0.01	0.09
Auxiliary Engines - Maneuvering	0.06	0.01	0.00	0.00	0.02
Auxiliary Boilers Underway	0.01	0.00	0.00	0.00	0.05
	3.65	0.41	0.19	0.38	1.90
Dockside Emissions					
Auxiliary Dwelling	1.36	0.16	0.04	0.03	0.42
Auxiliary Tanker Unloading	0.39	0.05	0.01	0.01	0.12
Auxiliary Dockside Boilers	0.04	0.01	0.00	0.00	0.17
	1.80	0.22	0.05	0.04	0.71
<b>Total</b>	5.45	0.63	0.24	0.42	2.62

### *ASSIST TUGBOATS*

Assist tugboats are used to help position large ships against the docks and are related to ship traffic patterns. In addition to positioning against the dock, all ships must be turned around to head out of the channel in a turning basin (because in most cases the ship is longer than the safe channel is wide). Dock positioning and turning can be considered to be two different tasks but have been modeled together.

Two assist tug companies in the area, Moran and Sea-Bulk, provide most of the assist tug operations in the area. The tugboats have a total engine horsepower ranging from 3,000 HP to 4,200 HP and are typically used 8 to 12 hours per day. The assist tugs generally have two auxiliary engines to run electrical generators, with one operating at a time. One company started using shore power for auxiliary uses in 2003 (“cold ironing”). For the required year 2000 emission estimates, however, no cold-ironing was modeled. The following modes of operation were considered:

- Actual maneuvering time (docking and/or turning basin)
- Transit time to the job site
- Generator time (main engines off, waiting for a job)

Through discussions with industry experts, Starcrest adopted the following key assumptions regarding time in mode. In general, most assist tugs operate 10 to 12 hours per day, of which a substantial portion is waiting on orders at the dock (generator time). Eleven hours was used to estimate auxiliary hours of operation per day. In addition, tankers were assumed to require two assist tugs (most ports require two in such cases because of the hazardous nature of the loads). Docking, ship turning, and transit time was modeled as 3 hours per ship trip, although there is a great deal of variation depending on the type of ship and its terminal location on the waterway. Average power was estimated from the eight assist tugs surveyed as follows:

**Table 20: Assist Towboat Power Converted to kW**

	<b>HP</b>	<b>kW</b>
Assist Tug	4,200	3,132
Assist Tug	3,900	2,908
Assist Tug	3,900	2,908
Assist Tug	3,300	2,461
Assist Tug	3,200	2,386
Assist Tug	3,900	2,908
Assist Tug	3,200	2,386
Assist Tug	3,900	2,908
<i>average</i>		2,750

Since emissions are also a function of time, power, load and emission factors, load factors were estimated in a slightly different manner than the method used with the ships. One average load factor was derived from data collected from an operator on the West Coast that uses similar equipment as found in the Beaumont-Port Arthur area. Three vessels representing over 10,000 hours of engine operation were evaluated as to time in each power level, from 0 to 100 percent. Results are shown in Table 21.

Table 21: Estimation of Average Assist Tug Load Factor

Load Factor		Time in Mode	
Load Range	Midpoint	Average	Weighted
0.00-0.04	2%	0.30%	0.01%
0.05-0.09	7%	0.07%	0.00%
0.10-0.14	12%	1.47%	0.18%
0.15-0.19	17%	21.82%	3.71%
0.20-0.24	22%	27.06%	5.95%
0.25-0.29	27%	11.73%	3.17%
0.30-0.34	32%	8.89%	2.84%
0.35-0.39	37%	10.93%	4.04%
0.40-0.44	42%	3.32%	1.39%
0.45-0.49	47%	2.25%	1.06%
0.50-0.54	52%	1.49%	0.78%
0.55-0.59	57%	1.42%	0.81%
0.60-0.64	62%	2.03%	1.26%
0.65-0.69	67%	1.59%	1.07%
0.70-0.74	72%	2.45%	1.77%
0.75-0.79	77%	1.04%	0.80%
0.80-0.84	82%	0.72%	0.59%
0.85-0.89	87%	0.49%	0.43%
0.90-0.94	92%	0.53%	0.49%
0.95-0.99	97%	0.29%	0.28%
1.00	102%	0.11%	0.11%
		100.00%	<b>30.73%</b>

The “Weighted” column is simply the product of power (“Midpoint”) times the average of the time-in-mode for the three test vessels. Results show an average of 31 percent load over the complete duty cycle of the three vessels surveyed. The standard deviation, which measures variation from the mean, is very tight except at low power settings (e.g., 15 to 20%). Variation at low power settings is perhaps more indicative of the individual operator and how low-speed boost is applied when maneuvering ships.

Emission factors were derived from ENTEC medium speed engines operating on gas oil (similar to US non-road diesel); they are very similar to those used by EPA in the 1999 Regulatory Impact Statement (e.g., 13.2 g/kW-hr versus 13.0 g/kW-hr NO<sub>x</sub>, respectively). The ENTEC emission factors were chosen because most assist tugs are Category 2 marine engines (over 5 liters per cylinder), while the EPA emission factors are meant to be used for small displacement engines (Category 1).

Since most of the assist towboats are active near terminal berths, emissions were modeled as a function of ship trips, not trip transit segments; that is, the activity data more resembled the process used to estimate ship dockside dwelling. Table 22 shows the results of this calculation. A SAF of 315 was used just as was done with the ships.

**Table 22: Assist Vessel Emissions**

<b>Assist Tugs - TPY</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	171.52	20.79	6.50	9.36	12.99
Auxiliary Engines	63.68	7.33	1.83	1.37	5.04
	235.20	28.12	8.33	10.73	18.03

<b>Assist Tugs - TPD</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	0.54	0.07	0.02	0.03	0.04
Auxiliary Engines	0.20	0.02	0.01	0.00	0.02
	0.75	0.09	0.03	0.03	0.06

### ***TOWBOATS***

Towboats are vessels that tow barges, while push boats push barges. Often the same boat can be used as an assist tug or a towboat, with the distinction that towboats are used to haul or push barges only. Some towboats have a square bow meant for pushing barges from behind, but functionally the design of the tug does not make a large difference in terms of emissions.

Towboat/push-boat movements were high in the area due to the large use of petrochemical barges within the intracoastal waterways between oil/chemical terminals in the area to Houston/Galveston and Louisiana terminals. Most of the towboats push barges that contain unrefined, crude oil (“black oil”). However, the industry is quite diverse, including:

- Black oil (lightering, collection from shallow water wells, etc.)
- Distribution of raw chemicals and sulfur
- Fuel bunkering (filling ships with engine fuel)
- Aggregates and other construction materials
- Agricultural products

The companies involved in the industry are also quite diverse. As in the trucking industry there are a few, large revenue carriers and then there are small, local companies called “jobbers.” In the year 2000, several large towboat companies would tow their barges from Houston to Port Arthur. The barges were then assembled in a shallow part of the Port of Port Arthur, a system called “fleeting.” Traditionally, the local jobbers would conduct the fleeting and send boats up towards Beaumont and Orange.

Towboat movements were not included in the Sabine Pilots database since a pilot is not required to board. At the terminals, tankers take priority and the product barges usually have to wait their turn, with one auxiliary engine running for power on the towboat. Towboat trips are summarized from COE data as shown in Table 23.

**Table 23: In-Port Towboat Trips, 2000**

<b>Trip Segment</b>	<b>Tow Inbound</b>	<b>Tow Outbound</b>	<b>Tow Total</b>
Beaumont - Neches	5,478	5,424	10,902
Sabine-Neches Waterway	14,439	10,847	25,286
Orange	534	436	970
Port Arthur	3,891	3,780	7,671
Sabine Pass Harbor	609	679	1,288
	24,951	21,166	46,117

Data regarding the 46,000 towboat moves was ordered from the U.S. Army Corps of Engineers but was not available in time for this report. Therefore, a “top-down” approach was used in which towboat trips were allocated to the ten transit segments of the Sabine-Neches Waterway, as is shown in Table 24.

**Table 24: Allocated Towboat Trips, 2000**

<b>Name</b>	<b>Zone</b>	<b>Dockings</b>	<b>Thru</b>	<b>Total</b>	<b>Miles</b>
Sabine Bar to Sabine Pass	BMT01	0	0	0	22
Sabine Pass to Port Arthur	BMT02	1,288	0	1,288	7.8
Port Arthur to N. Port Arthur	BMT03	7,671	38,446	46,117	5.4
N. Port Arthur to Fina	BMT04	25,286	10,902	36,188	3
Fina to Huntsman	BMT05	10,902	8,177	19,079	3.3
Huntsman to Smith's Bluff	BMT06	8,177	5,451	13,628	2.7
Smith's Bluff to Stanolind	BMT07	5,451	2,726	8,177	2.4
Stanolind to Beaumont	BMT08	2,726	0	2,726	3.9
Fina to Orange	BMT09	970	970	1,940	9.3
Jefferson County Line to Port Arthur	BMT10	0	46,117	46,117	25.5

There are several key aspects to note, foremost that there were no trips through the Sabine Pass out to sea; these trips were already covered by the Pilot data. Secondly, almost all the traffic was associated with inbound towboats coming from Houston along the Intracoastal Waterway (Jefferson County Line to Port Arthur). The other source of local towboat activity was the Intracoastal Waterway to the east of Orange, Texas, which was capped at 970 docking and through trips each. According to local industry officials, there is relatively less traffic in this direction, although it is the connection to the Port of New Orleans and the Mississippi River (the largest port in the U.S. by shipping tonnage). Finally, the Neches River between Beaumont and the confluence of the Sabine River was divided into four zones, so as to allocate towboat activity among large terminals such as Fina, Huntsman, Unocal, and Exxon-Mobil.

---

The methodology to estimate emissions is similar to that used for the large ships but is simpler. Instead of using ship arrivals and departures, as was done with the assist tugs, trips were assigned to various segments of the waterway. The following assumptions were used:

- Engine loads were assumed to be 69%<sup>16</sup>
- Engine horsepower was a combined 650 HP (see Table 25)
- Trip speed was 6.5 knots (source: Sabine Pilots)
- Fleeting delay (moving barges around) was assumed to be 30 minutes
- Idle “generator time” was assumed to be 20 percent higher than transit times
- Dockside dwelling was not estimated, given the complexities of the industry

An average of 650 HP was used in spite of the fact that there are three general types of towboats in terms of on-board power. Most of the revenue towboats are larger than local jobber towboats, perhaps 800 versus 500 HP, respectively. In addition, towboats used on the Mississippi tend to be larger than 1,000 HP, although these are few in number. Starcrest consulted the industry regarding their towboats in terms of horsepower, mostly by telephone survey (many of the smaller companies declined to participate). A simple average of ~650 HP was based on the following information (with vessel and company names removed).

Main engine and auxiliary engine emissions were estimated separately, with the average auxiliary engine having two 50 HP (37 kW) engines, of which one is used at a time (source: Kirby Inland Marine, Inc.). Table 26 shows the computations for estimating main engine power and Table 27 then reports the results of this procedure.

---

<sup>16</sup> This factor (69%) was used in Starcrest, 2000. ‘Houston-Galveston Vessel Emissions Inventory’ page 69. The value is based on an industry survey from 1997 and could be updated with new computer recorder data in the future.

**Table 25: Method to Determine Towboat Main Power**

	<b>HP</b>	<b>kW</b>
Towboats	400	298
Towboats	300	224
Towboats	400	298
Towboats	300	224
Towboats	330	246
Towboats	800	597
Towboats	800	597
Towboats	800	597
Towboats	600	447
Towboats	600	447
Towboats	600	447
Towboats	800	597
Towboats	330	246
Towboats	800	597
Towboats	1000	746
Towboats	900	671
Towboats	800	597
Towboats	1000	746
Towboats	800	597
Towboats	600	447
<i>average</i>	648	483

**Table 26: Towboat Main Engine Activity**

<b>Main Engines (Load): Name</b>	<b>Zone</b>	<b>Trips</b>	<b>Trip Hours</b>	<b>Hours</b>	<b>69.00% kW-Hours</b>
Sabine Bar to Sabine Pass	BMT01	0	3.38	0	0
Sabine Pass to Port Arthur	BMT02	1,288	1.20	2,190	730,063
Port Arthur to N. Port Arthur	BMT03	46,117	0.83	61,371	20,462,520
N. Port Arthur to Fina	BMT04	36,188	0.46	34,796	11,601,832
Fina to Huntsman	BMT05	19,079	0.51	19,225	6,410,140
Huntsman to Smith's Bluff	BMT06	13,628	0.42	12,474	4,159,251
Smith's Bluff to Stanolind	BMT07	8,177	0.37	7,107	2,369,724
Stanolind to Beaumont	BMT08	2,726	0.60	2,998	999,618
Fina to Orange	BMT09	1,940	1.43	3,746	1,248,899
Jefferson County Line to Port Arthur	BMT10	46,117	3.92	203,979	68,011,266

**Table 27: Towboat Main Engine Emissions**

<b>Main Engines (Factor):</b>		10.00	1.50	0.27	0.30	1.10
<b>Name</b>	<b>Zone</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Sabine Bar to Sabine Pass	BMT01	0.00	0.00	0.00	0.00	0.00
Sabine Pass to Port Arthur	BMT02	8.05	1.21	0.22	0.24	0.89
Port Arthur to N. Port Arthur	BMT03	225.56	33.83	6.09	6.77	24.81
N. Port Arthur to Fina	BMT04	127.89	19.18	3.45	3.84	14.07
Fina to Huntsman	BMT05	70.66	10.60	1.91	2.12	7.77
Huntsman to Smith's Bluff	BMT06	45.85	6.88	1.24	1.38	5.04
Smith's Bluff to Stanolind	BMT07	26.12	3.92	0.71	0.78	2.87
Stanolind to Beaumont	BMT08	11.02	1.65	0.30	0.33	1.21
Fina to Orange	BMT09	13.77	2.06	0.37	0.41	1.51
Jefferson County Line to Port Arthur	BMT10	749.68	112.45	20.24	22.49	82.47
		1,278.59	191.79	34.52	38.36	140.64

In a similar manner, auxiliary emissions were also estimated with each towboat assigned one 37-kW generator operating at 50 HP (37 kW). As noted previously, an extra 20 percent of “generator time” (1.2 Factor) was added to the estimated trip hours so as to reflect engine-off time. Table 28 and 29 detail towboat auxiliary engine activity and emissions.

**Table 28: Towboat Auxiliary Engine Activity**

<b>Auxiliary Engines (Load):</b>				1.2	65.00%
<b>Name</b>	<b>Zone</b>	<b>Trips</b>	<b>Trip Hours</b>	<b>Hours</b>	<b>kW-Hours</b>
Sabine Bar to Sabine Pass	BMT01	0	3.38	0	0
Sabine Pass to Port Arthur	BMT02	1,288	1.20	1,855	44,606
Port Arthur to N. Port Arthur	BMT03	46,117	0.83	45,975	1,105,701
N. Port Arthur to Fina	BMT04	36,188	0.46	20,043	482,024
Fina to Huntsman	BMT05	19,079	0.51	11,623	279,538
Huntsman to Smith's Bluff	BMT06	13,628	0.42	6,793	163,366
Smith's Bluff to Stanolind	BMT07	8,177	0.37	3,623	87,129
Stanolind to Beaumont	BMT08	2,726	0.60	1,962	47,195
Fina to Orange	BMT09	1,940	1.43	3,331	80,106
Jefferson County Line to Port Arthur	BMT10	46,117	3.92	217,105	5,221,367

**Table 29: Towboat Auxiliary Engine Emissions**

<b>Auxiliary Engines (Factor):</b>		11.00	2.00	0.27	0.90	1.10
<b>Name</b>	<b>Zone</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Sabine Bar to Sabine Pass	BMT01	0.00	0.00	0.00	0.00	0.00
Sabine Pass to Port Arthur	BMT02	0.49	0.07	0.01	0.01	0.05
Port Arthur to N. Port Arthur	BMT03	12.19	1.83	0.33	0.37	1.34
N. Port Arthur to Fina	BMT04	5.31	0.80	0.14	0.16	0.58
Fina to Huntsman	BMT05	3.08	0.46	0.08	0.09	0.34
Huntsman to Smith's Bluff	BMT06	1.80	0.27	0.05	0.05	0.20
Smith's Bluff to Stanolind	BMT07	0.96	0.14	0.03	0.03	0.11
Stanolind to Beaumont	BMT08	0.52	0.08	0.01	0.02	0.06
Fina to Orange	BMT09	0.88	0.13	0.02	0.03	0.10
Jefferson County Line to Port Arthur	BMT10	57.55	8.63	1.55	1.73	6.33
		82.79	12.42	2.24	2.48	9.11

It should be noted that the emission factors are EPA Category 1 numbers as opposed to Category 2 ENTEC emission factors. This presumption is based on the notion that two main engines averaging 650 HP would each be 325 HP, more akin to a “semi” truck engine, much smaller than the assist tugs that could be several thousand HP.

***OTHER HARBOR VESSELS***

Assist tugs and inland towboats are usually classified as harbor vessels to distinguish them from ocean-going ships (which can include the larger tugboats). In addition, there are a variety of harbor-related vessels to be included in an inventory, such as:

- Dredges
- Fishing boats
- Government vessels

Each is discussed in detail in the following sections. In general, there is less detail given to auxiliary engines, since the survey data (the FOIA response for government vessels) did not include useful information regarding these engines.

**DREDGES**

In 2000, there were about five maintenance dredging projects in the area managed by the Army Corps of Engineers. In addition, there were about seven private dredging projects at the various terminals docks, according to the Jefferson County Waterway and Navigation District that oversees the disposal areas receiving the dredged material. Table 30 reports the major dredge projects that could have been operating in the year 2000.

**Table 30: Major Dredge Projects (2000)**

<b>Project</b>	<b>Start</b>	<b>End</b>	<b>Cubic Yards</b>	<b>Dredge</b>
SNWW, Neches River, Lower R.	7/22/99	3/14/00	1,912,999	Cutter Suction
SNWW, Port Arthur TB to Jnct	2/10/99	1/26/00	4,218,452	Cutter Suction
SNWW, OUTER BAR AND BANK	12/17/99	5/1/00	2,065,576	Hopper
SNWW- JETTY CHANNEL	10/27/00	1/26/01	1,677,000	Cutter Suction
SNWW-Sabine-Neches Canal	9/1/00	11/2/00	925,291	Cutter Suction
			10,799,318	

Annual dredging volume was probably closer to six million cubic yards, compared to the eighteen million yards for the Houston Channel Deepening Project in 2000. Dredge emissions can be estimated in several ways, including use of dredge spoils (millions of cubic yards) or as used in this case, dredging days. Table 31 estimates days of dredging in 2000.

**Table 31: Estimation of Dredging Days**

<b>Project</b>	<b>Start</b>	<b>End</b>	<b>Days</b>	<b>Days-2000</b>
SNWW, Neches River, Lower R.	7/22/99	3/14/00	236	73
SNWW, Port Arthur TB to Jnct	2/10/99	1/26/00	350	25
SNWW, OUTER BAR AND BANK	12/17/99	5/1/00	136	121
SNWW- JETTY CHANNEL	10/27/00	1/26/01	91	66
SNWW-Sabine-Neches Canal	9/1/00	11/2/00	62	62
			<b>875</b>	<b>347</b>

The outer Sabine Bar work was performed by a hopper dredge, which resembles a small ship. The rest of the work was done by cutter-suction dredges. Power was provided by the U.S. Army Corps of Engineers for the various projects, as shown in Table 32.

**Table 32: Estimated Dredging Power**

<b>Project</b>	<b>HP</b>	<b>Hrs/Day</b>	<b>Days</b>	<b>Hours</b>	<b>80% kW-Hrs</b>
SNWW, Neches River, Lower R.	2,000	24	73	1,752	2,090,380
SNWW, Port Arthur TB to Jnct	4,500	24	25	600	1,610,738
SNWW, OUTER BAR AND BANK	8,400	9.5	121	1,150	5,760,358
SNWW- JETTY CHANNEL	4,000	24	66	1,584	3,779,866
SNWW-Sabine-Neches Canal	2,000	24	62	1,488	1,775,391

Using the same emission factors as those for assist tugboats (ENTEC Category 2 engines) emissions were first estimated for the main dredges, converting HP to kW, as shown in Table 33.

**Table 33: Dredge Emissions (TPY, 2000)**

<b>Project</b>	<b>Emission Factors:</b>				
	<b>13.20 NOx</b>	<b>1.60 CO</b>	<b>0.50 HC</b>	<b>0.72 PM-10</b>	<b>1.00 SO2</b>
SNWW, Neches River, Lower R.	30.42	3.69	1.15	1.66	2.30
SNWW, Port Arthur TB to Jnct	23.44	2.84	0.89	1.28	1.78
SNWW, OUTER BAR AND BANK	83.81	10.16	3.17	4.57	6.35
SNWW- JETTY CHANNEL	55.00	6.67	2.08	3.00	4.17
SNWW-Sabine-Neches Canal	25.83	3.13	0.98	1.41	1.96
	<b>218.50</b>	<b>26.48</b>	<b>8.28</b>	<b>11.92</b>	<b>16.55</b>

Some support vessels are also used in conjunction with dredging projects to position pipelines, change crews, move barges, and so forth. Such support vessels often include small tugboats but are always called “tenders.” Table 34 estimates tender power, often assuming that each tender would be an average of 250 horsepower, and using EPA Category 1 emission factors for the appropriate power level.

**Table 34: Dredge Tender Activity, 2000**

<b>Project</b>	<b>HP</b>	<b>Hrs/Day</b>	<b>Days</b>	<b>Hours</b>	<b>31% HP-Hrs</b>
SNWW, Neches River, Lower R.	500	24	73	1,752	202,506
SNWW, Port Arthur TB to Jnct	900	24	25	600	124,832
SNWW, OUTER BAR AND BANK	0	9.5	121	1,150	0
SNWW- JETTY CHANNEL	500	24	66	1,584	183,087
SNWW-Sabine-Neches Canal	500	24	62	1,488	171,991

Note that the hopper dredge used at the Sabine Bar does not require tenders. Table 35 shows the effect of applying emission factors to these power levels. In this case EPA factors for Category 1 engines were used.

**Table 35: Tender Emissions, Tons per Year, 2000**

<b>Project</b>	<b>Emission Factors:</b>				
	<b>10.00 NOx</b>	<b>1.50 CO</b>	<b>0.27 HC</b>	<b>0.30 PM-10</b>	<b>1.10 SO2</b>
SNWW, Neches River, Lower R.	2.95	0.36	0.11	0.16	0.22
SNWW, Port Arthur TB to Jnct	1.82	0.22	0.07	0.10	0.14
SNWW, OUTER BAR AND BANK	0.00	0.00	0.00	0.00	0.00
SNWW- JETTY CHANNEL	2.66	0.32	0.10	0.15	0.20
SNWW-Sabine-Neches Canal	2.50	0.30	0.09	0.14	0.19
	9.93	1.20	0.38	0.54	0.75

For the purposes of ozone modeling, a seasonal adjustment factor (SAF) should be applied to the annual numbers. It should be clarified that there was no dredging reported for the month of August, and very little for the month of September. Since dredge projects tend to be oriented towards channel maintenance that could occur at any time throughout the year, it was assumed that a SAF of 365 would best represent the daily emissions that could occur during a “typical ozone season day.” This is a consideration for projecting future emissions to out-years such as 2007 and 2010.

#### **FISHING VESSELS**

Based on Starcrest interviews with industry representatives, there are approximately 200 shrimp and fishing boats in the area. About 75% of the boats are docked at Sabine Pass, and the rest are in Port Arthur. The commercial fishermen spend 95% of their time at sea, up to 100 miles off shore during the fishing season. The fishing season is from July to December, when the fishing boats make one to two trips where they stay at sea for two to three weeks at a time. In general, the boats have 300 to 400 HP main engines with 60 hp auxiliary engines. For six months out the year, the boats will stay docked. There were a few other types of fishing vessels likely to be in the area, such as snapper boats, but there were not discovered during the survey of the major fish markets in the area. Table 36 summarizes fishing vessel activity in the study area.

**Table 36: Fishing Vessel Activity**

<b>Zone</b>	<b>Location</b>	<b>Number</b>	<b>Trip Time</b>	<b>Trips/Year</b>	<b>Hours</b>	<b>HP</b>	<b>43% kW-Hrs</b>
BMT01	Sabine	150	2.70	10	8,100	350	1,219,050
BMT02	Pt Arthur	50	4.08	10	4,075	350	613,288
							1,832,338

Using the EPA Category 1 emission factors, emissions were then calculated as shown in Table 36. The load factor rating is based on the NONROAD2002 model,<sup>17</sup> as opposed to using default EPA numbers that could be much higher (e.g., ~70%). This setting appears to be justified because the fishing boats are not pushing or pulling a big load, such as a barge. Further investigation is warranted and it would be likely that fishing vessels pulling a trawl net (such as a shrimp boat) could have higher loads factors when at sea. The numbers above the pollutants in Table 37 below indicate the emission factor that was used (g/kW-hr).

**Table 37: Annual Shrimp Boat Emissions**

Emission Factors:		<b>10.00</b>	<b>1.50</b>	<b>0.27</b>	<b>0.30</b>	<b>1.10</b>
<b>Zone</b>	<b>Location</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
BMT01	Sabine	13.44	2.02	0.36	0.40	1.48
BMT02	Pt Arthur	6.76	1.01	0.18	0.20	0.74
		20.20	3.03	0.55	0.61	2.22

Average daily emissions during the July, August, and September period were computed as being one trip per month. A SAF of 180 was used (one-half of a year). The results of this are shown in Table 38.

**Table 38: Average July-September Daily Emissions**

Emission Factors:		<b>10.00</b>	<b>1.50</b>	<b>0.27</b>	<b>0.30</b>	<b>1.10</b>
<b>Zone</b>	<b>Location</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
BMT01	Sabine	0.075	0.011	0.002	0.002	0.008
BMT02	Pt Arthur	0.038	0.006	0.001	0.001	0.004
		0.112	0.017	0.003	0.003	0.012

<sup>17</sup> EPA 2002. 'Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling.' EPA420-P-01-014.

## GOVERNMENT VESSELS

Government vessels include such as those operated by the Sabine Pilots, the U.S. Army Corps of Engineers (USACE), and the U.S. Coast Guard (USCG). Only diesel powered vessels were included, so many patrol and inspection boats were dropped from the list because they had outboard motors. Table 39 shows the vessel particulars and estimated annual emissions.

**Table 39: Government Vessels, Annual Emissions**

Organization	Type	Load Factor/Emission Factors:							
		HP	Hours	0.42 kW-Hrs	10.00 NOx	1.50 CO	0.27 HC	0.30 PM-10	1.10 SO2
Pilot	Pilot	265	586	48,637	0.54	0.08	0.01	0.02	0.06
Pilot	Pilot	528	1,800	297,664	3.28	0.49	0.09	0.10	0.36
Pilot	Pilot	1,250	5,600	2,192,394	24.17	3.62	0.65	0.72	2.66
USACE	Survey	400	1,400	175,391	1.93	0.29	0.05	0.06	0.21
USCG	Patrol	600	600	112,752	1.24	0.19	0.03	0.04	0.14
USCG	Insp.	160	500	25,056	0.28	0.04	0.01	0.01	0.03
USCG	Insp.	160	500	25,056	0.28	0.04	0.01	0.01	0.03
USCG	Insp.	160	500	25,056	0.28	0.04	0.01	0.01	0.03
				2,902,006	31.16	4.67	0.84	0.93	3.43

The Sabine Pilot boat was the greatest contributor to the activity. Daily emissions were simply computed using a SAF of 365, as summarized in Table 40.

**Table 40: Government Vessels, Average Daily Emissions**

Organization	NOx	CO	HC	PM-10	SO2
Pilot	0.001	0.000	0.000	0.000	0.000
Pilot	0.009	0.001	0.000	0.000	0.001
Pilot	0.066	0.010	0.002	0.002	0.007
USACE	0.005	0.001	0.000	0.000	0.001
USCG	0.003	0.001	0.000	0.000	0.000
USCG	0.001	0.000	0.000	0.000	0.000
USCG	0.001	0.000	0.000	0.000	0.000
USCG	0.001	0.000	0.000	0.000	0.000
USCG	0.001	0.000	0.000	0.000	0.000
	0.085	0.013	0.002	0.003	0.009

As was noted, emissions are dominated by the larger Sabine Pilot boat. In 2003, a new, even more powerful pilot boat was added to the pilot vessel fleet. All government vessels are assumed to travel throughout the local waterway system, and thus would be spatially allocated evenly throughout the area using a surrogate such as ship trips.

---

## DISCUSSION & CONCLUSION

The Texas Commission on Environmental Quality (TCEQ) published average ozone season day numbers for the 1996 Periodic Emissions Inventory. These values, illustrated in Table 41 in tons per day, would be slightly higher in the year 2000.

**Table 41: Previous TCEQ CMV Emissions Baseline, 1996**

<b>County</b>	<b>NOx</b>	<b>CO</b>	<b>HC</b>
Jefferson	5.12	1.91	0.59
Orange	6.30	2.40	0.69
	11.42	4.31	1.28

Note that for some reason, Orange County has a greater share of the emissions, which is not valid, given the robust locational data used in this report. However, on a combined area-wide scale, the numbers are reasonable. Subsequently, the TCEQ modeling section adopted a somewhat lower suite of emission levels, closer to 8 tons of NOx, which is probably too low but can be used to set a lower boundary on CMV emissions.

Results from this paper are between the two estimates, with very little in the way of emissions for Orange County (e.g., less than 0.06 tons per day NOx).

**Table 42: Report Findings, Tons per Average Day, 2000**

	<b>NOx</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Ships	5.45	0.63	0.24	0.42	2.62
Towboats	3.73	0.56	0.10	0.11	0.41
Harbor Vessels	1.57	0.19	0.06	0.07	0.13
	10.75	1.38	0.40	0.61	3.15

Care was taken to seasonally adjust ship as well as assist vessels and fishing boat activity (the latter two being considered harbor vessels). One of the main benefits of this study is that CMV emissions data was spatially allocated not only by county but by waterway segment. This approach has never been applied to the greater Beaumont area, to our knowledge. An appended spreadsheet contains all the technical details as well as a file suitable for ozone modeling inputs.

---

Finally, one can estimate uncertainties in a subjective sense, since there were so many variables in the emission calculations. These items and issues are noted below.

- Emission factor: as noted previously, a few steamships were treated as though they were diesel-powered. The result would be a very small reduction in overall ship emissions.
- Ship load factor: the cubic relationship of power with speed appears to be reasonable, although according to the Sabine Pilot officers, there is considerable boosting and coasting. In other words, the ship might coast for three minutes and use 50% power for the next 15-20 seconds. The ultimate impact of such transient power loads cannot be determined from the available data but would be an interesting topic for future study.
- Harbor vessel load factor: the 31% used for assist vessels appears to be reasonable but those for other vessel types (fishing, government, dredge operation) are less robust, perhaps requiring additional research.
- Dwelling time: since the Pilot data did not specify dockside times it was difficult to accurately characterize auxiliary dwelling emissions. Since dwelling accounted for approximately a third (33%) of the total ship emissions, small adjustments could have a significant impact on overall estimates.
- Seasonal adjustment factor (SAF): the ship data, dominated by petroleum tankers, appears to show a maxima in September which may be related to fuel switching from summer to winter grades of gasoline and diesel. The data on dredges is less than perfect, since their contracts can occur throughout the year.

In conclusion, the Sabine Pilots and a cast of dozens of others who prefer to remain anonymous are recognized for helping to make this a successful effort. A final recommendation would be to refine these emission projections to future years such as 2007 and 2010, which would be necessary for ozone attainment modeling.

---

**APPENDIX A – TRIP AND SUPPORTING DATA**

**Ship Emissions**  
**Tons per Year 2000**

<b>Transit Emissions</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	987.92	105.57	47.45	109.44	538.55
Main Engines - Maneuvering	46.68	9.42	9.12	7.35	9.28
Auxiliary Engines Transit	92.32	10.63	2.66	1.99	28.56
Auxiliary Engines - Maneuvering	20.04	2.31	0.58	0.43	6.20
Auxiliary Boilers Underway	3.88	1.45	0.12	0.41	17.01
	1,150.84	129.37	59.93	119.62	599.60
<b>Dockside Emissions</b>					
Auxiliary Dwelling	429.16	49.40	12.35	9.26	132.76
Auxiliary Tanker Unloading	124.08	14.28	3.57	2.68	38.39
Auxiliary Dockside Boilers	12.12	4.53	0.37	1.28	53.23
	565.37	68.22	16.30	13.22	224.37
<b>Total</b>	1,716.21	197.59	76.22	132.84	823.98

**Tons Per day**

<b>Transit Emissions</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	3.14	0.34	0.15	0.35	1.71
Main Engines - Maneuvering	0.15	0.03	0.03	0.02	0.03
Auxiliary Engines Transit	0.29	0.03	0.01	0.01	0.09
Auxiliary Engines - Maneuvering	0.06	0.01	0.00	0.00	0.02
Auxiliary Boilers Underway	0.01	0.00	0.00	0.00	0.05
	3.65	0.41	0.19	0.38	1.90
<b>Dockside Emissions</b>					
Auxiliary Dwelling	1.36	0.16	0.04	0.03	0.42
Auxiliary Tanker Unloading	0.39	0.05	0.01	0.01	0.12
Auxiliary Dockside Boilers	0.04	0.01	0.00	0.00	0.17
	1.80	0.22	0.05	0.04	0.71
<b>Total</b>	5.45	0.63	0.24	0.42	2.62

<b>Assist Tugs - TPY</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	171.52	20.79	6.50	9.36	12.99
Auxiliary Engines	63.68	7.33	1.83	1.37	5.04
	235.20	28.12	8.33	10.73	18.03

<b>Assist Tugs - TPD</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main Engines - Transit	0.54	0.07	0.02	0.03	0.04
Auxiliary Engines	0.20	0.02	0.01	0.00	0.02
	0.75	0.09	0.03	0.03	0.06

---

**Source Category Code (SCC)**

<b>Category</b>	<b>SCC</b>	<b>Type</b>
Assist Tug	2280002035	Harbor
Bulk	2280003011	Ship
Car Carrier	2280003017	Ship
Containership	2280003013	Ship
Cruise	2280003016	Ship
Dredge	2280002031	Harbor
Fishing	2280002032	Harbor
General Cargo	2280003012	Ship
Government	2280002034	Harbor
LPG	2280003014	Ship
Military	2280003023	Ship
MISC	2280003020	Ship
Reefer	2280003018	Ship
Roro	2280003019	Ship
Tanker	2280003015	Ship
Towboats	2280002033	Harbor
Tug	2280003021	Ship
Unknown	2280003022	Ship

<b>Dredges - TPY</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Dredges	218.50	26.48	8.28	11.92	16.55
Tenders	9.93	1.20	0.38	0.54	0.75
	228.43	27.69	8.65	12.46	17.31

<b>Dredges - TPD</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Dredges	0.60	0.07	0.02	0.03	0.05
Tenders	0.03	0.00	0.00	0.00	0.00
	0.63	0.08	0.02	0.03	0.05

<b>Towboats - TPY</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main	1278.59	191.79	34.52	38.36	140.64
Auxiliary	82.79	12.42	2.24	2.48	9.11
	1361.38	204.21	36.76	40.84	149.75

<b>Towboats - TPD</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Main	3.50	0.53	0.09	0.11	0.39
Auxiliary	0.23	0.03	0.01	0.01	0.02
	3.73	0.56	0.10	0.11	0.41

<b>Fishing - TPY</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Sabine	13.44	2.02	0.36	0.40	1.48
Port Arthur	6.76	1.01	0.18	0.20	0.74
	20.20	3.03	0.55	0.61	2.22

<b>Fishing - TPD</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Sabine	0.07	0.01	0.00	0.00	0.01
Port Arthur	0.04	0.01	0.00	0.00	0.00
	0.11	0.02	0.00	0.00	0.01

<b>Government</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Tons/Year	31.16	4.67	0.84	0.93	3.43
Tons/Day	0.09	0.01	0.00	0.00	0.01

<b>All Vessels - TPY</b>	<b>NOX</b>	<b>CO</b>	<b>HC</b>	<b>PM-10</b>	<b>SO2</b>
Ships	1,716.21	197.59	76.22	132.84	823.98
Towboats	1,361.38	204.21	36.76	40.84	149.75
Harbor Vessels	514.98	63.51	18.37	24.73	40.99
	3,592.57	465.31	131.35	198.42	1,014.72

**Ship Trips  
Master File by Destination**

Category	Segment	Zone	Inbound	Outbound	Shift_In	Shift_Out	Total
Bulk	Sabine Pass	BMT01	1	3	0	0	4
Chemical Tanker	Sabine Pass	BMT01	7	2	0	0	9
Containership	Sabine Pass	BMT01	0	0	0	0	0
General Cargo	Sabine Pass	BMT01	4	1	0	0	5
LPG	Sabine Pass	BMT01	0	0	0	0	0
Misc	Sabine Pass	BMT01	6	5	0	0	11
Military	Sabine Pass	BMT01	0	0	0	0	0
Roro	Sabine Pass	BMT01	0	0	0	0	0
Tanker	Sabine Pass	BMT01	8	1	0	0	9
Tug	Sabine Pass	BMT01	12	19	4	1	36
Unknown	Sabine Pass	BMT01	9	9	2	0	20
Bulk	Port Arthur	BMT02	60	59	3	0	122
Chemical Tanker	Port Arthur	BMT02	42	35	0	3	80
Containership	Port Arthur	BMT02	0	0	0	0	0
General Cargo	Port Arthur	BMT02	73	65	0	2	140
LPG	Port Arthur	BMT02	5	4	0	0	9
Military	Port Arthur	BMT02	0	0	0	0	0
Misc	Port Arthur	BMT02	2	2	0	0	4
Roro	Port Arthur	BMT02	3	3	0	0	6
Tanker	Port Arthur	BMT02	22	22	3	1	48
Tug	Port Arthur	BMT02	8	11	0	6	25
Unknown	Port Arthur	BMT02	5	7	0	0	12
Bulk	N. Port Arthur	BMT03	20	19	1	0	40
Chemical Tanker	N. Port Arthur	BMT03	23	17	0	1	41
Containership	N. Port Arthur	BMT03	0	0	0	0	0
General Cargo	N. Port Arthur	BMT03	1	2	1	1	5
LPG	N. Port Arthur	BMT03	1	1	0	0	2
Military	N. Port Arthur	BMT03	0	0	0	0	0
Misc	N. Port Arthur	BMT03	0	0	0	0	0
Roro	N. Port Arthur	BMT03	0	0	0	0	0
Tanker	N. Port Arthur	BMT03	18	13	0	3	34
Tug	N. Port Arthur	BMT03	17	25	2	1	45
Unknown	N. Port Arthur	BMT03	9	11	0	1	21
Bulk	Fina	BMT04	9	14	4	3	30
Chemical Tanker	Fina	BMT04	47	55	6	20	128
Containership	Fina	BMT04	0	0	0	0	0
General Cargo	Fina	BMT04	3	2	0	1	6
LPG	Fina	BMT04	2	6	3	2	13
Military	Fina	BMT04	0	0	0	0	0
Misc	Fina	BMT04	0	0	0	0	0
Roro	Fina	BMT04	0	0	0	0	0
Tanker	Fina	BMT04	97	144	39	51	331
Tug	Fina	BMT04	19	23	4	10	56
Unknown	Fina	BMT04	1	3	0	0	4
Bulk	Huntsman	BMT05	10	8	0	0	18
Chemical Tanker	Huntsman	BMT05	22	24	2	1	49

Containership	Huntsman	BMT05	1	0	0	0	1
General Cargo	Huntsman	BMT05	1	1	0	0	2
LPG	Huntsman	BMT05	33	33	0	1	67
Military	Huntsman	BMT05	0	0	0	0	0
Misc	Huntsman	BMT05	0	0	0	0	0
Roro	Huntsman	BMT05	0	0	0	0	0
Tanker	Huntsman	BMT05	174	162	0	2	338
Tug	Huntsman	BMT05	5	4	1	1	11
Unknown	Huntsman	BMT05	4	3	1	0	8
Bulk	Smiths Bluff	BMT06	31	25	1	0	57
Chemical Tanker	Smiths Bluff	BMT06	68	64	11	4	147
Containership	Smiths Bluff	BMT06	0	0	0	0	0
General Cargo	Smiths Bluff	BMT06	0	0	0	0	0
LPG	Smiths Bluff	BMT06	2	0	0	0	2
Military	Smiths Bluff	BMT06	0	0	0	0	0
Misc	Smiths Bluff	BMT06	0	0	0	0	0
Roro	Smiths Bluff	BMT06	0	0	0	0	0
Tanker	Smiths Bluff	BMT06	393	377	14	7	791
Tug	Smiths Bluff	BMT06	3	4	2	2	11
Unknown	Smiths Bluff	BMT06	5	6	0	0	11
Bulk	Stanolind	BMT07	12	1	0	0	13
Chemical Tanker	Stanolind	BMT07	32	26	10	2	70
Containership	Stanolind	BMT07	0	0	0	0	0
General Cargo	Stanolind	BMT07	6	4	4	0	14
LPG	Stanolind	BMT07	2	1	2	0	5
Military	Stanolind	BMT07	0	0	0	0	0
Misc	Stanolind	BMT07	0	0	0	0	0
Roro	Stanolind	BMT07	0	0	0	0	0
Tanker	Stanolind	BMT07	78	74	7	4	163
Unknown	Stanolind	BMT07	0	0	0	0	0
Tug	Stanolind	BMT07	26	26	2	2	56
Bulk	Beaumont	BMT08	68	78	18	1	165
Chemical Tanker	Beaumont	BMT08	106	124	19	15	264
Containership	Beaumont	BMT08	1	0	0	0	1
General Cargo	Beaumont	BMT08	64	75	16	6	161
LPG	Beaumont	BMT08	3	4	3	0	10
Military	Beaumont	BMT08	2	2	0	0	4
Misc	Beaumont	BMT08	4	4	3	1	12
Roro	Beaumont	BMT08	4	4	2	0	10
Tanker	Beaumont	BMT08	101	90	9	4	204
Tug	Beaumont	BMT08	32	27	3	0	62
Unknown	Beaumont	BMT08	10	9	5	1	25
Bulk	Orange	BMT09	3	1	0	0	4
Chemical Tanker	Orange	BMT09	0	0	0	0	0
Containership	Orange	BMT09	1	2	1	0	4
General Cargo	Orange	BMT09	1	0	0	0	1
LPG	Orange	BMT09	0	0	0	0	0
Military	Orange	BMT09	4	2	0	0	6
Misc	Orange	BMT09	0	0	0	0	0
Roro	Orange	BMT09	0	0	0	0	0
Tanker	Orange	BMT09	6	4	0	0	10
Tug	Orange	BMT09	1	1	0	0	2
Unknown	Orange	BMT09	15	19	0	1	35
			1868	1872	208	162	4110
				3740			

---

### Trips by Zone

Category	Segment	Zone	Trips
Bulk	Sabine Pass	BMT01	422
Chemical Tanker	Sabine Pass	BMT01	694
Containership	Sabine Pass	BMT01	5
General Cargo	Sabine Pass	BMT01	303
LPG	Sabine Pass	BMT01	97
Military	Sabine Pass	BMT01	10
Misc	Sabine Pass	BMT01	23
Roro	Sabine Pass	BMT01	14
Tanker	Sabine Pass	BMT01	1784
Tug	Sabine Pass	BMT01	263
Unknown	Sabine Pass	BMT01	125
Bulk	Port Arthur	BMT02	418
Chemical Tanker	Port Arthur	BMT02	685
Containership	Port Arthur	BMT02	5
General Cargo	Port Arthur	BMT02	298
LPG	Port Arthur	BMT02	97
Military	Port Arthur	BMT02	10
Misc	Port Arthur	BMT02	12
Roro	Port Arthur	BMT02	14
Tanker	Port Arthur	BMT02	1775
Tug	Port Arthur	BMT02	232
Unknown	Port Arthur	BMT02	107
Bulk	N. Port Arthur	BMT03	299
Chemical Tanker	N. Port Arthur	BMT03	608
Containership	N. Port Arthur	BMT03	5
General Cargo	N. Port Arthur	BMT03	160
LPG	N. Port Arthur	BMT03	88
Military	N. Port Arthur	BMT03	10
Misc	N. Port Arthur	BMT03	8
Roro	N. Port Arthur	BMT03	8
Tanker	N. Port Arthur	BMT03	1731
Tug	N. Port Arthur	BMT03	213
Unknown	N. Port Arthur	BMT03	95
Bulk	Fina	BMT04	260
Chemical Tanker	Fina	BMT04	568
Containership	Fina	BMT04	5
General Cargo	Fina	BMT04	157
LPG	Fina	BMT04	86
Military	Fina	BMT04	10
Misc	Fina	BMT04	8
Roro	Fina	BMT04	8
Tanker	Fina	BMT04	1700
Tug	Fina	BMT04	171
Unknown	Fina	BMT04	75
Bulk	Huntsman	BMT05	233
Chemical Tanker	Huntsman	BMT05	466

---

Containership	Huntsman	BMT05	2
General Cargo	Huntsman	BMT05	151
LPG	Huntsman	BMT05	78
Military	Huntsman	BMT05	4
Misc	Huntsman	BMT05	8
Roro	Huntsman	BMT05	8
Tanker	Huntsman	BMT05	1449
Tug	Smiths Bluff	BMT05	127
Unknown	Huntsman	BMT05	37
Bulk	Smiths Bluff	BMT06	215
Chemical Tanker	Smiths Bluff	BMT06	420
Containership	Smiths Bluff	BMT06	1
General Cargo	Smiths Bluff	BMT06	149
LPG	Smiths Bluff	BMT06	12
Military	Smiths Bluff	BMT06	4
Misc	Smiths Bluff	BMT06	8
Roro	Smiths Bluff	BMT06	8
Tanker	Smiths Bluff	BMT06	1113
Tug	Smiths Bluff	BMT06	118
Unknown	Smiths Bluff	BMT06	30
Bulk	Stanolind	BMT07	159
Chemical Tanker	Stanolind	BMT07	288
Containership	Stanolind	BMT07	1
General Cargo	Stanolind	BMT07	149
LPG	Stanolind	BMT07	10
Military	Stanolind	BMT07	4
Misc	Stanolind	BMT07	8
Roro	Stanolind	BMT07	8
Tanker	Stanolind	BMT07	343
Tug	Stanolind	BMT07	111
Unknown	Stanolind	BMT07	19
Bulk	Beaumont	BMT08	146
Chemical Tanker	Beaumont	BMT08	230
Containership	Beaumont	BMT08	1
General Cargo	Beaumont	BMT08	139
LPG	Beaumont	BMT08	7
Military	Beaumont	BMT08	4
Misc	Beaumont	BMT08	8
Roro	Beaumont	BMT08	8
Tanker	Beaumont	BMT08	191
Tug	Beaumont	BMT08	59
Unknown	Stanolind	BMT08	19
Bulk	Orange	BMT09	4
Chemical Tanker	Orange	BMT09	0
Containership	Orange	BMT09	3
General Cargo	Orange	BMT09	1
LPG	Orange	BMT09	0
Military	Orange	BMT09	6
Misc	Orange	BMT09	0
Roro	Orange	BMT09	0
Tanker	Orange	BMT09	10
Tug	Orange	BMT09	2
Unknown	Orange	BMT09	34

---

---

## GIS Parameters

### Nodes

<b>Zone</b>	<b>Location</b>	<b>LATITUDE</b>	<b>LONGITUDE</b>
BMT00	Sabine Bar Buoy	29.4166667	-93.6666667
BMT01	Sabine Pass	29.7375	-93.8825
BMT02	Port of Port Arthur	29.858889	-93.940278
BMT03	North Port Arthur	29.930278	-93.875278
BMT04	Fina	29.980278	-93.877778
BMT05	Huntsman	29.993611	-93.9425
BMT06	Smith's Bluff	30.01	-93.9925
BMT07	Stanolind	30.031389	-94.033611
BMT08	Municipal Docks Beaumont	30.078056	-94.088056
BMT09	Municipal Docks Orange	30.066944	-93.723056
BMT10	Jefferson County Line	29.6097222	-94.3533333

<b>Trip</b>	<b>Name</b>	<b>Actual</b>	<b>GIS</b>
BMT01	Sabine Bar to Sabine Pass	21.6	22.0
BMT02	Sabine Pass to Port Arthur	11.0	7.8
BMT03	Port Arthur to N. Port Arthur	4.2	5.4
BMT04	N. Port Arthur to Fina	4.9	3.0
BMT05	Fina to Huntsman	3.1	3.3
BMT06	Huntsman to Smith's Bluff	2.8	2.7
BMT07	Smith's Bluff to Stanolind	4.3	2.4
BMT08	Stanolind to Beaumont	4.2	3.9
BMT09	Fina to Orange	10.2	9.3
BMT10	Jefferson County Line to Port Arthur	25.5	25.5
		91.8	85.3

### Ship Transit Times

<b>Location</b>	<b>Zone</b>	<b>Hours</b>
Sabine Pass	BMT01	1.96
Port Arthur	BMT02	1.69
N. Port Arthur	BMT03	0.65
Fina	BMT04	0.75
Huntsman	BMT05	0.48
Smiths Bluff	BMT06	0.43
Stanolind	BMT07	0.66
Beaumont	BMT08	0.65
Orange	BMT09	1.57

---

### Ship HP Estimates

<u>Category</u>	<u>Kw</u>
Bulk	8,321
Chemical Tanker	7,738
Containership	7,302
General Cargo	7,207
LPG	7,709
Misc	7,355
Roro	5,291
Tanker	10,151
Tug	4,300
Unknown	7,634

### Ship Load Factors

<u>Category</u>	<u>Size</u>	<u>Speed</u>	<u>Twelve</u>	<u>Six Half</u>	<u>Three</u>
Bulk	Average	14.47	57.00%	9.06%	3.00%
Chemical Tanker	Small	14.79	53.47%	8.50%	3.00%
Containership	Small	17.77	30.81%	4.90%	3.00%
General Cargo	Small	14.96	51.66%	8.21%	3.00%
LPG	Small	16.12	41.29%	6.56%	3.00%
Military	Small	15.20	49.21%	7.82%	3.00%
Misc	Small	16.00	42.19%	6.70%	3.00%
Roro	Small	16.00	42.19%	6.70%	3.00%
Tanker	Average	14.47	57.01%	9.06%	3.00%
Tug	Small	13.00	78.65%	12.50%	3.00%
Unknown	Small	15.20	49.21%	7.82%	3.00%

### Ship Auxiliary Power

<u>Category</u>	<u>Number</u>	<u>AuxkW</u>
Bulk	2.99	506
Chemical Tanker	3.07	655
Containership	3.00	303
General Cargo	3.27	531
LPG	3.66	725
Misc	5.00	386
Roro	3.00	697
Tanker	3.00	598
Tug	2.00	125
Unknown	3.37	550

Category	SCC	Process	Segment	Zone	County	FIPS	NOX	CO	HC	PM-10	SO2
Bulk	2280003011	Transit	Sabine Pass	BMT01	Jefferson	48245	0.259773	0.02338053	0.008587916	0.026697125	0.149574493
Chemical Tanker	2280003017	Transit	Sabine Pass	BMT01	Jefferson	48245	0.37998	0.034416818	0.012545776	0.038474086	0.217206296
Containership	2280003013	Transit	Sabine Pass	BMT01	Jefferson	48245	0.001477	0.000133985	4.86258E-05	0.000150538	0.000857234
General Cargo	2280003012	Transit	Sabine Pass	BMT01	Jefferson	48245	0.148536	0.013446406	0.004913551	0.015108655	0.085237922
LPG	2280003014	Transit	Sabine Pass	BMT01	Jefferson	48245	0.04186	0.003819322	0.001372716	0.004156609	0.023764678
Military	2280003023	Transit	Sabine Pass	BMT01	Jefferson	48245	0.00565	0.000558811	0.000242039	0.000569705	0.003047247
Misc	2280003020	Transit	Sabine Pass	BMT01	Jefferson	48245	0.009324	0.000842515	0.000307186	0.000953268	0.005386936
Roro	2280003019	Transit	Sabine Pass	BMT01	Jefferson	48245	0.004367	0.00040274	0.000142708	0.000423928	0.002463856
Tanker	2280003015	Transit	Sabine Pass	BMT01	Jefferson	48245	1.337392	0.120170658	0.044167307	0.137565366	0.769040724
Tug	2280003021	Transit	Sabine Pass	BMT01	Jefferson	48245	0.112965	0.010104144	0.003841819	0.01187299	0.064828043
Unknown	2280003022	Transit	Sabine Pass	BMT01	Jefferson	48245	0.06276	0.005755672	0.002167546	0.00638703	0.035728652
Bulk	2280003011	Transit	Port Arthur	BMT02	Jefferson	48245	0.058061	0.008843467	0.004846455	0.006219138	0.025532061
Chemical Tanker	2280003017	Transit	Port Arthur	BMT02	Jefferson	48245	0.084621	0.012538719	0.006397422	0.008458093	0.037551907
Containership	2280003013	Transit	Port Arthur	BMT02	Jefferson	48245	0.000311	4.6525E-05	2.29792E-05	3.18143E-05	0.000150446
General Cargo	2280003012	Transit	Port Arthur	BMT02	Jefferson	48245	0.037145	0.005666359	0.003151998	0.003837229	0.015881146
LPG	2280003014	Transit	Port Arthur	BMT02	Jefferson	48245	0.010153	0.001479529	0.000725238	0.000944459	0.004462699
Military	2280003023	Transit	Port Arthur	BMT02	Jefferson	48245	0.001131	0.00016468	7.98226E-05	0.00010851	0.000507113
Misc	2280003020	Transit	Port Arthur	BMT02	Jefferson	48245	0.001176	0.000180805	0.000100666	0.000124868	0.000519379
Roro	2280003019	Transit	Port Arthur	BMT02	Jefferson	48245	0.001341	0.000196287	9.95899E-05	0.000116828	0.000561236
Tanker	2280003015	Transit	Port Arthur	BMT02	Jefferson	48245	0.271048	0.04051598	0.020942165	0.028832809	0.122856365
Tug	2280003021	Transit	Port Arthur	BMT02	Jefferson	48245	0.018752	0.002863182	0.001592017	0.002189551	0.00823848
Unknown	2280003022	Transit	Port Arthur	BMT02	Jefferson	48245	0.011808	0.001759837	0.00090445	0.001198388	0.005301983
Bulk	2280003011	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.016184	0.002473641	0.001371596	0.001737233	0.007059657
Chemical Tanker	2280003017	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.029379	0.004370347	0.002262796	0.002942757	0.012916718
Containership	2280003013	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.000119	1.77641E-05	8.77387E-06	1.21473E-05	5.74431E-05
General Cargo	2280003012	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.006551	0.000974971	0.000497075	0.000666372	0.002965994
LPG	2280003014	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.003458	0.000502541	0.00024356	0.000320987	0.001529883
Military	2280003023	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.000432	6.28777E-05	3.04777E-05	4.14313E-05	0.000193625
Misc	2280003020	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.000257	3.83423E-05	1.92123E-05	2.66059E-05	0.000120884
Roro	2280003019	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.000238	3.3939E-05	1.53616E-05	2.03601E-05	0.000106687
Tanker	2280003015	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.101877	0.01525658	0.007938809	0.010849567	0.04599158
Tug	2280003021	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.007346	0.00114881	0.000688351	0.000872237	0.003055142
Unknown	2280003022	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.004802	0.000737028	0.000419263	0.000497105	0.002013052
Bulk	2280003011	Transit	Fina	BMT04	Jefferson	48245	0.015902	0.002417111	0.001315544	0.001701161	0.007025165
Chemical Tanker	2280003017	Transit	Fina	BMT04	Jefferson	48245	0.03623	0.005489126	0.003034465	0.0036652	0.015220485
Containership	2280003013	Transit	Fina	BMT04	Jefferson	48245	0.000139	2.07248E-05	1.02362E-05	1.41718E-05	6.7017E-05
General Cargo	2280003012	Transit	Fina	BMT04	Jefferson	48245	0.007511	0.001118312	0.000570784	0.000764258	0.003398819
LPG	2280003014	Transit	Fina	BMT04	Jefferson	48245	0.004504	0.000668466	0.000351143	0.000425123	0.001897384
Military	2280003023	Transit	Fina	BMT04	Jefferson	48245	0.000504	7.33573E-05	3.55573E-05	4.83365E-05	0.000225896
Misc	2280003020	Transit	Fina	BMT04	Jefferson	48245	0.0003	4.47327E-05	2.24144E-05	3.10403E-05	0.000141032
Roro	2280003019	Transit	Fina	BMT04	Jefferson	48245	0.000278	3.95955E-05	1.79219E-05	2.37535E-05	0.000124468
Tanker	2280003015	Transit	Fina	BMT04	Jefferson	48245	0.133962	0.020564846	0.011648038	0.014487821	0.057143401
Tug	2280003021	Transit	Fina	BMT04	Jefferson	48245	0.007175	0.001131476	0.000694522	0.000856976	0.002925404
Unknown	2280003022	Transit	Fina	BMT04	Jefferson	48245	0.003699	0.000551582	0.000284085	0.000375537	0.001658687
Bulk	2280003011	Transit	Huntsman	BMT05	Jefferson	48245	0.009064	0.001379048	0.000752969	0.00097022	0.003995768
Chemical Tanker	2280003017	Transit	Huntsman	BMT05	Jefferson	48245	0.017924	0.002697175	0.00145609	0.001806568	0.007660981
Containership	2280003013	Transit	Huntsman	BMT05	Jefferson	48245	7.41E-05	1.24823E-05	8.77921E-06	8.5888E-06	2.73323E-05
General Cargo	2280003012	Transit	Huntsman	BMT05	Jefferson	48245	0.004496	0.000667464	0.000336923	0.000456655	0.002047919
LPG	2280003014	Transit	Huntsman	BMT05	Jefferson	48245	0.005699	0.000913965	0.000609439	0.000572472	0.001939005
Military	2280003023	Transit	Huntsman	BMT05	Jefferson	48245	0.000127	1.85639E-05	8.99818E-06	1.22321E-05	5.71655E-05
Misc	2280003020	Transit	Huntsman	BMT05	Jefferson	48245	0.00019	2.83002E-05	1.41805E-05	1.96377E-05	8.92241E-05

Category	SCC	Process	Segment	Zone	County	FIPS	NOX	CO	HC	PM-10	SO2
Roro	2280003019	Transit	Huntsman	BMT05	Jefferson	48245	0.000176	2.50502E-05	1.13383E-05	1.50277E-05	7.87449E-05
Tanker	2280003015	Transit	Huntsman	BMT05	Jefferson	48245	0.081651	0.012774048	0.007674979	0.008935796	0.033243374
Tug	2280003021	Transit	Smiths Bluff	BMT05	Jefferson	48245	0.003045	0.000470315	0.000271283	0.000358423	0.001303911
Unknown	2280003022	Transit	Huntsman	BMT05	Jefferson	48245	0.001473	0.000228157	0.000133587	0.000153436	0.000603697
Bulk	2280003011	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.009606	0.001516084	0.000928979	0.001051767	0.003873338
Chemical Tanker	2280003017	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.020002	0.003128833	0.001915871	0.002059296	0.007705248
Containership	2280003013	Transit	Smiths Bluff	BMT06	Jefferson	48245	1.58E-05	2.36854E-06	1.16985E-06	1.61964E-06	7.65909E-06
General Cargo	2280003012	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.003927	0.000580848	0.000289073	0.000397954	0.001803446
LPG	2280003014	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.00041	6.18823E-05	3.45994E-05	3.9213E-05	0.000165045
Military	2280003023	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.000115	1.67674E-05	8.12739E-06	1.10483E-05	5.16334E-05
Misc	2280003020	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.000171	2.55615E-05	1.28082E-05	1.77373E-05	8.05895E-05
Roro	2280003019	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.000159	2.2626E-05	1.02411E-05	1.35734E-05	7.11244E-05
Tanker	2280003015	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.089486	0.014739606	0.010187637	0.010118584	0.031538526
Tug	2280003021	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.002593	0.00040178	0.000234023	0.000305904	0.001102423
Unknown	2280003022	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.001322	0.000209735	0.000132039	0.000139955	0.000507608
Bulk	2280003011	Transit	Stanolind	BMT07	Jefferson	48245	0.008382	0.001270092	0.000683749	0.000894994	0.003730017
Chemical Tanker	2280003017	Transit	Stanolind	BMT07	Jefferson	48245	0.01678	0.002556071	0.001439176	0.001702544	0.00695132
Containership	2280003013	Transit	Stanolind	BMT07	Jefferson	48245	2.43E-05	3.63741E-06	1.79656E-06	2.4873E-06	1.17622E-05
General Cargo	2280003012	Transit	Stanolind	BMT07	Jefferson	48245	0.00666	0.001002272	0.000532005	0.000682188	0.002940699
LPG	2280003014	Transit	Stanolind	BMT07	Jefferson	48245	0.000652	0.000100935	6.10003E-05	6.36495E-05	0.00024607
Military	2280003023	Transit	Stanolind	BMT07	Jefferson	48245	0.000177	2.57499E-05	1.24814E-05	1.69671E-05	7.92941E-05
Misc	2280003020	Transit	Stanolind	BMT07	Jefferson	48245	0.000263	3.92552E-05	1.96698E-05	2.72394E-05	0.000123762
Roro	2280003019	Transit	Stanolind	BMT07	Jefferson	48245	0.000244	3.47471E-05	1.57273E-05	2.08449E-05	0.000109227
Tanker	2280003015	Transit	Stanolind	BMT07	Jefferson	48245	0.029879	0.004743685	0.002974609	0.003300374	0.011707534
Tug	2280003021	Transit	Stanolind	BMT07	Jefferson	48245	0.003408	0.000516774	0.000280945	0.000396002	0.001519272
Unknown	2280003022	Transit	Stanolind	BMT07	Jefferson	48245	0.003424	0.000579758	0.000429834	0.000379202	0.00107079
Bulk	2280003011	Transit	Beaumont	BMT08	Jefferson	48245	0.01501	0.002478068	0.001713765	0.001690437	0.005328224
Chemical Tanker	2280003017	Transit	Beaumont	BMT08	Jefferson	48245	0.023666	0.003818113	0.002550745	0.0024788	0.008293554
Containership	2280003013	Transit	Beaumont	BMT08	Jefferson	48245	6.28E-05	1.07905E-05	7.9436E-06	7.43192E-06	2.18615E-05
General Cargo	2280003012	Transit	Beaumont	BMT08	Jefferson	48245	0.012726	0.002080737	0.001417323	0.001373886	0.004491151
LPG	2280003014	Transit	Beaumont	BMT08	Jefferson	48245	0.00079	0.000127639	8.68008E-05	7.98336E-05	0.000262231
Military	2280003023	Transit	Beaumont	BMT08	Jefferson	48245	0.000382	6.07838E-05	3.95978E-05	3.86439E-05	0.000134573
Misc	2280003020	Transit	Beaumont	BMT08	Jefferson	48245	0.000756	0.000128866	9.47797E-05	8.76401E-05	0.000254314
Roro	2280003019	Transit	Beaumont	BMT08	Jefferson	48245	0.000653	0.000101828	6.39992E-05	5.95448E-05	0.000227113
Tanker	2280003015	Transit	Beaumont	BMT08	Jefferson	48245	0.023058	0.003798242	0.002625804	0.002607373	0.008124298
Tug	2280003021	Transit	Beaumont	BMT08	Jefferson	48245	0.00309	0.000516603	0.000368752	0.000384722	0.001074761
Unknown	2280003022	Transit	Stanolind	BMT08	Jefferson	48245	0.001943	0.000319938	0.000222245	0.000211031	0.000667576
Bulk	2280003011	Transit	Orange	BMT09	Orange	48361	0.000658	0.000103946	6.39431E-05	7.20749E-05	0.000264282
Chemical Tanker	2280003017	Transit	Orange	BMT09	Orange	48361	0	0	0	0	0
Containership	2280003013	Transit	Orange	BMT09	Orange	48361	0.000329	5.48356E-05	3.75401E-05	3.77102E-05	0.000125194
General Cargo	2280003012	Transit	Orange	BMT09	Orange	48361	0.000141	2.20764E-05	1.33582E-05	1.48041E-05	5.63149E-05
LPG	2280003014	Transit	Orange	BMT09	Orange	48361	0	0	0	0	0
Military	2280003023	Transit	Orange	BMT09	Orange	48361	0.000943	0.000145071	8.55205E-05	9.34783E-05	0.000367824
Misc	2280003020	Transit	Orange	BMT09	Orange	48361	0	0	0	0	0
Roro	2280003019	Transit	Orange	BMT09	Orange	48361	0	0	0	0	0
Tanker	2280003015	Transit	Orange	BMT09	Orange	48361	0.001991	0.00031462	0.000194595	0.000219282	0.00079028
Tug	2280003021	Transit	Orange	BMT09	Orange	48361	0.000188	3.00971E-05	1.91978E-05	2.27037E-05	7.41601E-05
Unknown	2280003022	Transit	Orange	BMT09	Orange	48361	0.004965	0.000779522	0.00047584	0.000521934	0.001963031

Category	SCC	Process	Segment	Zone	County	FIPS	NOX	CO	HC	PM-10	SO2
Assist Tug	2280002035	Transit	Sabine Pass	BMT01	Jefferson	48245	0.010758	0.001286249	0.000380998	0.000490803	0.00082486
Assist Tug	2280002035	Transit	Port Arthur	BMT02	Jefferson	48245	0.080446	0.009618069	0.002848957	0.003670035	0.006167983
Assist Tug	2280002035	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.029545	0.003532385	0.001046324	0.001347877	0.002265287
Assist Tug	2280002035	Transit	Fina	BMT04	Jefferson	48245	0.102765	0.012286555	0.003639386	0.004688268	0.00787926
Assist Tug	2280002035	Transit	Huntsman	BMT05	Jefferson	48245	0.085424	0.010213199	0.00302524	0.003897123	0.006549634
Assist Tug	2280002035	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.185459	0.022173393	0.006567955	0.008460859	0.014219601
Assist Tug	2280002035	Transit	Stanolind	BMT07	Jefferson	48245	0.062783	0.007506317	0.002223438	0.002864239	0.004813735
Assist Tug	2280002035	Transit	Beaumont	BMT08	Jefferson	48245	0.179839	0.021501472	0.006368926	0.008204469	0.013788704
Assist Tug	2280002035	Transit	Orange	BMT09	Orange	48361	0.009634	0.001151865	0.000341192	0.000439525	0.000738681
Dredge	2280002031	Transit	Huntsman	BMT05	Jefferson	48245	0.091403	0.011079152	0.003462235	0.004985618	0.00692447
Dredge	2280002031	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.069186	0.008386221	0.002620694	0.0037738	0.005241388
Dredge	2280002031	Transit	Sabine Pass	BMT01	Jefferson	48245	0.229629	0.027833867	0.008698083	0.01252524	0.017396167
Dredge	2280002031	Transit	Sabine Pass	BMT01	Jefferson	48245	0.157978	0.019148863	0.00598402	0.008616989	0.01196804
Dredge	2280002031	Transit	Port Arthur	BMT02	Jefferson	48245	0.07763	0.009409691	0.002940528	0.004234361	0.005881057
Towboats	2280002033	Transit	Sabine Pass	BMT01	Jefferson	48245	0	0	0	0	0
Towboats	2280002033	Transit	Port Arthur	BMT02	Jefferson	48245	0.023395	0.003509226	0.000631661	0.000701845	0.002573432
Towboats	2280002033	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.651356	0.097703401	0.017586612	0.01954068	0.071649161
Towboats	2280002033	Transit	Fina	BMT04	Jefferson	48245	0.36493	0.054739508	0.009853111	0.010947902	0.040142306
Towboats	2280002033	Transit	Huntsman	BMT05	Jefferson	48245	0.202027	0.030304042	0.005454727	0.006060808	0.022222964
Towboats	2280002033	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.130542	0.019581328	0.003524639	0.003916266	0.014359641
Towboats	2280002033	Transit	Stanolind	BMT07	Jefferson	48245	0.074196	0.011129472	0.002003305	0.002225894	0.008161613
Towboats	2280002033	Transit	Beaumont	BMT08	Jefferson	48245	0.031614	0.004742032	0.000853566	0.000948406	0.00347749
Towboats	2280002033	Transit	Orange	BMT09	Orange	48361	0.040136	0.006020357	0.001083664	0.001204071	0.004414928
Towboats	2280002033	Transit	ICWW	BMT10	Jefferson	48245	2.211611	0.33174165	0.059713497	0.06634833	0.24327721
Fishing	2280002032	Transit	Sabine Pass	BMT01	Jefferson	48245	0.074653	0.011197917	0.002015625	0.002239583	0.008211806
Fishing	2280002032	Transit	N. Port Arthur	BMT02	Jefferson	48245	0.037557	0.00563352	0.001014034	0.001126704	0.004131248
Government	2280002034	Transit	Sabine Pass	BMT01	Jefferson	48245	0.002148	0.000322194	5.79949E-05	6.44388E-05	0.000236275
Government	2280002034	Transit	Port Arthur	BMT02	Jefferson	48245	0.010054	0.001508141	0.000271465	0.000301628	0.00110597
Government	2280002034	Transit	N. Port Arthur	BMT03	Jefferson	48245	0.004067	0.000610112	0.00010982	0.000122022	0.000447415
Government	2280002034	Transit	Fina	BMT04	Jefferson	48245	0.008135	0.001220224	0.00021964	0.000244045	0.000894831
Government	2280002034	Transit	Huntsman	BMT05	Jefferson	48245	0.011425	0.001713797	0.000308483	0.000342759	0.001256785
Government	2280002034	Transit	Smiths Bluff	BMT06	Jefferson	48245	0.022942	0.003441305	0.000619435	0.000688261	0.002523623
Government	2280002034	Transit	Stanolind	BMT07	Jefferson	48245	0.007129	0.001069409	0.000192494	0.000213882	0.000784234
Government	2280002034	Transit	Beaumont	BMT08	Jefferson	48245	0.018052	0.002070779	0.000487404	0.00054156	0.00198572
Government	2280002034	Transit	Orange	BMT09	Orange	48361	0.001417	0.000212511	3.8252E-05	4.25022E-05	0.000155841
Bulk	2280003011	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.000562	6.94153E-05	1.62087E-05	1.3666E-05	0.000248478
Chemical Tanker	2280003017	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.005056	0.000615185	0.00014578	0.000119902	0.002086779
Containership	2280003013	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0	0	0	0	0
General Cargo	2280003012	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.002356	0.000290128	6.79513E-05	5.70016E-05	0.001027415
LPG	2280003014	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0	0	0	0	0
Military	2280003023	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.004786	0.000579299	0.000137954	0.000112523	0.001928411
Misc	2280003020	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0	0	0	0	0
Roro	2280003019	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0	0	0	0	0
Tanker	2280003015	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.00832	0.000995571	0.000239731	0.000191875	0.00317099
Tug	2280003021	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.002284	0.000262941	6.57351E-05	4.93014E-05	0.000706653
Unknown	2280003022	Dwelling	Sabine Pass	BMT01	Jefferson	48245	0.006706	0.00082397	0.000193396	0.000161652	0.002895586
Bulk	2280003011	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.0354	0.004373165	0.001021146	0.00086096	0.015654102
Chemical Tanker	2280003017	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.032506	0.003954762	0.000937158	0.000770798	0.01341501
Containership	2280003013	Dwelling	Port Arthur	BMT02	Jefferson	48245	0	0	0	0	0
General Cargo	2280003012	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.044174	0.005439899	0.001274088	0.00106878	0.019264039
LPG	2280003014	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.003988	0.000482749	0.000114961	9.37688E-05	0.001607009

Category	SCC	Process	Segment	Zone	County	FIPS	NOX	CO	HC	PM-10	SO2
Military	2280003023	Dwelling	Port Arthur	BMT02	Jefferson	48245	0	0	0	0	0
Misc	2280003020	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.000866	0.000109207	2.50115E-05	2.17777E-05	0.000417343
Roro	2280003019	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.002302	0.000279133	6.63479E-05	5.42895E-05	0.000935943
Tanker	2280003015	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.02704	0.003235605	0.000779127	0.000623593	0.010305717
Tug	2280003021	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.001881	0.000216539	5.41348E-05	4.06011E-05	0.000581949
Unknown	2280003022	Dwelling	Port Arthur	BMT02	Jefferson	48245	0.003048	0.000374532	8.79072E-05	7.3478E-05	0.001316175
Bulk	2280003011	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.0118	0.001457722	0.000340382	0.000286987	0.005218034
Chemical Tanker	2280003017	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.017336	0.002109207	0.000499818	0.000411092	0.007154672
Containership	2280003013	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0	0	0	0	0
General Cargo	2280003012	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.001767	0.000217596	5.09635E-05	4.27512E-05	0.000770562
LPG	2280003014	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.000798	9.65498E-05	2.29923E-05	1.87538E-05	0.000321402
Military	2280003023	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0	0	0	0	0
Misc	2280003020	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0	0	0	0	0
Roro	2280003019	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0	0	0	0	0
Tanker	2280003015	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.02184	0.002613373	0.000629295	0.000503671	0.008323848
Tug	2280003021	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.002687	0.000309342	7.73355E-05	5.80016E-05	0.000831356
Unknown	2280003022	Dwelling	N. Port Arthur	BMT03	Jefferson	48245	0.006096	0.000749064	0.000175814	0.000146956	0.002632351
Bulk	2280003011	Dwelling	Fina	BMT04	Jefferson	48245	0.00899	0.001110645	0.000259339	0.000218657	0.003975645
Chemical Tanker	2280003017	Dwelling	Fina	BMT04	Jefferson	48245	0.052731	0.006415503	0.001520279	0.001250405	0.021762127
Containership	2280003013	Dwelling	Fina	BMT04	Jefferson	48245	0	0	0	0	0
General Cargo	2280003012	Dwelling	Fina	BMT04	Jefferson	48245	0.002356	0.000290128	6.79513E-05	5.70016E-05	0.001027415
LPG	2280003014	Dwelling	Fina	BMT04	Jefferson	48245	0.005583	0.000675849	0.000160946	0.000131276	0.002249813
Military	2280003023	Dwelling	Fina	BMT04	Jefferson	48245	0	0	0	0	0
Misc	2280003020	Dwelling	Fina	BMT04	Jefferson	48245	0	0	0	0	0
Roro	2280003019	Dwelling	Fina	BMT04	Jefferson	48245	0	0	0	0	0
Tanker	2280003015	Dwelling	Fina	BMT04	Jefferson	48245	0.194478	0.023271468	0.005603722	0.004485074	0.074121886
Tug	2280003021	Dwelling	Fina	BMT04	Jefferson	48245	0.004434	0.000510414	0.000127604	9.57026E-05	0.001371738
Unknown	2280003022	Dwelling	Fina	BMT04	Jefferson	48245	0.00061	7.49064E-05	1.75814E-05	1.46956E-05	0.000263235
Bulk	2280003011	Dwelling	Huntsman	BMT05	Jefferson	48245	0.005619	0.000694153	0.000162087	0.00013666	0.002484778
Chemical Tanker	2280003017	Dwelling	Huntsman	BMT05	Jefferson	48245	0.018059	0.00219709	0.000520644	0.000428221	0.007452783
Containership	2280003013	Dwelling	Huntsman	BMT05	Jefferson	48245	0.000344	4.43334E-05	9.9382E-06	8.96318E-06	0.00018107
General Cargo	2280003012	Dwelling	Huntsman	BMT05	Jefferson	48245	0.000589	7.2532E-05	1.69878E-05	1.42504E-05	0.000256854
LPG	2280003014	Dwelling	Huntsman	BMT05	Jefferson	48245	0.02712	0.003282694	0.000781738	0.000637628	0.010927662
Military	2280003023	Dwelling	Huntsman	BMT05	Jefferson	48245	0	0	0	0	0
Misc	2280003020	Dwelling	Huntsman	BMT05	Jefferson	48245	0	0	0	0	0
Roro	2280003019	Dwelling	Huntsman	BMT05	Jefferson	48245	0	0	0	0	0
Tanker	2280003015	Dwelling	Huntsman	BMT05	Jefferson	48245	0.183038	0.021902559	0.005274092	0.004221246	0.069761775
Tug	2280003021	Dwelling	Huntsman	BMT05	Jefferson	48245	0.000941	0.00010827	2.70674E-05	2.03006E-05	0.000290975
Unknown	2280003022	Dwelling	Huntsman	BMT05	Jefferson	48245	0.003048	0.000374532	8.79072E-05	7.3478E-05	0.001316175
Bulk	2280003011	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0.017981	0.00222129	0.000518677	0.000437313	0.00795129
Chemical Tanker	2280003017	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0.059955	0.007294339	0.001728537	0.001421693	0.024743241
Containership	2280003013	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0	0	0	0	0
General Cargo	2280003012	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0	0	0	0	0
LPG	2280003014	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0.001595	0.0001931	4.59846E-05	3.75075E-05	0.000642804
Military	2280003023	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0	0	0	0	0
Misc	2280003020	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0	0	0	0	0
Roro	2280003019	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0	0	0	0	0
Tanker	2280003015	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0.430555	0.051520791	0.012406102	0.009929521	0.16409872
Tug	2280003021	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0.000941	0.00010827	2.70674E-05	2.03006E-05	0.000290975
Unknown	2280003022	Dwelling	Smiths Bluff	BMT06	Jefferson	48245	0.003048	0.000374532	8.79072E-05	7.3478E-05	0.001316175
Bulk	2280003011	Dwelling	Stanolind	BMT07	Jefferson	48245	0.006743	0.000832984	0.000194504	0.000163992	0.002981734

Category	SCC	Process	Segment	Zone	County	FIPS	NOX	CO	HC	PM-10	SO2
Chemical Tanker	2280003017	Dwelling	Stanolind	BMT07	Jefferson	48245	0.031783	0.003866879	0.000916333	0.000753669	0.013116899
Containership	2280003013	Dwelling	Stanolind	BMT07	Jefferson	48245	0	0	0	0	0
General Cargo	2280003012	Dwelling	Stanolind	BMT07	Jefferson	48245	0.00589	0.00072532	0.000169878	0.000142504	0.002568539
LPG	2280003014	Dwelling	Stanolind	BMT07	Jefferson	48245	0.003191	0.000386199	9.19692E-05	7.5015E-05	0.001285607
Military	2280003023	Dwelling	Stanolind	BMT07	Jefferson	48245	0	0	0	0	0
Misc	2280003020	Dwelling	Stanolind	BMT07	Jefferson	48245	0	0	0	0	0
Roro	2280003019	Dwelling	Stanolind	BMT07	Jefferson	48245	0	0	0	0	0
Tanker	2280003015	Dwelling	Stanolind	BMT07	Jefferson	48245	0.092559	0.011075726	0.002667012	0.002134607	0.035277261
Tug	2280003021	Dwelling	Stanolind	BMT07	Jefferson	48245	0	0	0	0	0
Unknown	2280003022	Dwelling	Stanolind	BMT07	Jefferson	48245	0.018288	0.002247192	0.000527443	0.000440868	0.007897052
Bulk	2280003011	Dwelling	Beaumont	BMT08	Jefferson	48245	0.048886	0.006039133	0.001410154	0.001188945	0.02161757
Chemical Tanker	2280003017	Dwelling	Beaumont	BMT08	Jefferson	48245	0.101129	0.012303705	0.002915604	0.002398037	0.041735586
Containership	2280003013	Dwelling	Beaumont	BMT08	Jefferson	48245	0.000344	4.43334E-05	9.9382E-06	8.96318E-06	0.00018107
General Cargo	2280003012	Dwelling	Beaumont	BMT08	Jefferson	48245	0.050652	0.006237751	0.001460954	0.001225535	0.022089431
LPG	2280003014	Dwelling	Beaumont	BMT08	Jefferson	48245	0.004786	0.000579299	0.000137954	0.000112523	0.001928411
Military	2280003023	Dwelling	Beaumont	BMT08	Jefferson	48245	0.001595	0.0001931	4.59846E-05	3.75075E-05	0.000642804
Misc	2280003020	Dwelling	Beaumont	BMT08	Jefferson	48245	0.003466	0.000436829	0.000100046	8.71107E-05	0.00166937
Roro	2280003019	Dwelling	Beaumont	BMT08	Jefferson	48245	0.004603	0.000558267	0.000132696	0.000108579	0.001871887
Tanker	2280003015	Dwelling	Beaumont	BMT08	Jefferson	48245	0.118559	0.014186885	0.003416173	0.002734216	0.045186604
Tug	2280003021	Dwelling	Beaumont	BMT08	Jefferson	48245	0.004703	0.000541348	0.000135337	0.000101503	0.001454873
Unknown	2280003022	Dwelling	Stanolind	BMT08	Jefferson	48245	0.009754	0.001198502	0.000281303	0.00023513	0.004211761
Bulk	2280003011	Dwelling	Orange	BMT09	Orange	48361	0.001686	0.000208246	4.8626E-05	4.09981E-05	0.000745433
Chemical Tanker	2280003017	Dwelling	Orange	BMT09	Orange	48361	0	0	0	0	0
Containership	2280003013	Dwelling	Orange	BMT09	Orange	48361	0.000688	8.86669E-05	1.98764E-05	1.79264E-05	0.000362141
General Cargo	2280003012	Dwelling	Orange	BMT09	Orange	48361	0.000589	7.2532E-05	1.69878E-05	1.42504E-05	0.000256854
LPG	2280003014	Dwelling	Orange	BMT09	Orange	48361	0	0	0	0	0
Military	2280003023	Dwelling	Orange	BMT09	Orange	48361	0.003191	0.000386199	9.19692E-05	7.5015E-05	0.001285607
Misc	2280003020	Dwelling	Orange	BMT09	Orange	48361	0	0	0	0	0
Roro	2280003019	Dwelling	Orange	BMT09	Orange	48361	0	0	0	0	0
Tanker	2280003015	Dwelling	Orange	BMT09	Orange	48361	0.00624	0.000746678	0.000179799	0.000143906	0.002378242
Tug	2280003021	Dwelling	Orange	BMT09	Orange	48361	0.000134	1.54671E-05	3.86677E-06	2.90008E-06	4.15678E-05
Unknown	2280003022	Dwelling	Orange	BMT09	Orange	48361	0.009754	0.001198502	0.000281303	0.00023513	0.004211761