SF Bay Area Seaports Air Emissions Inventory

Port of San Francisco 2005 Emissions Inventory

Prepared for: Bay Planning Coalition

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ENVIRON

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LIST OF ABBREVIATIONS

BAAQMD – Bay Area Air Quality Management District
BPC – Bay Planning Coalition
BSFC – Brake specific fuel consumption
CARB – California Air Resources Board
CHE – Cargo handling equipment
CO – Carbon monoxide
DWT – Dead weight tonnage
HC – Harbor craft
HC – hydrocarbons
HDV – Heavy duty vehicles
HHDT – Heavy heavy duty vehicles
LOA – Length overall
LPG – Liquid petroleum gas
M&N – Moffatt & Nichol
NOx – Nitrogen oxides
OGV – Ocean going vessels
PM – Particulate matter
POSF – Port of San Francisco
RL – Rail locomotives
ROG – Reactive organic gases
RSZ – Reduced speed zone
SF – San Francisco
SO2 – Sulfur dioxide
SOx – Sulfur oxides
TRU – Transportation refrigeration unit
VMT – Vehicle miles traveled

GLOSSARY OF TERMS

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

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

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

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

Barge: A flat-bottomed craft built mainly for water transport of heavy goods. Most barges are not self-propelled and need to be moved by tugboats or towboats.

Berth: A location in the water, usually alongside a wharf, in a port or harbor used specifically for mooring vessels.

Bollard pull class: A power measure of the tug's capacity to push or pull ships.

Brake-specific fuel consumption (BSFC): This is the measure of the engines efficiency in terms of the fuel consumption rate (weight of fuel burned per hour) divided by the engine load or output (e.g. kilowatts). For marine engines a different term, standard fuel oil consumption (SFOC), is sometimes used to describe the identical efficiency measure.

Cargo handling equipment: Equipment used or bulk materials transfer cargo or containers. Cargo handling equipment is used to move containers or bulk materials from one mode of transportation to another. Typical cargo handling equipment found at ports include yard trucks, rubber-tired gantry (RTG) cranes, top and side picks, front end leaders forklifts, and other general industrial equipment.

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

Dead weight tonnage (DWT): The weight of the ship, all her stores and fuel, pumps and boilers, crews quarters with crew and the cargo. In other words, how much water the vessel displaces when loaded.

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

Emissions inventory: A listing of all the pollutant emissions included in the study.

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

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

Heavy Duty On-Road Vehicles: The large diesel powered trucks bringing cargo to and from the Port. Large passenger buses bringing tourists to and from cruise terminals are also included in this category.

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

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

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

Link: A defined portion of a vessel's, train's, or truck's travel. For example a link was established extending from the November Buoy out in the ocean to the location where the pilot boards the vessel. A series of links defines all of the movements within a defined area or a trip.

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

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

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

Medium speed engine: A 4-stroke engine used for auxiliary power and rarely, for propulsion. Medium speed engines typically have rated speeds of greater than 250 revolutions per minute.

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

NOx: nitrogen oxides. Includes all different nitrogen oxide compounds.

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

Off-Road activity: Activity that occurs off of established roadways. Activity within a marine terminal yard is considered off-road activity.

On-road activity: Activity that occurs on established roadways.

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

PM10: particulate matter emissions less than 10 micrometers in diameter.

PM2.5: particulate matter emissions less than 2.5 micrometers in diameter

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

Propulsion engine: Shipboard engine used to propel the ship.

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

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

ROG: reactive organic gas; all hydrocarbon compounds that can assist in producing ozone (smog). Includes hydrocarbons (HC) plus aldehyde and alcohol compounds minus methane, often used interchangeably with HC although they are not quite the same.

Roll on/roll off vessels: Ships designed to carry wheeled cargo such as automobiles, trailers, or railway carriages that drive or are pulled onto the vessels.

Shoaling: Shoaling is term used in this report to describe subsidence of the shore or other filling of the navigation channel near shore.

SOx: Oxides of sulfur. Interchangeable term with sulfur dioxide but include some other minor forms of sulfur oxides.

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

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

Slow speed engine: Typically a 2-stroke engine or an engine that runs below 250 rpm.

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

Steam turbines: A mechanical device that extracts thermal energy from pressurized steam, and converts it into useful mechanical work.

Tender: a utility vessel used to service another type of vessel, for example, transporting crew or supplies, or serving a clamshell dredge.

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

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

Tonnes: metric tons (1,000 kg)

Tug class: A tugboat's bollard pull class designation.

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

EXECUTIVE SUMMARY

Introduction

The Port of San Francisco (Port) 2005 Seaport Air Emissions Inventory (emissions inventory) identifies and quantifies air emissions from the Port's maritime activities in year 2005, organized by the major source categories as follows:

- Ocean-Going Marine Vessels (OGV)
- Harbor Craft (HC)
- Cargo Handling Equipment (CHE)
- Heavy Duty On-Road Vehicles (HDV – trucks, buses)
- Rail Locomotives (RL)

The Introduction section of this report has a more thorough description of the process behind the creation of this emissions inventory. Briefly, though, following the Bay Area Air Quality Management District's (BAAQMD) 2007 announcement of its "Green Ports Initiative," the Bay Planning Coalition (BPC) brought together the five public Bay Area seaports (the Ports of Benicia, Oakland, Redwood City, Richmond, and San Francisco - all of whom are BPC members) and the BAAQMD in a voluntary and collaborative effort to quantify the air emissions due to marine activity at those five ports.

A Memorandum of Agreement was signed by all parties in January 2008 establishing a Steering Committee and general guidelines for the preparation of the inventory. One of the chief tenets of the agreement was that the new inventories would follow the methodologies established in the Port of Oakland's 2005 inventory (ENVIRON, 2008) as much as possible. It was also agreed that any potential BAAQMD regulations would be based on findings of the regional inventory.

One of the main goals of creating a consistent set of inventories was to be able to put the seaports' emissions into the context of regional emissions. This creates a better understanding of the ports' contribution to the region's emissions by source and location.

All of the inventories, except Oakland, were done in parallel by the same team of consultants, Moffatt & Nichol and ENVIRON (M&N/ENVIRON), and BAAQMD's inventory staff. The effort was coordinated by the BPC and involved active participation during all stages by the BAAQMD. The BAAQMD contributed in-kind services by performing the harbor craft and locomotive emissions estimates in their entirety. These are included in this report as Appendices A and C. The results from their analysis are included in the summary results tables and graphs in the body of the report.

This emissions inventory highlights the Port's commitment to improve understanding of the nature, location and magnitude of emissions from its maritime-related operations. The inventory will be used by the Port as a baseline to quantitatively evaluate the effectiveness of ongoing emission reduction programs implemented by the Port and its tenants.

Purpose

The purpose of this inventory is to better understand the sources and quantities of emissions that occur from typical Port activities so the Port can better address its impact on air quality. The inventory will:

- Establish a baseline for evaluating changes in Port emissions as air pollution control regulations are phased in.
- Provide an input to regional air quality plans – plans that are required by the Federal and State Clean Air Acts and are designed to map the region's approach to attaining Federal and State ambient air quality standards.
- Inform local, state and federal regulatory decision-makers in their effort to reduce air emissions from Port-related sources and improve air quality.
- Provide air quality background information to be used in future environmental documents.
- Provide a technical basis for setting priorities and evaluating the cost-effectiveness and potential benefits of air pollution control measures.

The inventory provides estimates for emissions of five criteria air pollutants, reported in tons per year. The pollutants are:

- Reactive organic gases (ROG)
- Carbon monoxide (CO)
- Nitrogen oxides (NOx)
- Particulate matter (including diesel) (PM)
- Sulfur dioxides (SOx as SO2)

Overview of Port of San Francisco Operations

The Port of San Francisco manages about 7.5 miles of coastline, from the Hyde Street Pier in the north, across the Fisherman's Wharf tourist area, the Ferry Building, the base of the Bay Bridge, the baseball stadium, and then south through the waterfront industrial areas up through the Islais Creek area ending at Berth 96. The Port has over 500 tenants, conducting a wide variety of businesses. Most of the Port's tenants, although located near the water, have no waterside activity and therefore are not considered maritime businesses. Examples of these businesses include parking lots, restaurants, retailers, shops, a baseball stadium, offices, etc. The Port has small boat marinas and a ferry terminal. However, similar to the Port of Oakland, these are not included in the inventory

The Port has two types of ocean-going vessel traffic, cruise ships and cargo ships. There is a large and busy cruise ship dock at Berth 35. The industrial area south of the ball park includes several cargo terminals, some lay berthing of large military supply vessels, and a large ship dry dock and repair yard. The cargo activity is bulk and break bulk, mainly imports. One terminal, Darling International, exports tallow.

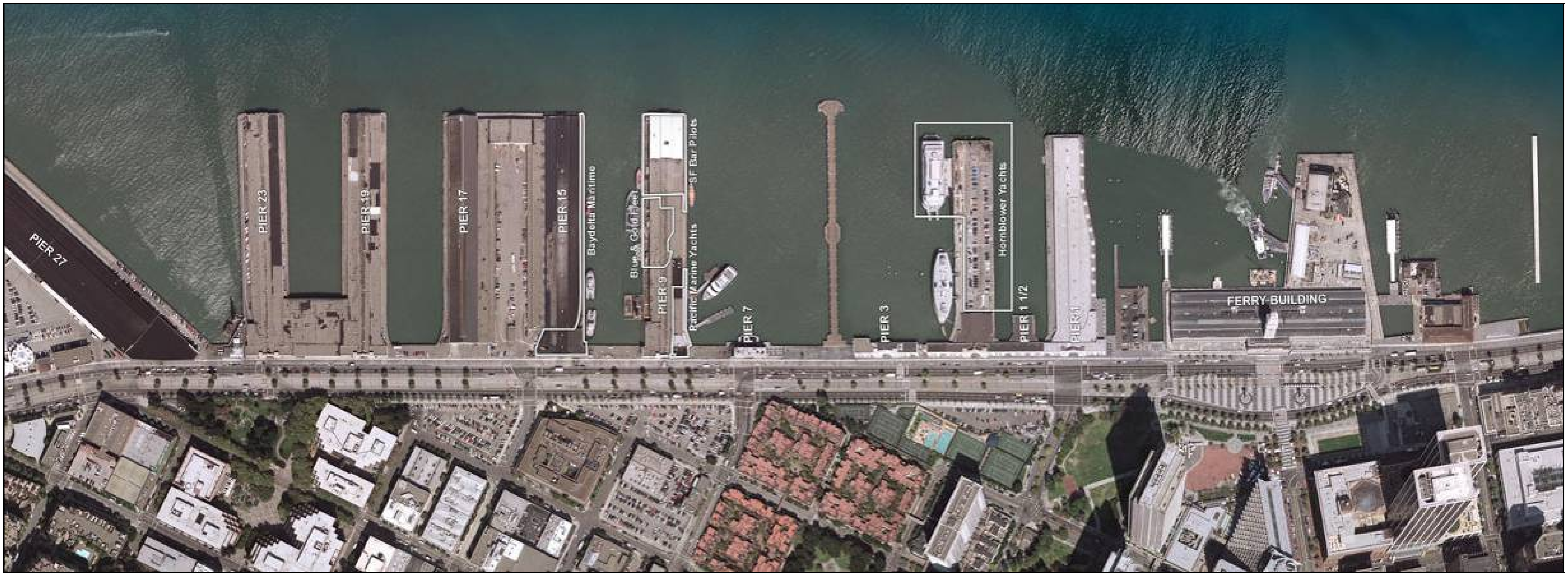
The Port has a large number of tenants that operate vessels classified as harbor craft. The SF Bar Pilots lease space on a pier, as well as several excursion vessel companies. There is a commercial and charter boat fishing fleet and a fish processing shed with many individual fish processing tenants. Two different tug companies are home-berthed in San Francisco. Finally, there is an historic vessel which has occasional outings on the Bay.

Figure ES-1 through Figure ES-3 show aerial views of the Port of San Francisco, with the property boundaries shown in white. The facilities included in this inventory are labeled in white.

(source: Google Earth)

Figure ES-1. Aerial Image of Port of San Francisco – Hyde St to Pier 27

The outlined areas indicate areas of maritime activity.



(source: Google Earth)

Figure ES-2. Aerial Image of Port of San Francisco – Pier 27 to Ferry Building

The outlined areas indicate areas of maritime activity.

(source: Google Earth)
Figure ES-3. Aerial Image of Port of San Francisco – South of Bay Bridge

The outlined areas indicate areas of maritime activity.

Figure ES-4 is a schematic diagram with a summary of the types and quantities of goods being shipped through San Francisco and shows the direction of flow. Numbers of passengers for the cruise industry are shown near the bottom of the diagram. It also shows the number and type of ocean-going ship calls. It does not include the harbor craft activity.

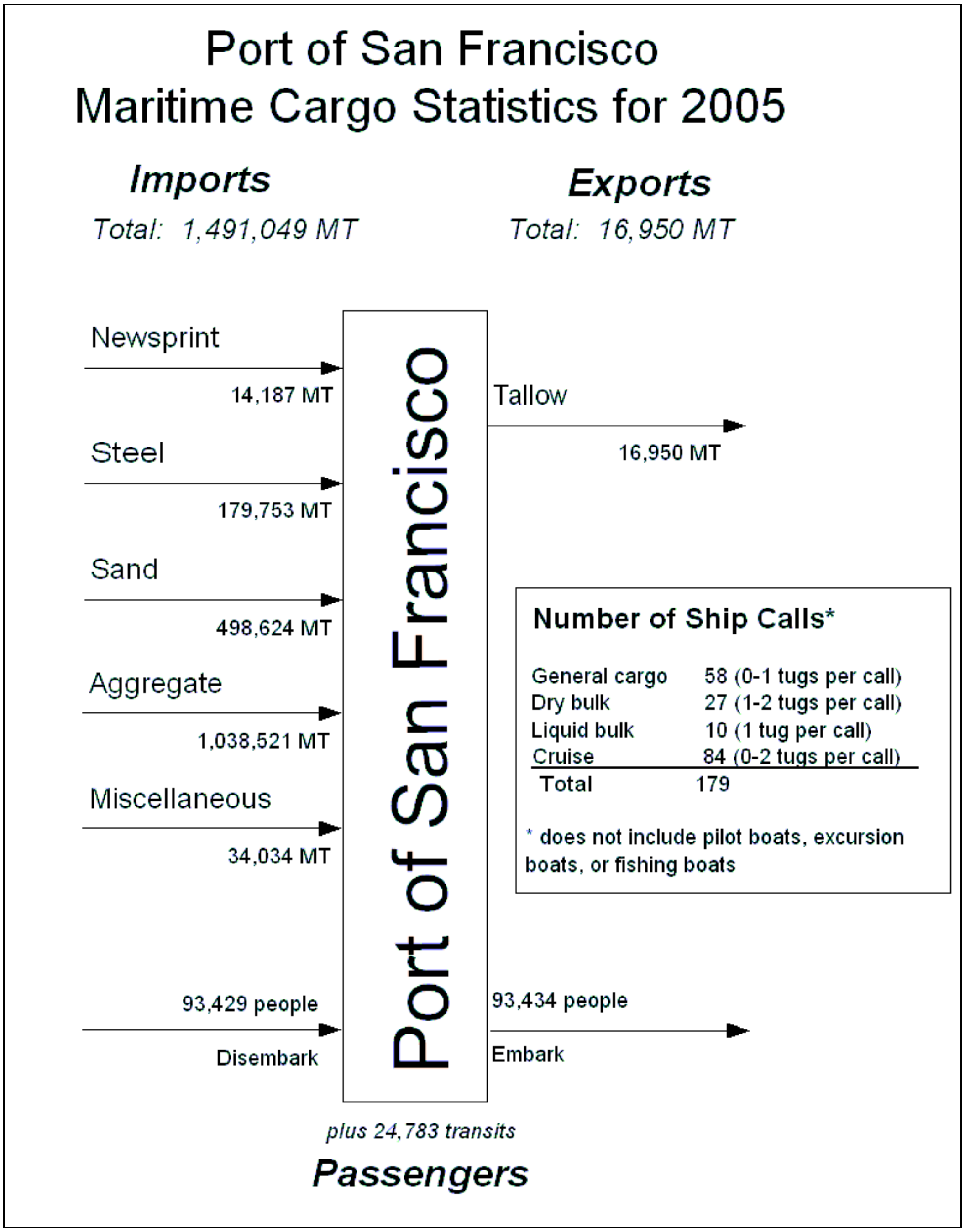


Figure ES-4. Schematic of the Port of San Francisco Cargo Flow

The diagram in Figure ES-5 lists the tenants at the Port of San Francisco affiliated with the water, and shows the mode of both waterside and landside transport along with arrows which indicate the direction of flow of the commodity. The five tenants shown in orange were included in the inventory. The harbor craft associated with the tenants in green, with the exception of the commercial fishing fleet, were included in the inventory. The steering committee agreed that it made more sense to address fishing fleet emissions outside of this inventory effort.

Three of the tenants shown in green – California Sealift (MARAD), BAE Systems (or SF Dry Dock), and the Jeremiah O'Brien (historic vessel) – had large ocean going vessel traffic, not harbor craft. The listings in blue give examples of some of the types of businesses in San Francisco that were not included in this inventory. Either they have no maritime connection, or, like the marinas, were not included in the Port of Oakland's inventory. The harbor craft emissions associated with the fuel dock and the small boat repair yards (under "Recommended Out") were not included.

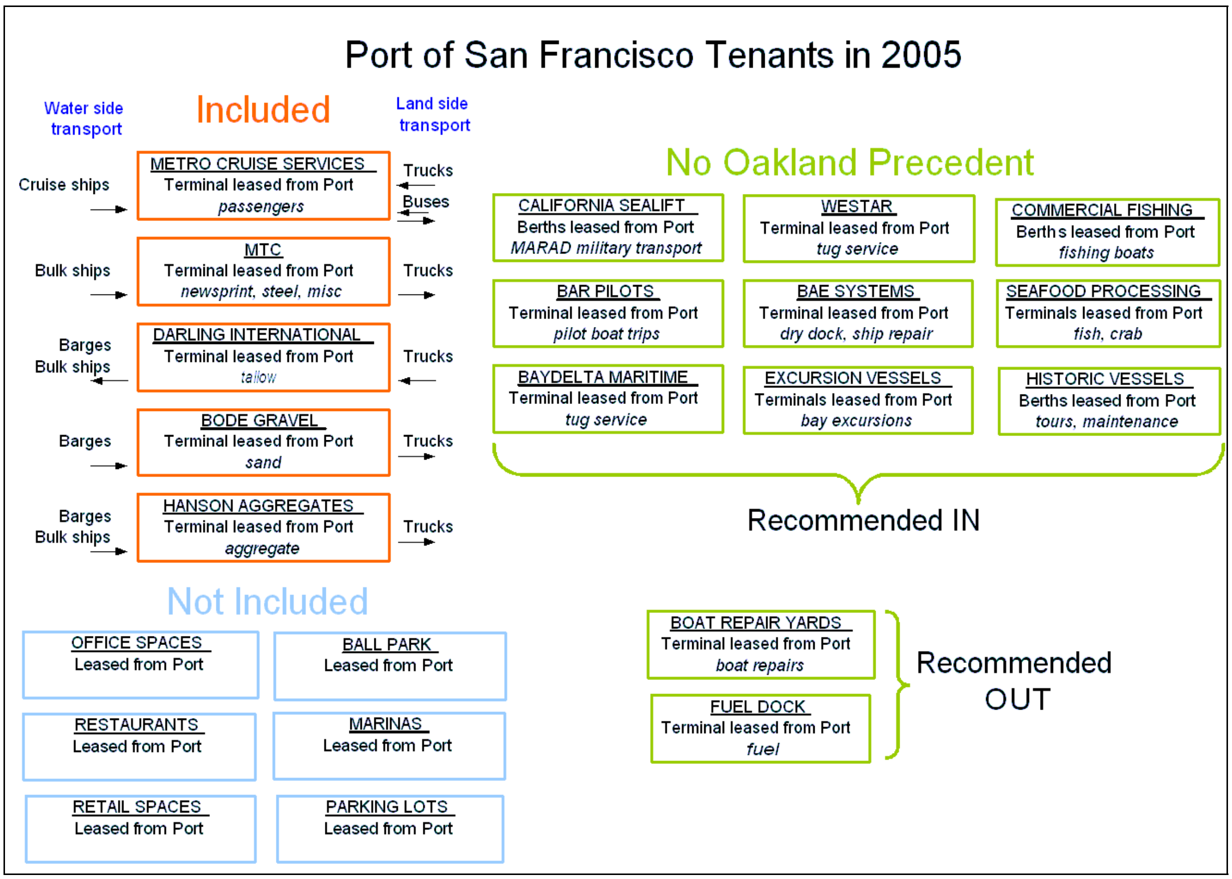


Figure ES-5. Terminals and Commodity Flow Modes at the Port of San Francisco

Staff members at BAAQMD have indicated that they will be reporting the emissions for facilities not covered in this report.

Spatial Boundary

On the water side, the spatial domain of the inventory includes vessel transit inbound and outbound between the outer buoys west of the Sea Buoy (approximately 17 miles west of the Golden Gate Bridge) and the berths at San Francisco. This is the same western boundary used in the Port of Oakland inventory.

On the land side, the spatial scope of the inventory includes all the property owned by the Port and engaged in maritime commerce including the road traffic between those facilities and the nearest freeway interchanges.

The boundaries chosen on both the water side and the land side are consistent with those used in the Port of Oakland inventory.

Source Categories

Emissions were estimated for the five source categories as described below. A summary of the emission results are presented in Table ES-1.

Ocean-Going Vessels: Ocean-going vessel emissions were estimated in several operating modes: cruising, cruising in the reduced speed zone (RSZ) inside the Bay, maneuvering (lower speed operation directly in front of the berths), and hotelling (vessels at berth and at anchor in the Bay). Emissions sources included the vessels' main propulsion engines, auxiliary engines, and boilers.

Harbor Craft: The inventory includes tug emissions estimates in two operating modes, vessel assist and transit to and from the vessel assist point. Pilot boats and excursion boats that home berth in San Francisco are also included in this category. Emissions sources include propulsion and auxiliary diesel engines.

Cargo Handling Equipment: CHE has been loosely defined as any equipment used to move freight to and from ships arriving at ports. To date, studies have largely focused on equipment primarily used to move containers. The Port of San Francisco does not move containers, so the equipment used is atypical of cargo handling equipment. Therefore the approach used in this study was to include all of the off-road equipment used at the facility. Examples include forklifts, cranes, excavators, backhoes, and sweepers, front-end loaders.

Heavy Duty On-Road Vehicles: The on-road vehicles at San Francisco include the trucks used to transport cargo on and off the Port and the buses used to bring passengers to the cruise ships and excursion trips.

Locomotives: The San Francisco Bay Railroad (SFBR) operates two small switch engines at the Port of San Francisco. Emissions for these locomotive engines are included.

Summary of Results

The results of the Port of San Francisco Seaport Air Emissions Inventory are given in Table ES-1. The same results are presented graphically in Figure ES-6. The contribution of transportation refrigeration units, TRU, is not shown in the graph because it is too small to be seen.

Table ES-1. Port of San Francisco Emissions Summary by Source (tons in 2005)

Source Category	ROG	CO	NOx	PM10	SO_2
Ocean-Going Vessels (OGV)	7.6	19.9	246.1	25.5	195.5
Harbor Craft (HC)	31.1	96.4	361.8	14.8	4.1
Cargo Handling Equipment (CHE)	3.1	13.0	40.3	0.3	1.5
Heavy Duty On-Road Vehicles (HDV)	2.1	6.5	13.6	0.8	0.1
Transportation Refrigeration Units (TRU)	0.0	0.1	0.0	0.0	0.0
Rail Locomotives (RL)	0.0	0.1	0.2	0.0	0.0
Total	**43.9**	**135.9**	**662.0**	**41.5**	**201.2**

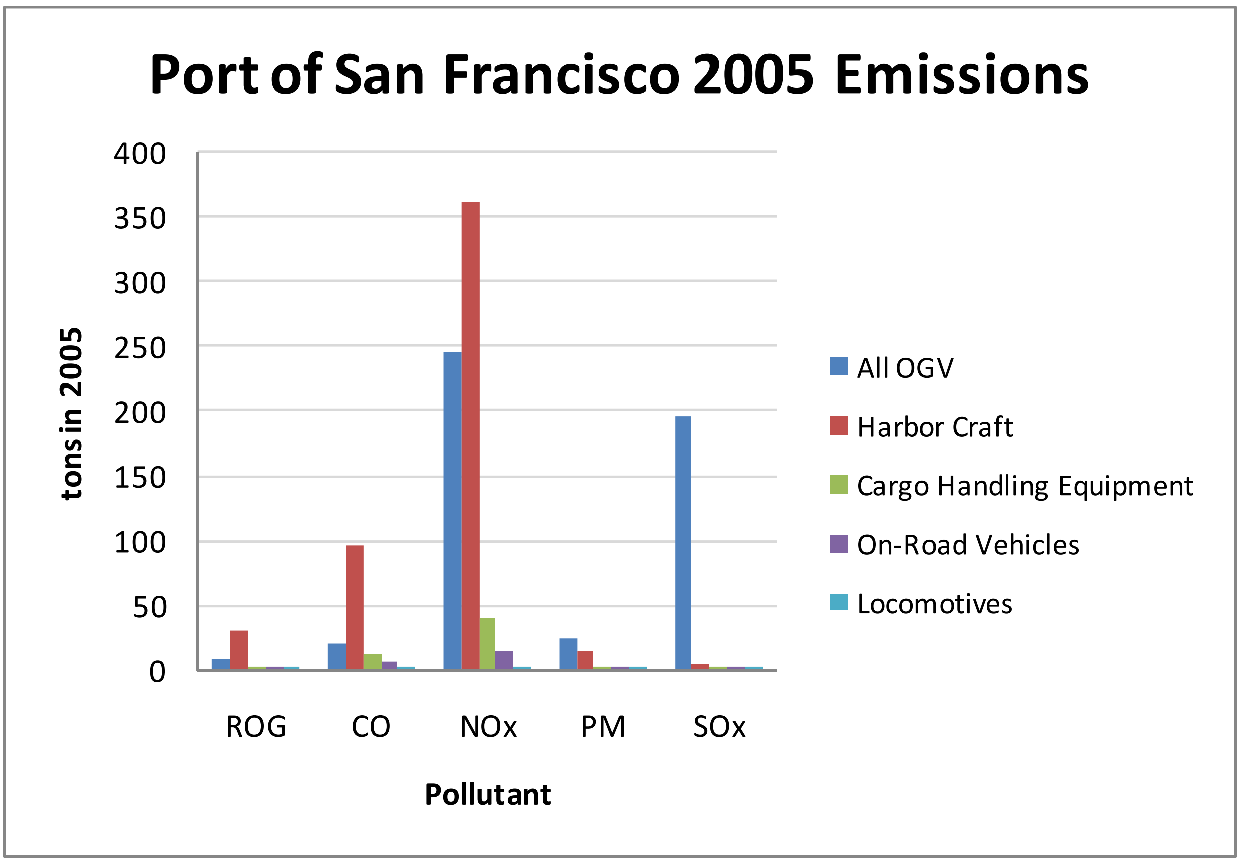


Figure ES-6. Summary of Port of San Francisco 2005 Emissions by Source & Pollutant

This graph clearly shows that the bulk of San Francisco's maritime emissions (between 86% and 99% depending on the pollutant) are produced on the waterside. Harbor craft are the major source for ROG and CO (71% for each). They produce about 55% of the Port's NOx, 36% of the Port's PM, and 2% of SOx. Ocean going vessels produce almost all (97%) of the Port's SOx.

Table ES-2 and Figure ES-7 show a more detailed assessment of ocean-going vessel emissions by type of ship.

Table ES-2. Port of San Francisco OGV Emissions Summary (tons in 2005)

Ship Type	ROG	CO	NOx	PM10	SO_2
Cruise	5.66	14.98	187.85	20.26	156.82
Cargo	1.60	4.11	47.96	4.13	30.17
Other (military, historic, etc)	0.32	0.83	10.33	1.11	8.53
Total	**7.6**	**19.9**	**246.1**	**25.5**	**195.5**

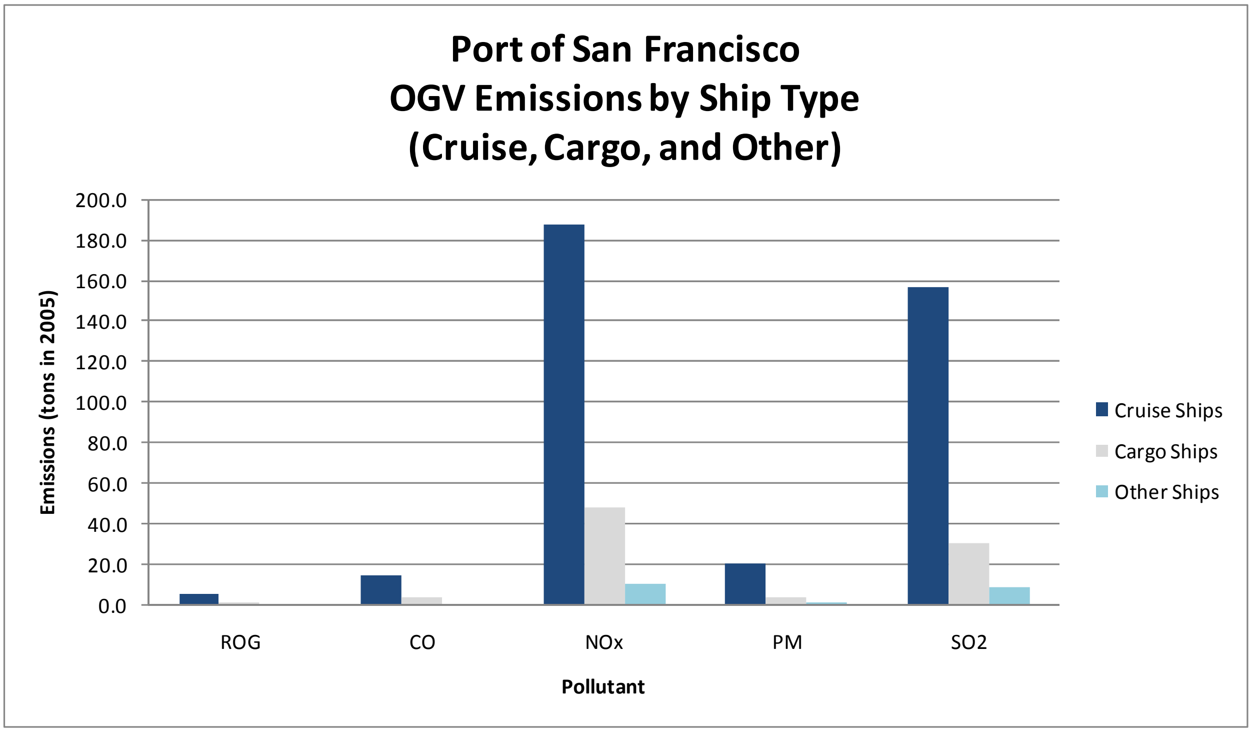


Figure ES-7. Summary of All OGV Emissions by Ship Type

Cruise ships are by far the biggest emitters of all the ship types calling in San Francisco. Cruise ships produce about 75-80% of the OGV emissions at San Francisco for all the different criteria pollutants. Over half of the cruise ship emissions occur while the ships are at berth (in hotelling mode).

An emissions inventory is best understood as an estimate of the quantity of pollutants that a group of sources produce in a given area over a prescribed period of time. Emissions inventories should be used with care and in conjunction with other information and tools to evaluate and assess air quality issues.

1. INTRODUCTION

1.1 Purpose

In January 2008, the Bay Planning Coalition (BPC), the five public seaports, and the Bay Area Air Quality Management District (BAAQMD) signed a Memorandum of Agreement establishing a Steering Committee and general guidelines for the preparation of a maritime emissions inventory for the four Bay Area public ports other than the Port of Oakland. The methodology used in the Port of Oakland's inventory formed the basis for the other public ports. The goal was to have a consistent set of inventories for 2005 for all the public ports in the region.

The Port of San Francisco (Port) 2005 Seaport Air Emissions Inventory (emissions inventory) identifies and quantifies air emissions from the Port's maritime activities, organized by major source categories as follows:

- Ocean-Going Marine Vessels (OGV)
- Harbor Craft (HC)
- Cargo Handling Equipment (CHE)
- Heavy Duty On-Road Vehicles (HDV – trucks, buses)
- Transportation Refrigeration Units (TRU)
- Rail Locomotives (RL)

The Port of San Francisco voluntarily chose to prepare an air emissions inventory of its marine operations along with the other major public seaports in the San Francisco Bay Area. The other ports were Benicia, Redwood City, and Richmond. The Port of Oakland conducted their 2005 inventory prior to this project (ENVIRON, 2008).

All of the inventories, except Oakland, were done in parallel by the same team of consultants, Moffatt & Nichol and ENVIRON (M&N/ENVIRON), and BAAQMD's inventory staff in order to assure consistency in methodology. The effort was coordinated by the BPC and involved active participation during all stages by the BAAQMD. The BAAQMD contributed in-kind services by performing the harbor craft and locomotive emissions estimates. These are included in this report as Appendices A and C. The results from the BAAQMD analysis are included in the summary results tables and graphs in the body of the report.

This emissions inventory highlights the Port of San Francisco's commitment to improve understanding of the nature, location and magnitude of emissions from its maritime-related operations. The Port is committed to improving its operations to promote more sustainable and environmentally sensitive practices.

1.2 Background

Early in 2007 the BAAQMD announced as part of its "Green Ports Initiative" that it would be proposing regulations in 2008 to "reduce air pollution and health risks from marine port activities and require the ports to develop comprehensive action plans to meet those goals." Each port, as part of its action plan, would be required to create an air emissions inventory.

The BPC, with its history of being proactive towards issues facing the Bay Area marine industry, organized the five major public ports in an effort to coordinate any forthcoming air quality issues and solutions. All five ports (listed alphabetically: Benicia, Oakland, Redwood City, Richmond, and San Francisco) are members of the BPC. The BPC engaged the consulting team of M&N/ENVIRON to assist in the effort to create a regional air emissions inventory for the five seaports.

By January 2008, the BPC, the five public seaports, and the BAAQMD had a signed Memorandum of Agreement establishing a Steering Committee and general guidelines for the preparation of a maritime emissions inventory. One of the chief tenets of the agreement was that the regional inventory would follow the methodologies established in the Port of Oakland's 2005 inventory as much as possible. It was also agreed that any potential BAAQMD regulations would be based on findings of the regional inventory.

Because the Port of Oakland's 2005 inventory was already complete, no further work was required for that port. The work was instead focused on creating 2005 inventories for the remaining four public ports; in effect "catching them up" to the status of the Oakland inventory. The goal was to produce five consistent inventories which could be combined to produce a regional inventory of maritime related emissions from the Bay Area's public ports. It should be noted that maritime activity in the Bay Area is diverse and that there are additional maritime activities (such as private terminals and traffic due to the Ports of Stockton and Sacramento) that are outside the scope of the public ports' inventories.

The emissions inventory work was divided into four phases as follows:

Phase I – collecting data for each port for each source category

Phase II – developing a work plan based on the data collected

Phase III – gaining approval of the work plan by the Steering Committee

Phase IV – creating the inventory and writing the report

An important part of Phase I was to identify any significant issues or data gaps. The Phase I findings provided the groundwork to prepare a refined scope of work for Phases III and IV of the project.

In February 2008 the data collection effort (Phase I) began, with multiple interviews conducted at each port. Additional research, interviews, emails and phone calls with a variety of third party sources including the California Air Resources Board (CARB) and individual port tenants were conducted during the same period. Data collection continued through mid-April at which point a presentation was made to the Steering Committee on the findings of the data collection effort. A draft work plan (M&N/ENVIRON, 2008) was developed in May 2008 (Phase II) and was approved with comments by the Steering Committee in October 2008 (Phase III). The consultant team was authorized to begin development of the inventory (Phase IV) in March 2009.

As previously stated, the Port of Oakland's inventory was the primary source of guidance for this project, yet the operations in Oakland are limited to containerized cargo. The types of cargo and operations at the other four ports are far more varied than those found in Oakland. In fact, it should be noted that none of the other ports handles containers. Also unlike the Port of Oakland, the other four ports have tenants conducting non-maritime business.

The Steering Committee made decisions on a case-by-case basis as to which operations at which ports would be included in their individual inventories. Figure 1-1 shows the flow chart that was used to guide the decisions.

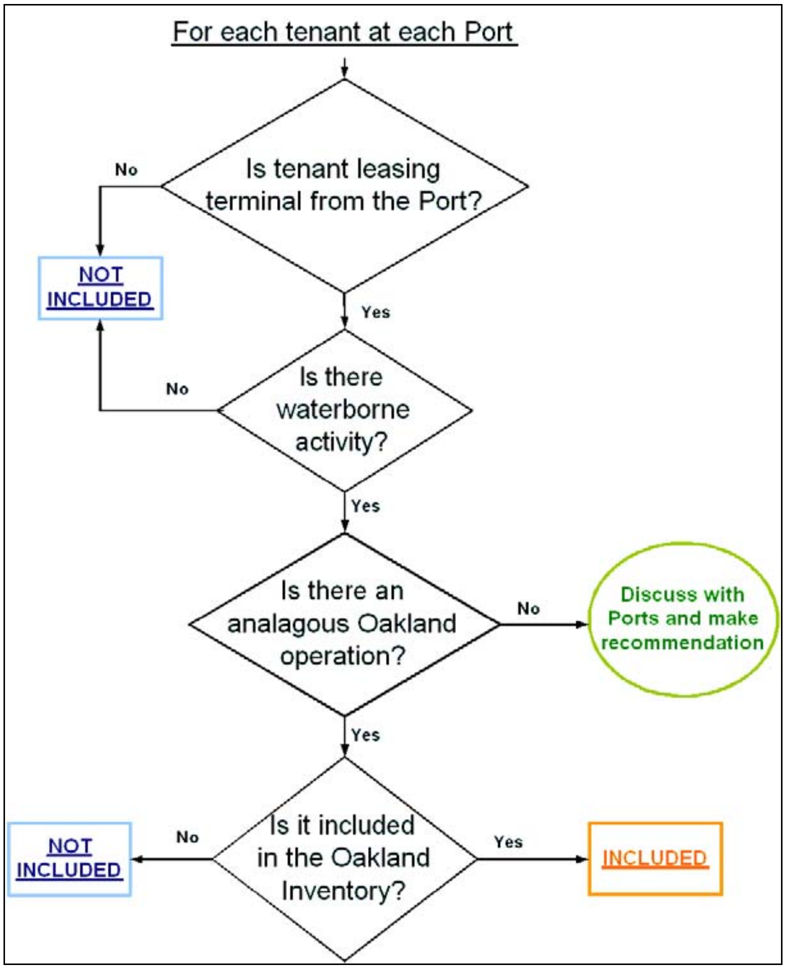


Figure 1-1. Decision-Making Flow Chart

The Port of Oakland inventory established two major precedents for exclusion. The first is that privately owned terminals (such as Schnitzer Steel in Oakland) are not included. The second is that non-maritime operations (such as the small boat marinas or retail spaces in Jack London Square) on port-owned property are not included. The exclusion of ferry boats leaving from Oakland also led to the decision to exclude San Francisco's ferry terminal.

The Port of San Francisco manages about 7.5 miles of coastline, from the Hyde Street Pier in the north, across the Fisherman's Wharf tourist area, the Ferry Building, the base of the Bay Bridge, the baseball stadium, and then south through the waterfront industrial areas up through the Islais Creek area ending at Berth 96. The Port has over 500 tenants, conducting a wide variety of businesses. The majority of the tenants, although located near the water, has no waterside activity. Examples of these businesses include parking lots, restaurants, retailers, shops, a baseball stadium, offices, etc. The Port has small boat marinas and a ferry terminal; however, as with the Port of Oakland inventory, these are not included in this study.

The port has two types of ocean-going vessel traffic, cruise ships and cargo ships. There is a large and busy cruise ship terminal at Berth 35. The industrial area south of the ball park includes several cargo terminals, some lay berthing of large military supply vessels, and a large ship dry dock and repair yard. The cargo activity is bulk and break bulk, mainly imports. One terminal, Darling International, exports tallow.

The port has a large number of tenants that operate vessels classified as harbor craft. The SF Bar Pilots lease a terminal, as well as several excursion vessel companies. There is a commercial and charter boat fishing fleet and a fish processing shed with many individual fish processing tenants. Two different tug companies are home-berthed in San Francisco. Finally, there are some historic vessels which have occasional outings on the Bay.

1.3 Considerations When Using Emissions Inventories

Emissions inventories are used for multiple purposes: to analyze air quality, to develop pollutant control strategies or plans, and to track and communicate progress toward air quality goals. Emissions inventories are essential tools, but they have some inherent shortcomings that are often overlooked and lead to misconceptions about their use and value. The term inventory is something of a misnomer because it implies greater precision in counting emissions than is really the case. An emissions inventory is better understood as an estimate of the quantity of pollutants that a group of sources produce in a given area, over a prescribed period of time. The methods of making estimates are usually very technical in nature, a characteristic that makes the limitations of emissions inventories less transparent to the general public.

The accuracy of emissions estimates varies due to a number of factors. Even a well-conducted, detailed and professional inventory, such as this one, does not have access to direct emissions measurements from the specific, individual sources being studied. As a result, it is necessary to rely on surrogate information to characterize sources, describe source activities, and specify pollutant emission rates. Emissions estimation methodologies are continuously in flux, changing and evolving over time as better and more accurate information becomes available.

This emissions inventory was purposefully kept consistent with the Port of Oakland's 2005 inventory, even though updated emission factors or load factors may have been available in certain instances. This allows for consistency in estimates among the five Bay Area public ports.

Another important consideration in interpreting emissions inventories is the fact that there can be a poor correlation between the magnitude of a set of emissions and their impact on air quality. The importance of a given ton of emissions may differ from another ton because of the location at which it is emitted, because of the meteorological conditions that affect its dispersion, or because of the chemical reactions that occur in the atmosphere. Emissions inventories should be used with care and in conjunction with other information and tools to evaluate and assess air quality problems.

1.4 Important Features of this Emissions Inventory

Some features of the emissions inventory that should be kept in mind throughout this report are described below.

Scope

The inventory estimates emissions from the Port's maritime operations that occurred in the calendar year 2005. It is not intended to represent emissions in other years, or emissions outside the geographic domains identified for each major source category, as described in Section 1.6 of this report.

Sources

The inventory focuses on the largest sources of air emissions from maritime operations, which, except for ship boilers (included), are all diesel engines powering ocean-going vessels, harbor craft assisting those vessels, cargo handling equipment, trucks and buses, and locomotives engaged in transport of maritime cargo. The inventory does not address other sources, such as gasoline powered, light-duty vehicles that may have operated at the Port.

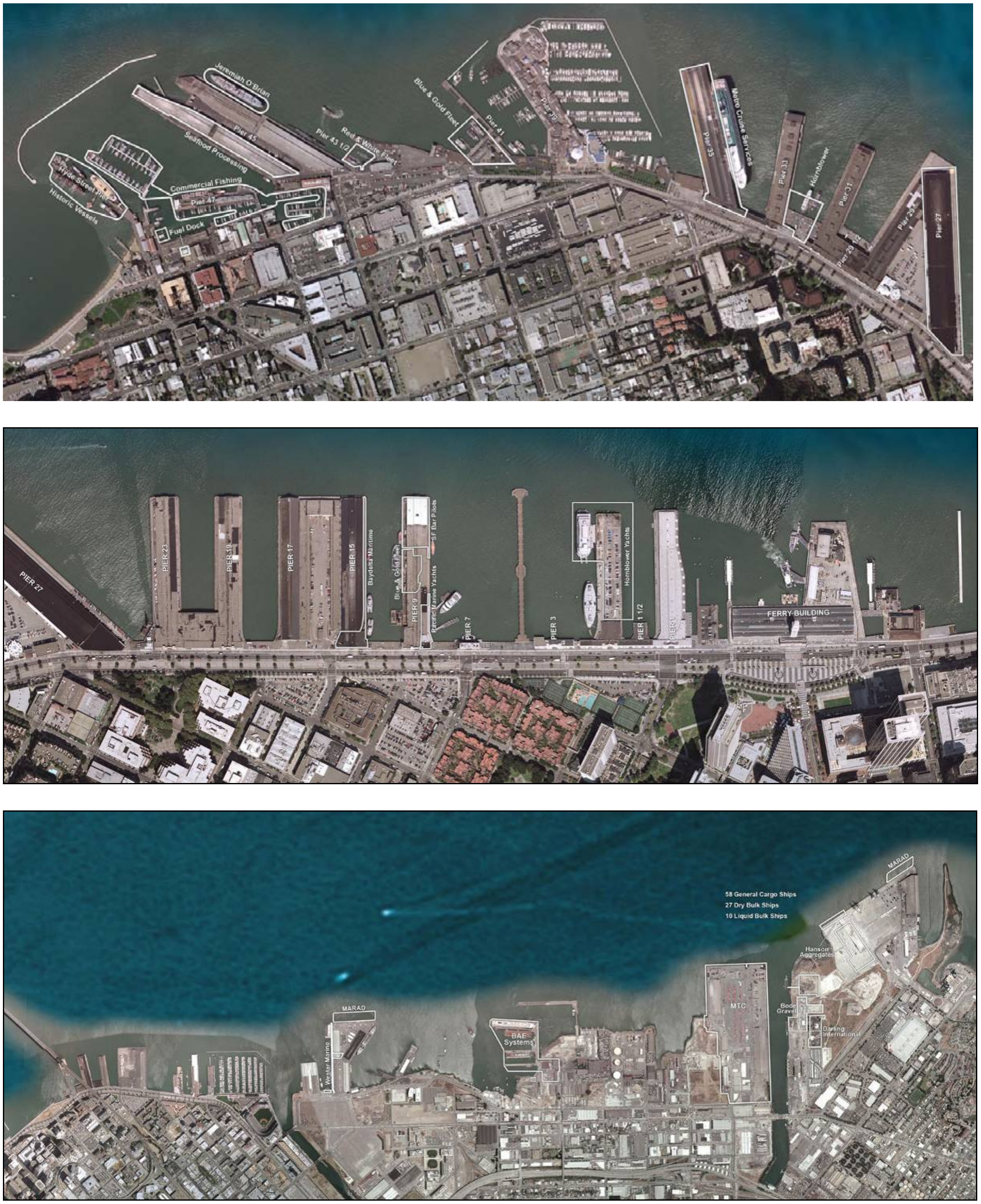
Boundary

On the water side, the spatial domain of the inventory includes vessel transit back and forth between the outer buoys west of the Sea Buoy (approximately 17 miles west of the Golden Gate Bridge) and the berths. This is the same western boundary used in the Port of Oakland inventory.

On the land side, the spatial scope of the inventory includes all the property owned by the Port and engaged in maritime commerce and the road traffic between those facilities and the nearest freeway interchanges.

The boundaries chosen on both the water side and the land side are consistent with those used in the Port of Oakland inventory.

Figure 1-2 shows the boundary of the terminals at Port of San Francisco. Larger sizes of these images can be found in the Executive Summary of this report. The outlined areas indicate areas of maritime activity.



(Source: Google Earth)

Figure 1-2. Port of San Francisco Aerial Images (shown north to south, from top to bottom)

1.5 Criteria Air Pollutants

The inventory provides estimates for emissions of five criteria air pollutants described in Table 1-1, reported in tons per year.[1]

Table 1-1. Criteria Pollutants Included in this Inventory

Reactive Organic Gases (ROG)	Generally colorless gases that are emitted during combustion or through evaporation. They react with other chemicals in the ambient air to form ozone or particulate matter, both of which can have adverse health effects at higher concentrations. ROG are similar to hydrocarbons (HC) except ROG includes aldehydes (and alcohols, which are only found in light-duty vehicles) and excludes methane. These two differences between ROG and HC tend to offset each other within a few percent. OGV emissions are calculated for HC and then converted to ROG as described in that section.
Carbon Monoxide (CO)	Colorless gas that is a product of incomplete combustion. Has an adverse health effect at higher concentrations.
Nitrogen Oxides (NOx)	Nitrogen oxides include nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen dioxide is a light brown gas formed during combustion from reactions with both the nitrogen in the fuel or the combustion air. Nitrogen dioxide has adverse health effects at higher concentrations. Both nitrogen dioxide and nitric oxide participate in the formation of ozone and particulate matter in the ambient air.
Particulate Matter (PM)	Solid or liquid particles that form from a variety of chemical reactions during the combustion process. Solid particulate may also be emitted from activities that involve abrasion or friction. Particulates have adverse health effects at higher concentrations. In this report, PM refers to particles with diameter of 10 micrometers or less, often written as PM10.
Sulfur Dioxide (SO_2)	Gas that is formed during combustion of a fuel that contains sulfur. SO_2 has adverse health effects at higher concentrations and participates in the formation of particulate matter in the ambient air.

1 The term "criteria" pollutant is applied to pollutants for which an ambient air quality standard has been set by Federal or State regulation, or which are chemical precursors to pollutants for which an ambient air quality standard has been set.

1.6 Technical Approach

The inventory was prepared by analyzing all maritime activity in 2005, including the time in different modes of operation, the load, speed, and the engine characteristics of all equipment and vessels used in the Port's maritime operations. Records were obtained from the Port, individual terminal operators, rail operators, the State Lands Commission, and CARB as necessary to get a comprehensive data set of all engine activity.

The team relied heavily on the Port of Oakland inventory as a guide for methodology and emission and load factors. The Port of Oakland inventory was prepared by ENVIRON, working in conjunction with CARB and the BAAQMD. During preparation of the Oakland inventory, port staff, ENVIRON, CARB, and BAAQMD had weekly conference calls and discussed many different input factors and reviewed different emissions inventory methodologies.

1.7 Report Organization

This emissions inventory report is organized as follows.

- The Executive Summary briefly describes the methodologies used to estimate air emissions for all Port activities, and a summary of the results (Tables ES-1 and ES-2)
- Section 1 contains this introduction to the report.
- Section 2 describes the ocean-going vessel activity and emissions estimate results.
- Section 3 summarizes the harbor craft emissions estimate results. Harbor craft emissions were analyzed independently by BAAQMD. Their report, in its entirety is included as Appendix A.
- Section 4 describes the cargo handling equipment activity and emissions estimate results.
- Section 5 describes the on-road truck and any bus activity associated with cargo or passenger movements followed by emissions estimate results. Truck routes are shown on aerial images in Appendix B.
- Section 6 describes the emissions created by transportation refrigeration units, the diesel powered units used to keep trucks carrying temperature sensitive goods cold.
- Section 7 summarizes the locomotive emissions estimate results. Locomotive emissions were analyzed independently by BAAQMD. Their report, in its entirety is included as Appendix C.
- Section 8 contains the summary and results of the report.
- Section 9 provides the references used in developing the emissions inventory.
- Appendix A provides the BAAQMD independent emissions estimate for harbor craft activity.
- Appendix B provides a summary chart and aerial images showing truck routes to the different piers in San Francisco.
- Appendix C provides the BAAQMD independent emissions estimate for locomotive activity.

2. OCEAN-GOING VESSELS

2.1 Ocean-Going Vessel Activity

This section documents the emission estimation methods and results for large ocean-going vessels calling at the Port of San Francisco in 2005. M&N/ENVIRON followed the Port of Oakland's methodology for their 2005 inventory, which in turn was based on EPA guidance for best practices (ICF Consulting, 2006) for maritime emissions inventory and CARB guidance provided in weekly conference calls from October 2006 until June 2007.

The two main types of OGVs calling at the Port are cruise ships and bulk carriers (or general cargo ships). Cruise ships brought over 25,000 passengers through San Francisco, and over 93,000 additional passengers took cruises originating or terminating in San Francisco. Cargo ships brought imports of aggregate, sand, steel, and newsprint to the industrial terminals at the southern end of the Port. There were also ten calls by small tanker ships calling at a tallow exporting terminal. The tanker calls are included with the general cargo ship calls.

A third, or "other" category of OGVs calling San Francisco in 2005 includes military vessels for the U.S. Maritime Administration (MARAD), ships calling at SF Dry Dock, and the historic vessel *Jeremiah O'Brien* docked at Pier 45.

These ships use propulsion engines for movements, auxiliary engines for electrical power and small boilers for steam and hot water, all of which produce emissions. The methodology used for estimating emissions was to multiply the total time by the engine in different operational modes by the load factors and by the emission factors derived for these sources. Each vessel has unique characteristics of speed, engine type and power that affect the estimate of time and engine load for each call.

2.2 Input Data

<u>Vessel Call Information</u>

The Port of San Francisco provided complete vessel call data for 2005. The cruise data included arrival date, arrival time, departure date, departure time, vessel name, vessel operator, number of passengers, and previous and next ports. The cargo call data included arrival and departure dates and times, vessel type, vessel name, carrier, and facility name.

Figure 2-1 shows a schematic summary of the amount of cargo, the direction of cargo flow, and the number of ship calls for the Port in 2005.

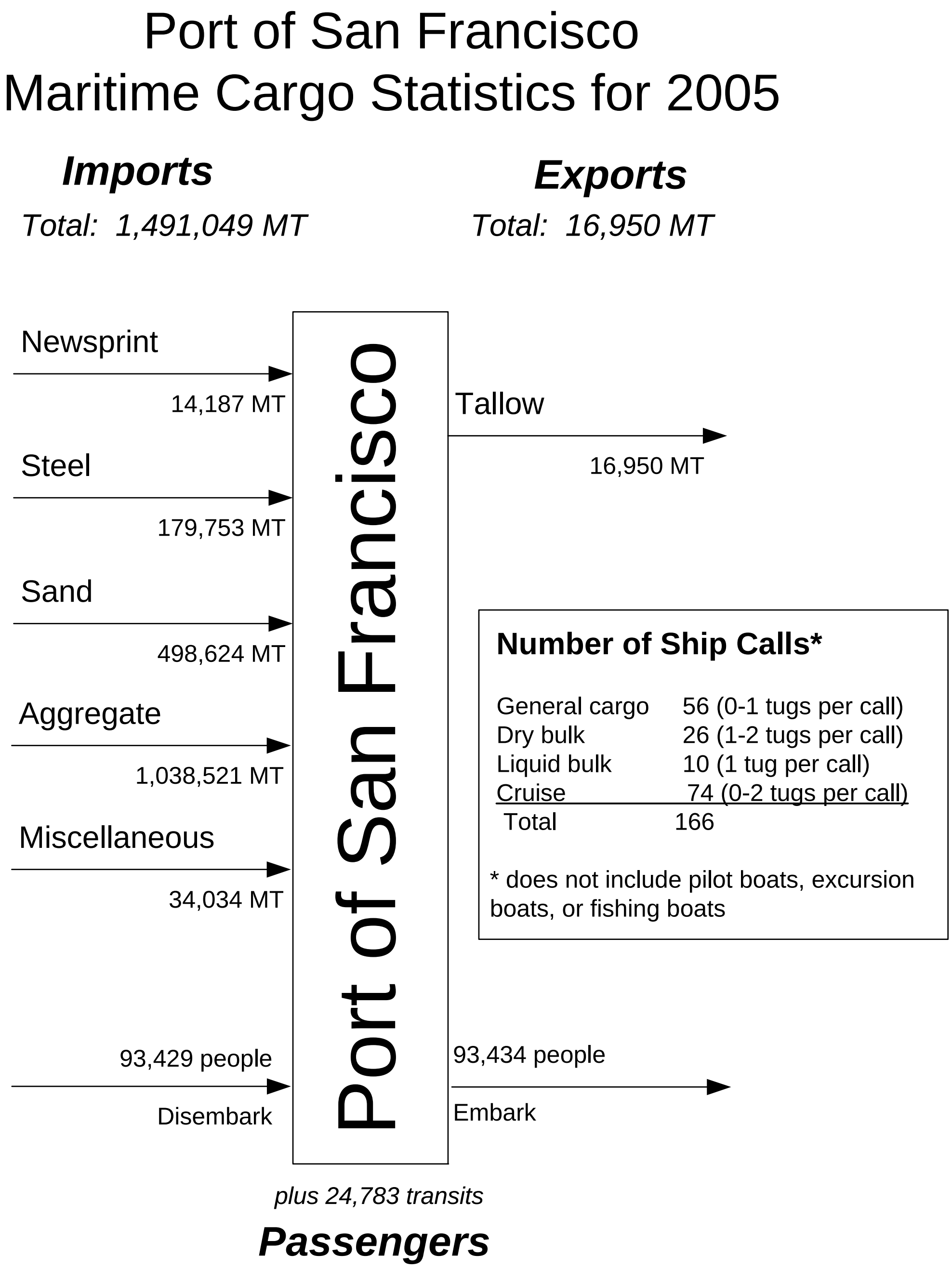


Figure 2-1. Schematic of the Port of San Francisco Cargo Flow

The 166 vessel calls at the Port of San Francisco in 2005 were split roughly evenly between cruise ships (45%) and cargo ships (55%). The 74 cruise ship calls were made by 19 unique vessels, making this the port with the most frequent callers. Ten ships called one time, but the other 64 calls were made by only nine ships. Three ships called more than nine times each.

The 92 cargo calls were made by 51 unique ships. The *Nelvana* made 21 calls to San Francisco (it also called in Redwood City on nine of those visits). Two ships called four times, three called three times, and nine called twice. The remaining 36 calls were made by 36 different vessels.

According to Marine Exchange[2], in 2005 there were nine ship calls to SF Dry Dock (the large ship repair yard located just south of Mission Bay. Repeated attempts were made to find more details about traffic to the ship yard in 2005, but to no avail. Lacking better information, M&N/ENVIRON used the conservative assumption that all nine calls were made by large cruise ships. The *Regal Princess* was chosen as a representative cruise ship because its engine size most closely matches the average engine size for cruise ship calls in 2005.

According to BAAQMD[3], there were three ship calls for MARAD dock in San Francisco (located just south of AT&T Park) in 2005. Attempts to find out exact details of these military calls were not successful. An internet search revealed that MARAD keeps Cape H Class ro/ro vessels in San Francisco. The *Cape Henry* was used as a representative vessel for these three calls.

The *Jeremiah O'Brien* is the last in the category of "other" ships. It is a U.S. Liberty Ship that was built in 1943 and served in World War II. After a long history, including thirty-three years spent in Suisun Bay as part of the mothball fleet, it is currently in seaworthy condition and is docked near Fisherman's Wharf. The ship runs occasionally, making several passenger excursions in the Bay each year. Exact excursion details for 2005 were not available. However, M&N/ENVIRON was able to estimate emissions using fuel consumption data provided by the ship keeper[4] at the time.

Vessel Information Research

A list of vessels calling the SF Bay in 2005 was given to BAAQMD to research ship particulars such as length overall (LOA), dead weight tons (DWT), main engine and auxiliary engine sizes, boiler size, build year, capacity, vessel type, etc. BAAQMD used three sources to find vessel information: the Clarkson Register, and the 2005 air emission inventories for the Ports of Los Angeles and Long Beach (Starcrest 2007a and 2007b). All auxiliary engine and boiler values provided by BAAQMD were taken from the database compiled by CARB from the two San Pedro Bay 2005 emission inventories referenced above. The values are average values by vessel type taken from the 2005 CARB Ocean Going Vessel Survey, and as such do not represent ship-specific values.

BAAQMD was unable to find any information for some of the vessels and was missing auxiliary engine information for others. M&N/ENVIRON looked up about 100 vessels using a combination of web searches and Lloyd's database to fill in any blanks. Many of these vessels

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2 Marine Exchange data provided through BAAQMD in an email from T. Dinh on 8/31/2009.

3 MARAD information provided through BAAQMD in an email from T. Dinh on 8/31/2009 based on a conversation he had with MARAD operator John Hummer.

4 From a phone conversation on 10/12/2009 with Phil O'Brian, the *Jeremiah O'Brien* ship keeper.

had been broken up or renamed since 2005.

Auxiliary engine information was unavailable for over half of the ships calling in the SF Bay. In some cases, auxiliary generator information was listed where auxiliary engine size was not. Consistent with Oakland's methodology, auxiliary generator information was used to approximate auxiliary engine information when necessary. It is understood that the value listed for auxiliary generators may be lower than the actual auxiliary engine, however the difference is not large. (In the four instances where both auxiliary generator and auxiliary engine information were available, the generator power represented 86% of the engine power.)

In cases where auxiliary generator was not available either, an effort was made to find a sister ship with the same approximate dimensions used in the same vessel string calling regularly at the port. For example, the *Arcadia Highway* was used to approximate auxiliary engine information for the *Caribbean Highway*.

In cases where a sister ship could not be found, three different approximations were compared. Where there was agreement with two of the three, that value was used. When there was no agreement among the three then the middle value was used. The three approximations were:

1. The ratio of auxiliary engines to main engines for that ship type calling in the SF Bay multiplied by the main engine size for the ship in question.
2. The average value for auxiliary engines for that ship type calling in the SF Bay.
3. The default auxiliary engine size for that ship type provided by CARB in Table II-4 of Appendix D of their port emissions inventory guidance document (CARB, 2008).

This comparative method had to be used for 8% of the vessels.

Vessel Characteristics

Table 2-1 through Table 2-3 summarizes some of the characteristics of the different types of vessels calling at the Port.

Table 2-1: General Cargo Carrier Characteristics

	LOA (ft)	DWT	Main Engine (kW)	Design Speed (knots)	Age (yrs)
Minimum	393	10,536	3,361	11	4
Maximum	797	74,973	12,528	18	51
Average	683	50,792	9,061	15	20

Table 2-2: Tanker Characteristics

	LOA (ft)	DWT	Main Engine (kW)	Design Speed (knots)	Age (yrs)
Minimum	455	16,008	4,959	14	5
Maximum	496	19,997	7,159	17	20
Average	485	18,801	5,858	16	10

Table 2-3: Cruise Ship Characteristics

	LOA (ft)	DWT	Main Engine (kW)	Design Speed (knots)	Age (yrs)
Minimum	Not avail	2,581	6,637	18	4
Maximum		11,788	70,742	24	19
Average		7,571	40,482	22	14

The chart below, Figure 2-2, gives a histogram (bars, read off left axis) and the cumulative percentage (lines, read off right axis) for the age distribution of the calls at the Port. The blue bars and lines represent bulkers, red is for tankers, and green for cruise ships.

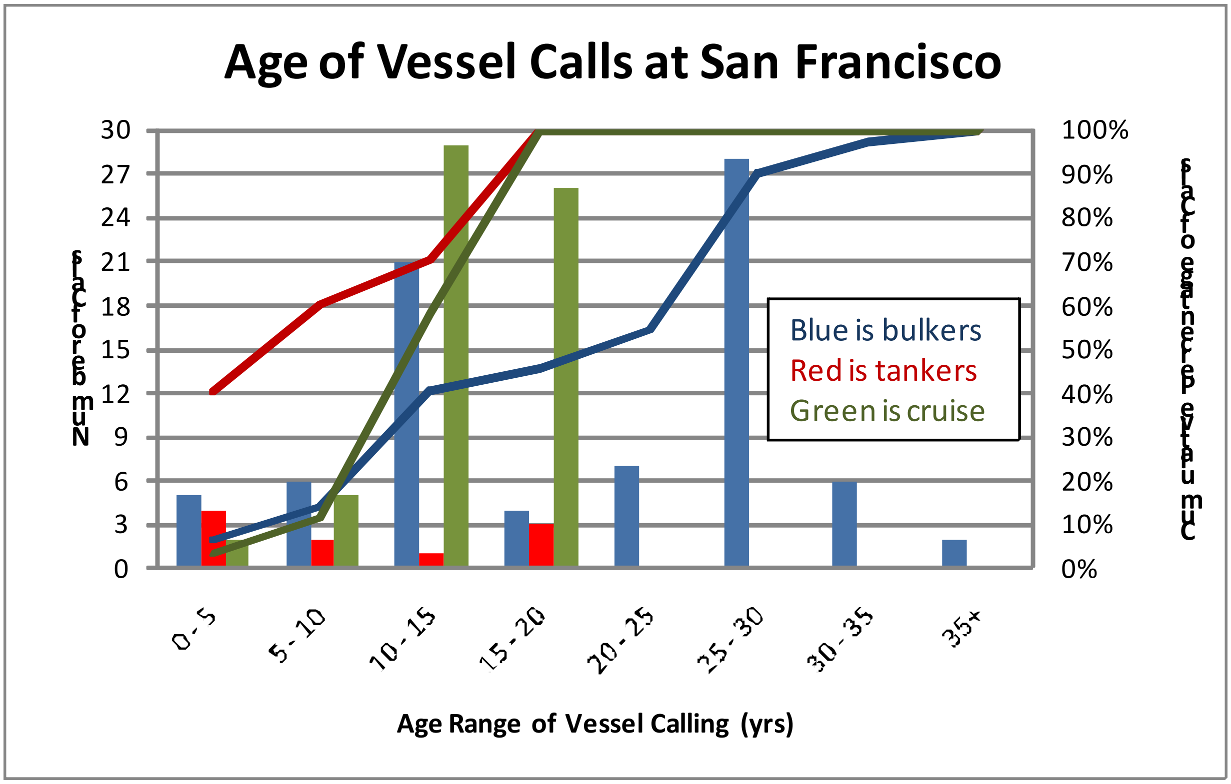


Figure 2-2. Age Distribution of OGV Calls at Port of San Francisco

This shows that all of the cruise ships and edible oil tankers calling in San Francisco are less than 20 years old. Most of the cruise ships are in the 10 to 20 year range. Some of the bulkers are over 30 years old.

Anchorage Time and Previous/Next Ports of Call

CARB provided ship call data for the entire state of California for 2005, including vessel name, arrival dates, departure dates, time at berth, previous and next ports of call, and anchorage time. Not every call had both previous and next port information, and not every call had anchorage time information. It was assumed that if the anchorage time was left blank then the ship did not anchor on that call.

The CARB database is based on information recorded by the State Lands Commission (SLC). According to CARB[5], the SLC fills in previous and next port of call information by asking the captains for their destination. This method creates many inaccuracies. For example, the captain of an inbound ship may declare that they are bound for “San Francisco” when in reality they are bound for a specific port or terminal somewhere within the San Francisco Bay. Calls such as this are recorded as Port of San Francisco calls, vastly overstating the number of calls to San Francisco. Similarly, a captain may say “Carquinez” to refer to a terminal somewhere near or past the Carquinez Strait, even though there is no port named Carquinez. For this reason, the

5 Phone conversation with Andy Alexis of CARB on April 14, 2009.

previous and next ports of call are sometimes unreliable.

The port-provided ship call data were more accurate than the SLC database. In the case of any discrepancies between the port-provided call data and the SLC database, the port's data governed. In particular, time at berth was calculated directly from the port-provided arrival and departure dates and times instead of using the at-berth times listed in the CARB database which were often generic. However, the Port did not provide any information about anchorage or previous and next ports of call. The anchorage information was obtained by CARB staff from the U.S. Coast Guard Vessel Traffic Service and was reconciled with the SLC database. All information regarding previous and next ports of call came from the SLC database.

Anchorage time is significant because of extra travel time to and from the anchorage plus hotelling time while at anchor. The SLC database does not indicate which anchorage was used, just the number of hours at anchor. It was assumed that all anchoring occurred at Anchorage 9, which is the most frequently used anchorage in the SF Bay. It was also assumed that the anchorage portion of the visit occurred before the vessel went to port. Sometimes anchoring is done after leaving port so ships can bunker (take on fuel), make repairs, or wait for fog to clear before leaving the Bay. In any event, since the entire visit is included, it does not affect the emissions whether the ship anchored before or after going to berth.

The previous and next ports of call are significant because they give an indication of the direction the ship arrived from or departed to outside of the Golden Gate. Following Oakland's methodology, the spatial domain for OGV emissions includes transit activity inside the three outer sea buoys (one each to the north, west, and south) Distances to the outer buoys from the Sea Buoy differ in distance by as much as 1.4 nm, as described in the next section.

Ship Routes and Speeds

Figure 2-3 below, copied from the Port of Oakland 2005 Emissions Inventory, shows the routes outside of the Golden Gate for all ships in this inventory. The routes inside the Golden Gate are given next in this section, after a discussion of the previous and next ports of call.

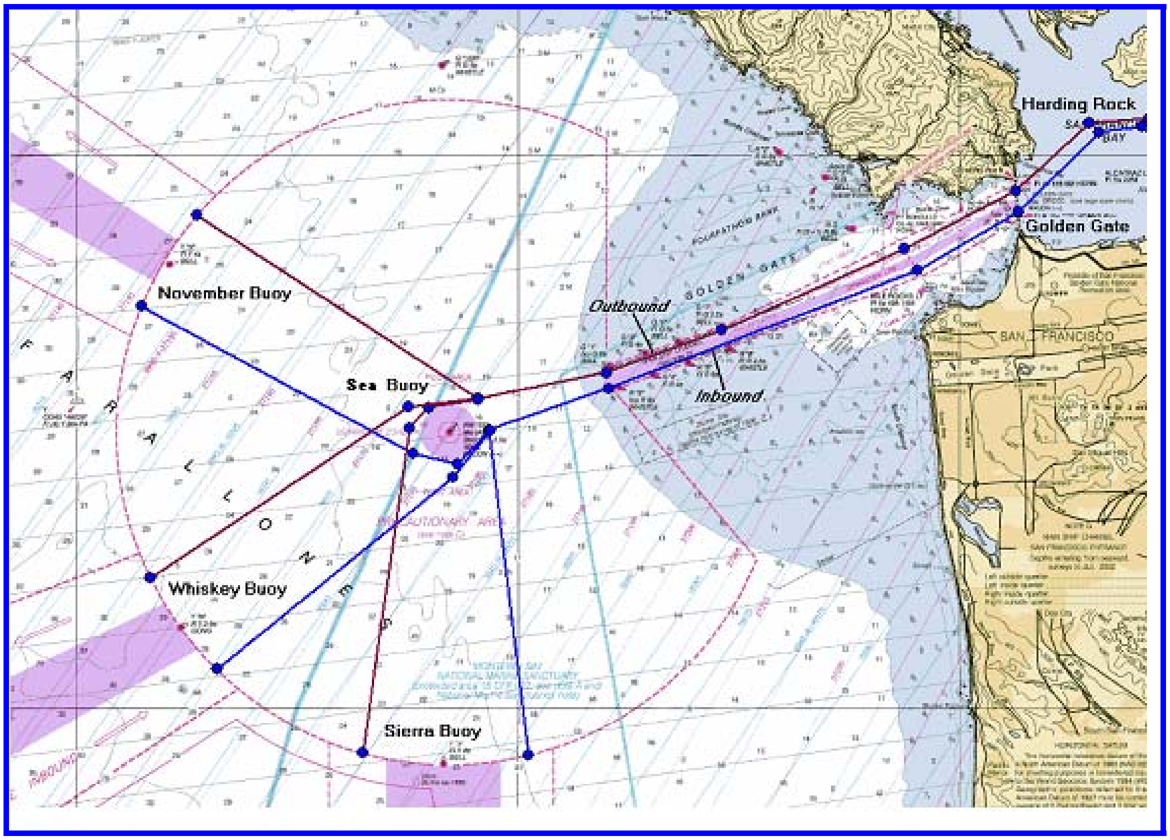


Figure 2-3. Ship Routes Outside of Golden Gate to the Outer Sea Buoys

Calls to or from Korea, Japan, China, Canada, or Seattle were assumed to pass the November Buoy. Calls to or from Southeast Asia, Hawaii, or Australia were assumed to pass the Whiskey Buoy. Calls to or from Southern California, Mexico, or Latin America were assumed to pass the Sierra Buoy.

Sometimes the previous or next port of call was a different port within the San Francisco Bay or Delta region. The emissions for these calls were handled on a case by case basis, depending on whether the call was to or from another port included in the inventory. The methodology for multiple-port calls is described later in this report.

Not all calls reported by the Port were found in the SLC database. Likewise, the SLC database sometimes reported calls that were not recorded by the Port. As previously stated, the Port's data governed in all cases. When there was agreement between the two data sources (a ship with the same name calling within a couple of days of the port-recorded date), the anchorage times and previous/next ports reported by the SLC were used.

If a Port-reported call did not have a matching call in the SLC database, (or the SLC database had blanks for previous or next port) then the previous and next ports were assigned based on the dominant previous/next port for that type of carrier at that port. The default anchorage time assumption was zero for calls with no matching entry in the SLC database.

The previous and next ports for cruise ship calls were very straight forward and well documented for the most part. The only exception was the *Norwegian Star* which had two cruises "To Nowhere," as it is advertised. These calls did not have itineraries, but it was assumed that they went straight out the Golden Gate and headed west before returning the next day. This was based on web research that indicates the vessels leave regulated waters as soon as possible so that their casinos can open.

For San Francisco cargo calls, 82% of the calls reported by the port had corresponding calls in the SLC database that included 'previous' port information (75 of the 92 calls). Almost all, 91%, had corresponding calls that included 'next' port information (84 of the 92 calls). The table below summarizes the previous and next port directional information found using the SLC database combined with the Port-provided data. The highlighted directions were used for cargo calls when no other data were available.

Table 2-4: Bulk Carrier & Tanker Previous/Next Port from SLC Database

Direction of Previous Port	No. of Calls	Percent of Calls
North	30	40%
West	5	7%
South	25	33%
Within SF Bay	15	20%
	75	100%

Direction of Next Port	No. of Calls	Percent of Calls
North	41	49%
West	2	2%
South	28	33%
Within SF Bay	13	15%
	84	100%

Generally, vessel activity is by four modes of operation; cruise, reduced speed zone (RSZ), maneuvering, and hotelling.

- The cruise mode occurs in the open ocean where there are fewer navigational challenges and where ships typically operate at their design speed. The average cruising speed for cruise ships is around 20 knots or more and for bulk carriers and tankers it is about 15 knots.
- The RSZ mode requires ships to slow down and stay within prescribed lanes. For arriving ships, the RSZ mode occurs after a pilot takes command of the vessel at the Sea Buoy until the vessel slows to a maneuvering speed directly in front of the Port. For this study, the RSZ mode is further broken down into legs at different operating speeds. General cargo carriers generally travel at 12 knots east of the Sea Buoy. The RSZ mode is similar in reverse order for ships leaving the Port.
- The maneuvering time for this study is considered the time when the vessel is in front of its berth and is maneuvering with tug assistance into or out of berth. It was assumed that each call had 30 minutes total of maneuvering time, 15 minutes inbound and 15 minutes outbound.
- Lastly, the hotelling mode occurs when the vessel is stopped at berth or at anchor in the Bay. During hotelling, the main engines are assumed to be off and only the auxiliary engines are running.

Table 2-5. Summary of Operational Modes and Corresponding Geographic Area

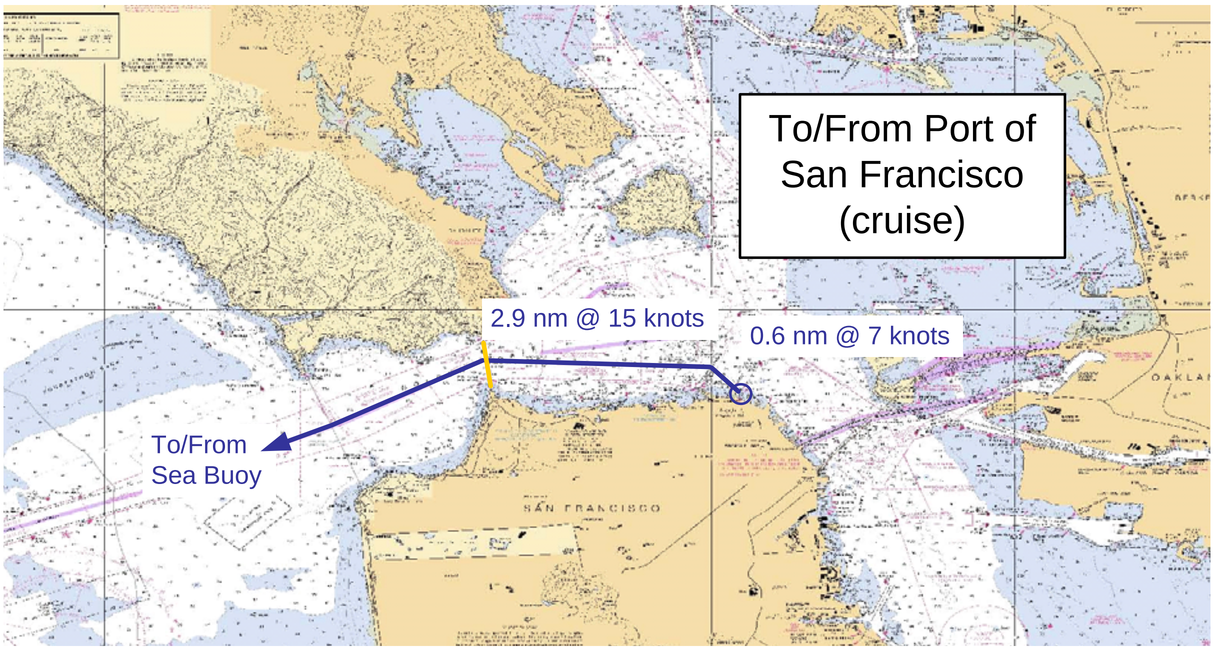
Operation Mode	Description of Corresponding Area
Cruise	The open ocean, west of the Sea Buoy. The limit for tracking emissions in this study is the ring of outer sea buoys about 6-7 nautical miles west of the Sea Buoy
RSZ (Reduced Speed Zone)	The area between the Sea Buoy and the port, essentially most of the time inside the Bay. Ships go different speeds inside the RSZ, anywhere from 3 knots to 15 knots, depending on ship type and destination port (some ports have shoals or turns which require slowing down).
Maneuver	The time spent directly in front of the terminal, maneuvering with tug assist into and out of berth
Hotel	The time spent at berth with the main engines off (discharging and loading cargo) plus any time spent at anchor.

Typical vessel routes and speeds[6] to San Francisco cruise and cargo terminals are shown in dark

6 From a meeting with SF Bar Pilot Captain Larwood on 7/21/09.

blue (cruise) and orange (cargo) on the nautical charts on the next page, Figure 2-4. The labels show the distance for legs with the same speed; the approximate location of speed changes are marked with a black X on the chart. According to SF Bar Pilot, cruise ships can travel at 15 knots for most of the transit to Pier 35, but bulk carriers in general can only go 12 knots inside the Bay.

The black dashed line on the cargo chart shows the route and speed to Anchorage 9. No cruise ships anchored in 2005. About 27% of San Francisco's cargo calls spent time at anchorage in 2005. When anchoring occurred, the average length of time was 10 hours.



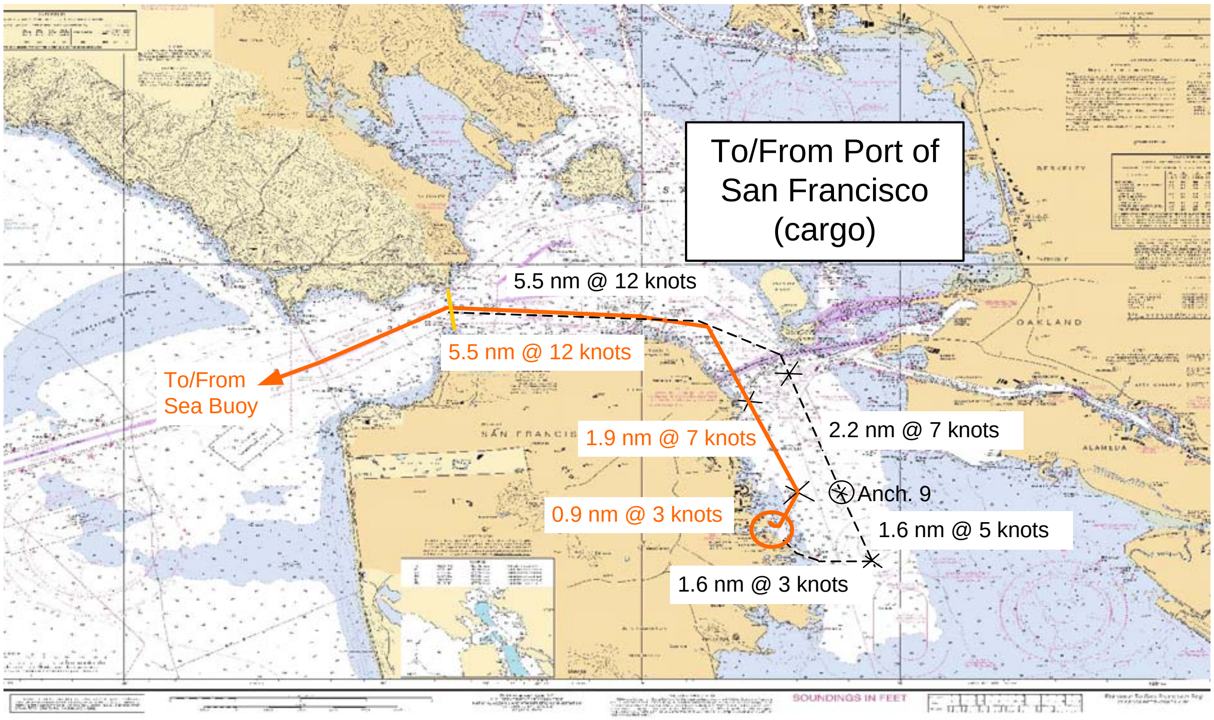


Figure 2-4. Ship Routes Inside of Golden Gate to San Francisco

Table 2-6 through Table 2-8 summarize the information presented graphically on the nautical charts above. The first table describes the links for cruise ships going to Pier 35. None of these calls anchored.

Table 2-6. Summary of Cruise Ship Transit Links

Link Description	Distance (nm)	Speed (knots)	Duration (hrs)
Outer ring of sea buoys to Sea Buoy (Distance: north buoy/west buoy/south buoy)	7.2/6.5/5.8 avg = 6.5	15	0.43
Pilot Boarding Activity	1.7	8	0.21
Sea Buoy to Golden Gate	8.7	15	0.58
Total outside Golden Gate*	**16.9**		**1.2**
Golden Gate to point north of Pier 45	2.9	15	0.19
Point north of Pier 45 to berth	0.6	7	0.09
Total inside Golden Gate	**3.5**		**0.3**
* Calculated using average of three outer buoys.			

The second two tables describe the links for the cargo ships that went to the industrial terminals at Piers 80, 82, and 94; the first table for ships that did not go to Anchorage 9, and the second for ships that did go to Anchorage 9.

Table 2-7. Summary of Cargo Ship Transit Links - Without Anchorage

Link Description	Distance (nm)	Speed (knots)	Duration (hrs)
Outer ring of sea buoys to Sea Buoy (Distance: north buoy/west buoy/south buoy)	7.2/6.5/5.8 avg = 6.5	12	0.54
Pilot Boarding Activity	1.7	8	0.21
Sea Buoy to Golden Gate	8.7	12	0.73
Total outside Golden Gate*	**16.9**		**1.5**
Golden Gate to point south of Bay Bridge	5.5	12	0.46
Point south of Bay Bridge to entrance to Islais Creek channel	1.9	7	0.27
Entrance to Islais Creek channel to berth	0.9	3	0.30
Total inside Golden Gate	**8.3**		**1.0**
* Calculated using average of three outer buoys.			

Table 2-8. Summary of Cargo Ship Transit Links - With Anchorage

Link Description	Distance (nm)	Speed (knots)	Duration (hrs)
Outer ring of sea buoys to Sea Buoy (Distance: north buoy/west buoy/south buoy)	7.2/6.5/5.8 avg = 6.5	12	0.54
Pilot Boarding Activity	1.7	8	0.21
Sea Buoy to Golden Gate	8.7	12	0.73
Total outside Golden Gate*	**16.9**		**1.5**
Golden Gate to point south of Bay Bridge	5.5	12	0.46
Point south of Bay Bridge to center of Anchorage 9	2.2	7	0.31
Time at anchor	n/a	n/a	n/a
Center of Anchorage 9 to point east of India Basin	1.6	5	0.32
Point east of India Basin to berth	1.6	3	0.53
Total inside Golden Gate	**10.9**		**1.6**
* Calculated using average of three outer buoys.			

As noted previously, there were some non-cargo, non-passenger calls to San Francisco in 2005. The in-Bay transit distance (from Golden Gate to berth) to the MARAD dock is 6.7 nm and takes about 40 minutes. The in-Bay transit distance to SF Dry Dock is 7.4 nm and takes almost 50 minutes.

Multiple Port Calls

As stated before, the emissions for ships calling multiple ports within the SF Bay are more complex than single port callers. These are handled on a case by case basis, as described in this section.

In 2005, the *Nelvana* called nine times at both Redwood City and at the Hanson terminal at the Port of San Francisco (it also called 12 other times in San Francisco without visiting Redwood City). It anchored first in all nine instances. The transit and anchoring emissions for these nine calls were divided equally between Redwood City and San Francisco. The hotelling emissions were attributed to each port accordingly.

Similarly, the *Spring Virgo* called both at Darling International in San Francisco and at Cal Oils in Richmond in May 2005. It was assumed that the two calls occurred on the same visit (Cal Oils did not provide arrival dates, only the month). Therefore, the transit emissions for the whole visit were divided equally between San Francisco and Richmond. The hotelling emissions were attributed to each port accordingly, and there was no anchoring.

There were three calls that went to Oakland after leaving San Francisco. Since these were bulk carriers and not container ship calls, it was assumed that they were bound for Schnitzer Steel (a metal recycling terminal in Oakland's inner harbor). Schnitzer Steel was not included as part of Oakland's inventory because it is a private terminal. Accordingly, this inventory includes the transit from the sea buoy to San Francisco and the hotelling emissions while at San Francisco, but not the transit to Oakland or back out the Golden Gate. None of these three calls involved anchoring.

Similarly, there were ten calls to San Francisco that came from Oakland. Again, these must have come from Schnitzer Steel which is not included in this inventory. Therefore, the transit emissions from the Golden Gate to Oakland and Oakland to San Francisco are not included. Only the hotelling while at San Francisco and the transit emissions outbound from San Francisco are included. None of these ten calls involved anchoring.

There were two calls that went from Stockton to San Francisco and then departed for Southern California. The inbound transit emissions to Stockton and from Stockton to San Francisco are not included because the Port of Stockton is not part of this inventory. For these two calls, only the hotelling emission while at San Francisco and the transit emissions out the Golden Gate to the south are counted. Similarly, there were two calls that sailed to Stockton after leaving San Francisco. For these two calls, only the inbound transit emissions and the San Francisco hotelling emissions were included. None of the four calls associated with Stockton included any anchoring.

One call, by *Le Grand Bleu* on 9/20/2005, came from Sacramento, went to anchor, went to San Francisco, and then left for Hawaii. For this call, the anchorage emissions, the transit from Anchorage 9 to San Francisco, hotelling while at San Francisco, and transit out the Golden Gate to the west were all included. Inbound transits through the Golden Gate to Sacramento and from Sacramento to Anchorage 9 were not included.

Three tanker calls came from Richmond before calling at Darling International. Although tankers do travel between Darling and Cal Oils, Cal Oils did not report any calls by the *Akademik Semenov* (two calls, April and August) or by the *Kamogawa* in June. Therefore, it was assumed that these three calls were from a private terminal in Richmond that is not part of this inventory. Accordingly, the inbound transit from the Golden Gate to Richmond and transit from Richmond to San Francisco are not included. The hotelling emissions while at San Francisco and the outbound transit through the Golden Gate are included. None of these three calls went to anchor.

2.3 Emission Calculation

The equation below is the basic equation used to estimate emissions. The inputs are the engine rated power, typical load factor, and time at that load. Emissions for propulsion engines, auxiliary engines, and boilers were determined separately using emission factors provided by CARB. The rated power is the maximum power that the engine can produce.

> Emissions per vessel/mode = (Rated Power) x (Load Factor) x (Time) x (Emission Factor)
> Emissions total = Σ\{All vessel calls and modes\}

The time in each mode was calculated using the link lengths and estimated speeds, as shown on the nautical charts above. The load factor depends on the vessel's maximum speed and the actual vessel speed in each mode.

2.4 Load Factors

Main Engine Load Factors

The maximum power and speed of each vessel (not the design power and design speed) are needed to calculate load factors. Factors derived from the Port of Los Angeles emission inventory study (Starcrest, 2005) survey data were used to adjust the design power and design speeds as shown in the equations below.

> Maximum Propulsion Power = Design Power / (0.968)
> Maximum Speed = Design Speed / (0.968)

The load factors for the propulsion power over any given link were determined from the classic Stokes Law cubic relationship for speed and load. The proportional relationship of load to vessel speed is expressed in the following equation. A 100% load factor corresponds to the vessel operating at its maximum speed.

> Load Factor = $(\text{Vessel Speed} / \text{Vessel Maximum Speed})^3$

From the Port of Los Angeles study (Starcrest, 2005), the cruise speed of the vessel was estimated to be 0.937 of the maximum speed. This definition of cruise speed results in a load factor of 0.823 during cruise conditions.

Auxiliary Engine Load Factors

The CARB (2005a) load factors listed in Table 2-9 were used in this study, consistent with the Oakland inventory.

Table 2-9. Auxiliary Engine Load Factors

Ship Type	Cruise	Reduced Speed Zone (RSZ)	Maneuver	Hotel
Container Ship	0.13	0.13	0.50	0.18
Car Carrier (or Ro/Ro)	0.15	0.15	0.45	0.26
Bulk Carrier (or General)	0.17	0.17	0.45	0.10
Cruise Ship (or Passenger)	0.80*	0.80*	0.64	0.16
Tanker	0.24	0.24	0.33	0.26
* Cruise ship load factors in RSZ mode were adjusted as is described in the next paragraph.				

Source: CARB, 2005a

Cruise Ship Load Factors

The load factors for cruise ships must be handled differently from the load factors for any of the other types of ships included in this inventory. This is because cruise ships have a different engine arrangement than other ship types. They do not have the same clear distinction between main engines and auxiliary engines that other ships have. For cruise ships, the emissions were calculated for total ship power and not for main engines and auxiliary engines separately.

Cruise ships use diesel-electric engines, meaning they have a bank of diesel engines that are connected to an electrical generator. The electrical generator provides power for propulsion as well as for all on-board electrical requirements. On-board electricity demand on cruise ships can be substantial, considering these ships are like small cities. The individual engines connected to the generator can be turned on and off by the captain as needed, so they are not all always running.

M&N/ENVIRON applied the CARB load factors shown in Table 2-9 in the following manner:

- Hotelling load factor is 16% of total ship power
- Maneuvering load factor is 64% of total ship power
- Cruising load factor is 82.3% of total ship power (this follows the main engine methodology, which relies on calculating maximum ship power and maximum ship speed based on the stated design power and speed)
- The RSZ load factors, which apply to all speeds between hotelling and cruising, were calculated by interpolating between the hotelling and cruising load factors using Stokes law (the cube of actual speed divided by maximum speed).

2.5 Emission Factors

Emission factors depend on the type of engine and fuel used in the vessel for propulsion or auxiliary engines. Three types of engines can be used on ships; slow speed engines (2-stroke and typically lower than 250 rpm), medium speed engines (4-stroke and used primarily for auxiliary engines), and steam boilers coupled with steam turbines.

The propulsion engines used on vessels calling at cargo terminals at the Port of San Francisco were mostly slow speed engines. Only two ships (which each called once) were medium speed engines. It was assumed that all of the cruise ships were medium speed engines. Consistent with Oakland's inventory, it was assumed that all vessels use medium speed engines in their auxiliary engines based on experience and limited survey information.

CARB provided a set of emission factors to be used in this study for consistency with other work performed for the San Pedro Bay ports and elsewhere in California. These emission factors are shown in Table 2-10.

Table 2-10. Emission Factors, Propulsion and Auxiliary Engines

Emission Factors (g/kW-hr)						
Engine Type	**Fuel Type**	**HC**	**CO**	**NOx**	**PM10**	**SO2**
Slow Speed Propulsion	Residual Oil	0.6	1.4	18.1	1.50	10.5
Medium Speed Propulsion	Residual Oil	0.5	1.1	14.0	1.50	11.5
Medium Speed Auxiliary	Residual Oil	0.4	1.1	14.7	1.50	12.3
Medium Speed Auxiliary	Marine Distillate (0.5% S)	0.4	1.1	13.9	0.38	4.3
Steam Boiler	Residual Oil	0.1	0.2	2.1	1.50	16.5

Sources: CARB (2006)

One area of uncertainty in estimating emissions from OGVs is the particulate matter (PM) emission factors, including the factors shown in Table 2-10. This is because there is a smaller set of data for particulate emissions than for other pollutants. During weekly coordination conference calls with the Port of Oakland and BAAQMD staff, CARB (2007a) described in detail the available data and noted that, while the range of PM emission rates is from 1.7 to 1.1 g/kW-hr, the preponderance of the data indicated that the 1.5 g/kW-hr emission factor is justified.

The NOx emission factor for vessels built in year 2000 or after was adjusted according to MARPOL Annex VI, Regulation 13 for NOx emissions. For slow speed engines, the NOx factor drops from 18.1 g/kW-hr to 17 g/kW-hr. For medium speed engines, the NOx factor is calculated as:

$$\text{NOx factor in g/kW-hr} = 45 \times (\text{engine speed in rpm})^{-0.2}$$

<u>Fuel Types</u>

CARB (2005a) determined from ship surveys that 92% of passenger vessels use residual oil and 8% use distillate in their auxiliary engines. For all other types of vessels, 71% use residual oil and 29% use distillate in their auxiliary engines.

Consistent with Oakland's inventory, a weighted average for the two emission factors was calculated and applied to all auxiliary engines. This was derived by multiplying the medium speed auxiliary emission factors using residual oil by 71% (or 92% for cruise ships), and the medium speed auxiliary emission factors using marine distillate by 29% (or 8% for cruise), and adding the two together.

Conversion from HC to ROG

Hydrocarbons and reactive organic gases are similar, although not identical. ROG includes aldehydes and alcohols, but excludes methane. Emission factors for OGVs are listed in terms of HC, which must be converted to ROG to be consistent with the other sources. The conversion from HC to ROG used the same factors that were used in the Oakland inventory.

ROG to HC ratio is 0.8347 for residual fuels and 0.8785 for distillate fuels. For auxiliary engines, of which 71% use residual oil and 29% use distillate (see above), the weighted average conversion factor is 0.8474.

Main Engine Low Load Adjustment Factors

Emission factors for OGVs were derived from data at high operational loads. To estimate emissions at low operational loads (when the engine is less efficient), factors are needed to adjust the emission factors upwards. The factors shown in Table 2-11 below are the same adjustment factors used in Oakland's inventory. These factors do not apply to cruise ships, which mostly have diesel-electric engines, except for the *Oriana*, the *Mercury*, and the *Seven Seas Navigator*, which are motorships.

Table 2-11. Low Load Adjustment Factors for Propulsion Engines

Load %	HC	CO	NOx	PM*	SO2
2	31.62	10.00	4.63	5.60	1.00
3	17.21	6.67	2.92	4.03	1.00
4	11.18	5.00	2.21	3.19	1.00
5	8.00	4.00	1.83	2.66	1.00
6	6.09	3.33	1.60	2.29	1.00
7	4.83	2.86	1.45	2.02	1.00
8	3.95	2.50	1.35	1.82	1.00
9	3.31	2.22	1.27	1.65	1.00
10	2.83	2.00	1.22	1.52	1.00
11	2.45	1.82	1.17	1.40	1.00
12	2.15	1.67	1.14	1.31	1.00
13	1.91	1.54	1.11	1.22	1.00
14	1.71	1.43	1.08	1.15	1.00
15	1.54	1.33	1.06	1.09	1.00
16	1.40	1.25	1.05	1.03	1.00
17	1.28	1.18	1.03	1.00	1.00
18	1.17	1.11	1.02	1.00	1.00
19	1.08	1.05	1.01	1.00	1.00
20	1.00	1.00	1.00	1.00	1.00
*The PM adjustment factor is from CARB, not from the EPA (2000) study like the other pollutants. This is consistent with the Port of Oakland inventory					

Source: Table 2.21 from Starcrest, 2005 (except for PM factors)

A 2% average load was assumed for the maneuvering mode (directly in front of the berth). For the reduced speed zone modes (between the Sea Buoy and berth), the load factor used for each link was derived specifically for each vessel as the cube root of the ratio of actual speed to the calculated maximum speed of the vessel, with a minimum value of 2%.

The maneuvering mode in this study encompasses a number of operations within one average load. Maneuvering emissions were calculating using average emission rates and average adjustment factors. Individual operations during maneuvering include low speed propulsion and vessel turns away from dock as well as engine idling at dock prior to shut down and after the initial start up. In addition, cold start emissions could be significant but have yet to be considered as a separate operational mode. Anecdotal accounts indicate that some load testing of the propulsion engine may occur in the vessel prior to departure from the berth. Emissions and engine loads during all maneuvering activity should be further evaluated to explicitly analyze engine operations, now collectively estimated under the more general term of maneuvering.

Low load adjustment factors only affect propulsion engine emissions because no single (typically each vessel usually has a set of three or more auxiliary engines to provide auxiliary power) auxiliary engine operates below 20% load.

Boiler Emission Factors

Boilers are used on board modern vessels for heat, hot water, and other needs. A fuel consumption rate of 0.0125 metric tonnes per hour (ICF Consulting, 2006) was used to estimate total activity for boilers. For cruise ships, the fuel consumption rate is 0.0305 metric tonnes per hour. ICF Consulting (2006) provided emission factors for boilers which, combined with the fuel consumption rate, were used to estimate emission rates from boilers. Both the emission factors (in terms of emissions per unit of fuel consumed) and the emission rates (emissions per hour) for boilers are shown in Table 2-12.

Table 2-12. Boiler Emission Factors and Emission Rates

Estimate	Units	HC	CO	NOx	PM10	SO_2
Emission Factors	kg / metric tonne of fuel	0.38	4.6	12.3	1.3	54
Emission Rates	kg / hour (using 0.0125 tonnes/hour)	0.005	0.058	0.154	0.016	0.68
Emission Rates for Cruise Ships	kg / hour (using 0.0305 tonnes/hour)	0.012	0.140	0.375	0.040	1.647

Source: ICF Consulting, 2006

A study by the Chamber of Shipping (2007) estimated boiler fuel consumption at 0.14 to 0.18 metric tonnes per hour based on their assessment of the activity of these units. Therefore, the overall activity and emissions could be more than a factor of 10 higher than modeled here. Future studies are needed to better understand the activity and emissions of auxiliary boilers.

2.6 Emission Results

The estimated total emissions from the Port of San Francisco OGVs are presented in

Table 2-13 through Table 2-15 by each mode (cruise, reduced speed zone, maneuver, and hotel). Cruise ships are listed first, followed by cargo ships, and “other” ships. The “other” category includes MARAD vessels, ships going to SF Dry Dock, and the *Jeremiah O’Brien*.

Table 2-13. Emission Results for Cruise Ships (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.90	2.35	29.55	3.21	24.62
RSZ	1.29	3.40	42.47	4.61	35.61
Maneuver	0.54	1.43	17.88	1.94	14.95
Hotel	2.93	7.79	97.96	10.50	81.65
Total	**5.7**	**15.0**	**187.9**	**20.3**	**156.8**

Table 2-14. Emission Results for Cargo Ships (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.31	0.87	11.17	0.94	6.63
RSZ	0.85	2.01	23.64	2.03	13.61
Maneuver	0.16	0.18	1.48	0.14	0.59
Hotel	0.27	1.04	11.67	1.02	9.34
Total	**1.6**	**4.1**	**48.0**	**4.1**	**30.2**

Table 2-15. Emission Results for “Other” Ships (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.15	0.41	5.17	0.53	4.04
RSZ	0.14	0.36	4.41	0.50	3.93
Maneuver	0.03	0.06	0.75	0.08	0.52
Hotel	0.00	0.00	0.00	0.00	0.00
Total	**0.3**	**0.8**	**10.3**	**1.1**	**8.5**

The next set of figures show the same results graphically.

The first chart, Figure 2-5, shows cruise ship emissions by mode (cruise, reduced speed zone, maneuver, hotel). Cruise ship emissions cannot be listed by engine type (main v. auxiliary) the way cargo ship emissions are because of the engine arrangement discussed in Section 2.4.

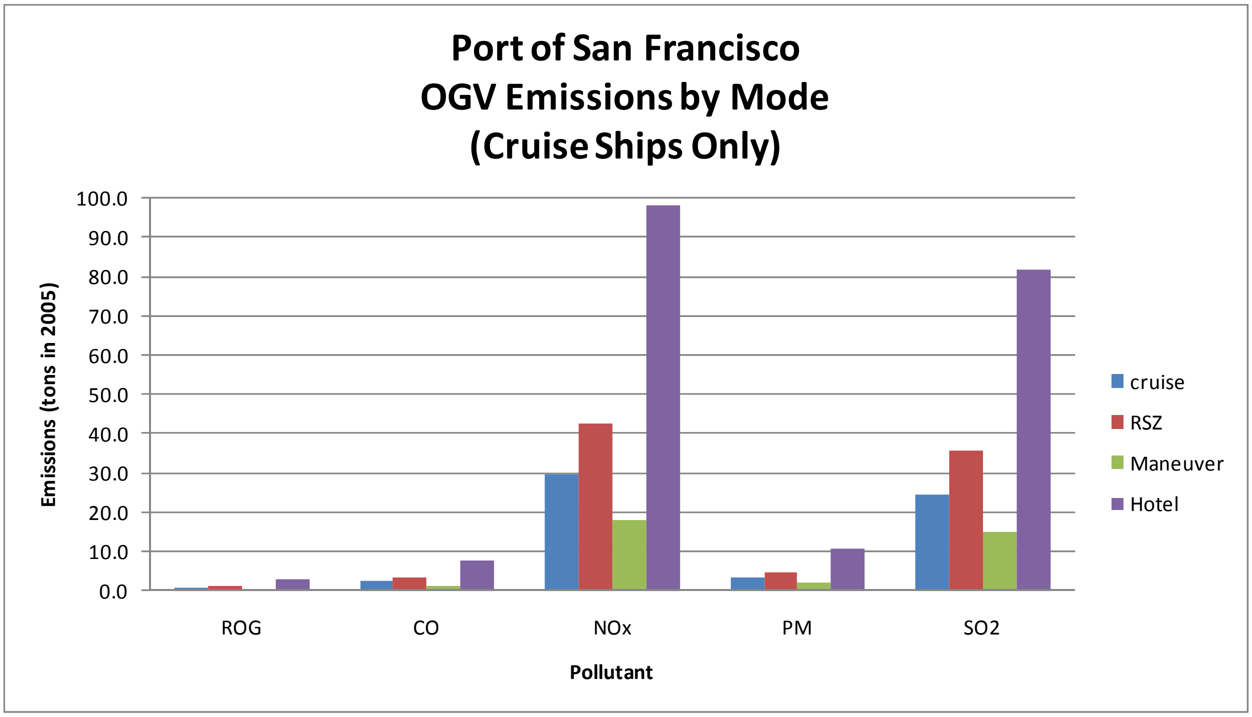


Figure 2-5. Summary of Cruise Ship Emissions by Operational Mode

This figure shows that a little over half of cruise ship emissions (52%) occur while the ships are at berth hotelling.

The next two charts, Figure 2-6 and Figure 2-7, show cargo ship emissions by mode and then by engine type.

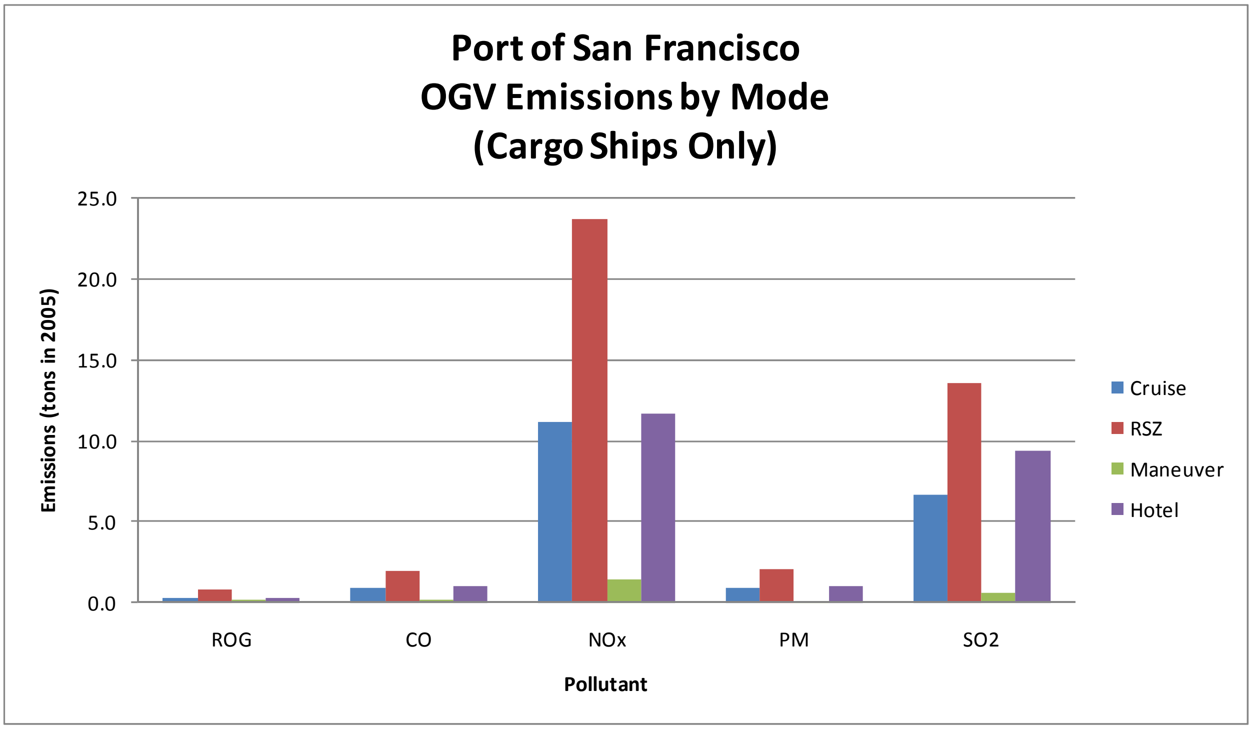


Figure 2-6. Summary of Cargo Ship Emissions by Operational Mode

This shows that cargo ships produce the most emissions during their transit between the Sea Buoy and the dock. Emissions are roughly equal for time spent in cruise mode (outside of the Sea Buoy) and in hotel mode (including time at anchor).

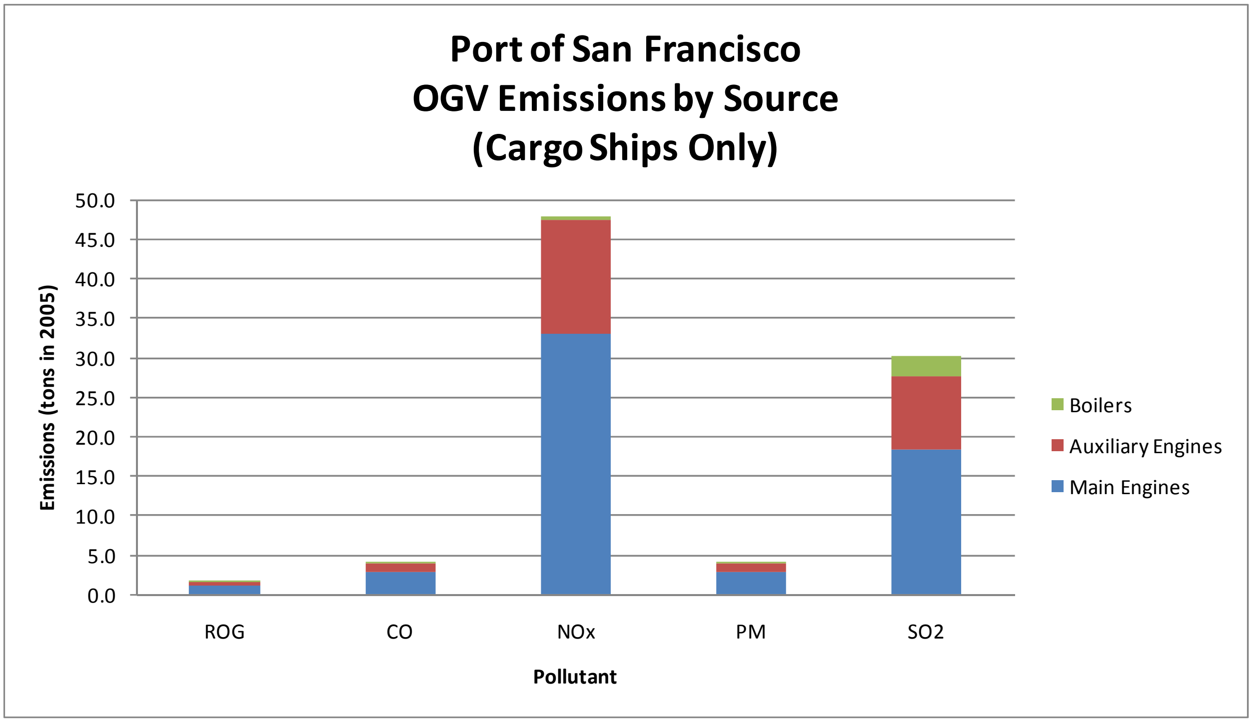


Figure 2-7. Summary of Cargo Ship Emissions by Source

This shows that propulsion engines create the most emissions for cargo ships. This is an intuitive result considering that on-board electrical requirements for cargo ships are relatively low, especially compared with cruise ship power requirements.

The next chart, Figure 2-8, shows the emissions produced by ships going to DryDock (nine calls, all assumed to be by cruise ships), MARAD (three calls, all military), and by the *Jeremiah O'Brien* (six excursions in 2005). All *Jeremiah O'Brien* emissions are included in the reduced speed zone mode, even though some of the emissions probably occurred while at berth.

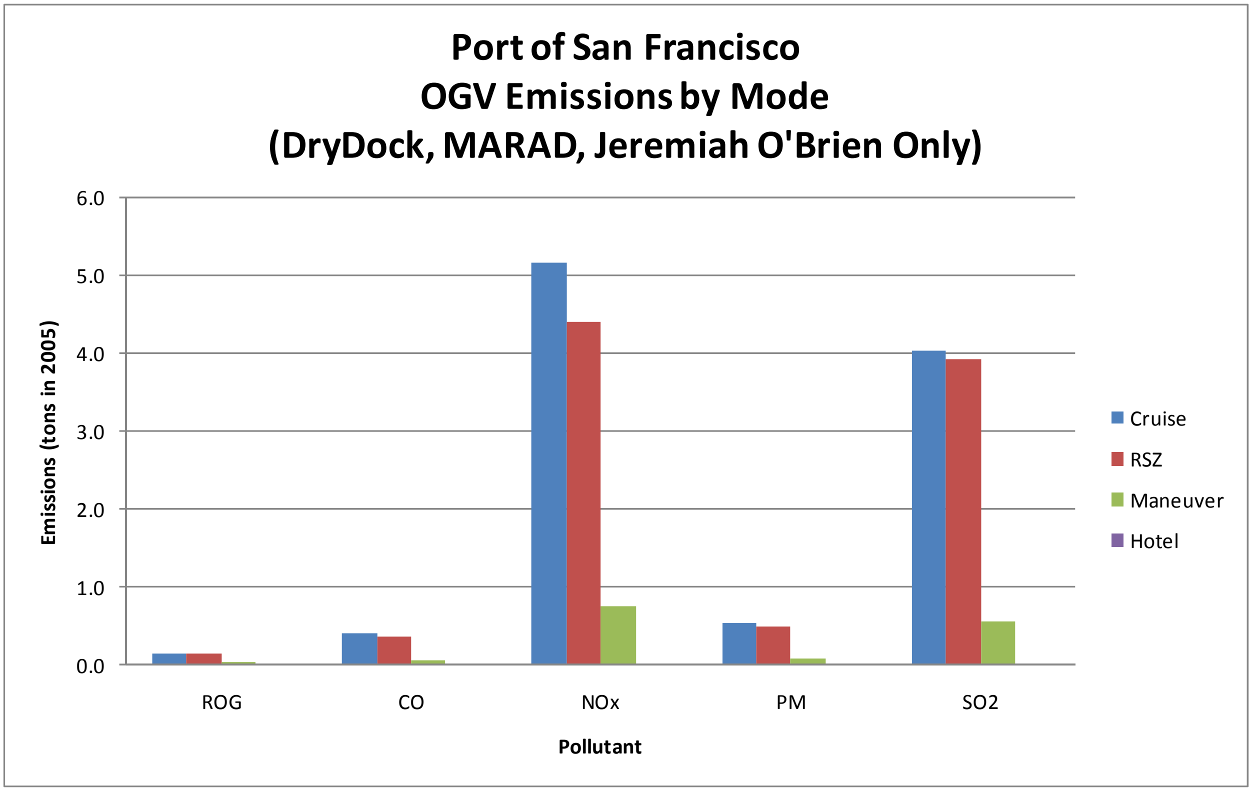


Figure 2-8. Summary of "Other" Ship Type Emissions by Operational Mode

These "other" types of ships produce less than 5% of San Francisco's OGV emissions.

The last chart, Figure 2-9, compares the emissions for all the ship types calling in San Francisco.

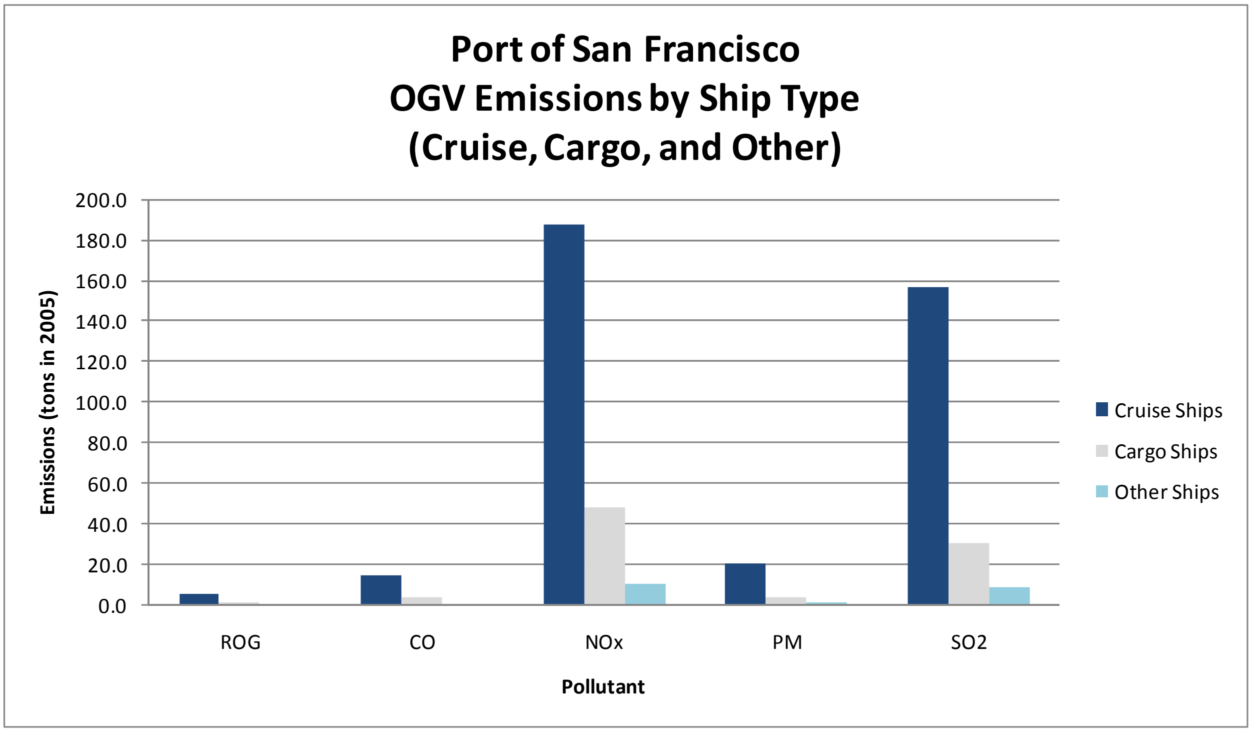


Figure 2-9. Summary of All OGV Emissions by Ship Type

This graph shows that cruise ships are by far the biggest emitters of all the ship types calling in San Francisco. Cruise ships produce about 75-80% of the OGV emissions at San Francisco for all the different criteria pollutants.

3. HARBOR CRAFT

The harbor craft emissions estimates were performed by the Bay Area Air Quality Management District as their in-kind contribution to this inventory effort. They provided a stand-alone report for harbor craft emissions estimates methodology, calculations, and results. The BAAQMD harbor craft report is included as Appendix A of this report.

The main results are presented here in Table 3-1 for easy reference.

Table 3-1. Emission Results for Harbor Craft (tons in 2005)

Harbor Craft	ROG	CO	NOx	PM10	SO_2
Tug Assist					
Main	0.46	1.85	7.51	0.30	0.06
Auxiliary	0.02	0.09	0.31	0.02	0.00
Tug Transit					
Main	0.37	1.48	6.00	0.24	0.05
Auxiliary	0.01	0.05	0.15	0.01	0.00
Barge Tugs					
Main	2.41	7.25	27.71	1.15	0.16
Auxiliary	0.18	0.49	1.17	0.06	0.01
Excursion Vessels					
Main	17.33	55.49	218.76	8.68	2.71
Auxiliary	2.66	7.20	17.42	0.90	0.09
Pilot Boats					
Main	7.07	21.34	81.63	3.35	1.00
Auxiliary	0.54	1.18	1.12	0.10	0.05
Total	**31.1**	**96.4**	**361.8**	**14.8**	**4.1**

4. CARGO HANDLING EQUIPMENT

Emission inventories have been developed for cargo handling equipment, heavy duty trucks, buses and transportation refrigeration units (TRUs) that operate at Port of San Francisco facilities based on the facilities included in this study as specified in the workplan. Sources of associated activity identified in the workplan for inclusion in this study included the following facility types: aggregate processors, bulk processors, break bulk processors, fish processors, cruise vessels and excursion vessels. In coordination with Port of San Francisco staff, data was gathered from each of the above facility types, with the exception of fish processors. Though repeated attempts were made to gather truck and equipment activity associated with fish processors, the data gathered was ultimately not sufficient for use in this project. Therefore, the estimated emissions are not inclusive of emissions from fish processors. Based on the limited data obtained about fish processing facilities, equipment and truck activity at fish processing facilities is likely to be relatively minor compared to other sources included in this study, while the extent of TRU activity is unknown at this time.

4.1 Cargo Handling Equipment Activity and Inventory

This section documents the emission estimation methods and results for cargo handling equipment (CHE) operated at Port of San Francisco in 2005.

CHE has been loosely defined as any equipment used to move freight to and from ships arriving at ports and more specifically defined by a list of equipment types by CARB (2005a). To date, studies (Starcrest, 2008 and ENVIRON, 2008) have largely focused on equipment primarily used to move containers. The Port of San Francisco does not move containers, so the equipment used is atypical of cargo handling equipment. Therefore the approach used in this study was to identify all of the off-road equipment used at maritime Port facilities included in this study regardless of equipment use.

4.2 Emission Calculation Methodology

The approach used to estimate CHE emissions was to determine annual 2005 emissions for each piece of equipment at the Port of San Francisco according to engine characteristics (model year, rated power, and equipment type) and equipment operation (hours of operation and fuel consumption rates). The equipment population and operation estimates were derived from terminal surveys provided to the contractor in 2008 by the Port of San Francisco maritime facility operators (M&N/ENVIRON, 2008). Per CARB (2005a) guidance, the following types of equipment were used to categorize CHE:

- Cranes (including rubber tire gantry cranes)
- Excavators
- Forklifts
- Container Handling Equipment
- Other General Industrial Equipment
- Sweeper/Scrubbers
- Tractor/Loader/ Backhoe
- Yard Trucks

CHE emissions were calculated using the following equation:

$$E_p = EF_{p,t} * (1 - CF) * LF * n * hp * hrs$$

where: E_p = annual emissions of pollutant "p"
EF = emission factor (g/hp-hr)
CF = control factor (% reduction) by pollutant
LF = load factor (average load expressed as a % of rated power)
n = equipment population
hp = rated power (hp)
hrs = hours of activity per year (hr/year)
p = pollutant species (ROG, CO, NOx, PM, SO_2)
t = equipment type

Emission factors depend on the fuel type, model year, rated power, cumulative hours/age, and retrofit control factor, if applicable.

4.3 Input Data and Use

Surveys sent out to the Port of San Francisco were returned with the following detailed information for each piece of CHE. This information was used as input for the emissions estimation.

1. Equipment Type
2. Engine Type
3. Engine Model Year
4. Engine Retrofit Type/Repower
5. Chassis
6. Chassis Model Year
7. Fuel Type
8. Annual hours of operation
9. Rated horsepower
10. Cumulative hours of operation
11. Fuel consumption per piece of equipment

For equipment specific operation and characteristics that were not provided, CHE emissions inventory guidance documentation published by CARB (2005a) were used to obtain estimates of load factor and useful life. Zero hour emission factors, deterioration rates, and fuel correction factors were also taken from CARB (2005a) CHE inventory guidance documentation. For off-road equipment types not defined as CHE, the input data were derived from CARB's OFFROAD2007 (http://www.arb.ca.gov/msei/offroad/offroad.htm) emission inventory model in conjunction with equipment characteristics (model year, rated power, equipment type) and operation (hours of operation) as provided by the terminal operator. Some operators provided activity for the calendar year other than 2005. For those operator's CHE equipments, hours of operation were adjusted by applying the ratio of the tonnage throughput in 2005 to the provided calendar year.

The CHE were grouped into equipment type categories as defined by CARB (2005a). The resulting populations by equipment type for the Port of San Francisco are summarized in Table 4-1. Out of 38 total pieces of CHE equipment, 20 were diesel powered and 18 were LPG (liquid petroleum gas) powered.

Table 4-1. Cargo Handling Equipment - Population by Type.

Equipment Type	Population	Percentage
Forklift	27	71%
Tractor/Loader/Backhoe	9	24%
Other General Industrial Equipment	1	3%
Sweeper/Scrubbers	1	3%
Total	**38**	**100%**

Table 4-2 summarizes the average horsepower and annual use by equipment type and power range. Actual annual hours of operation for each piece of equipment were used to estimate emissions.

Table 4-2. Cargo Handling Equipment – Engine Size and Operating Hours

ARB General Equipment Type	Upper End Power Range (hp)	Number of Equipment	Average Power (hp)	Average Annual Operation (hours)
Forklift	120	67	16	224
	250	190	1	213
	500	278	10	1,582
Tractor/Loader/Backhoe	120	74	1	500
	250	205	1	320
	500	307	3	1,761
	750	750	4	1,217
Other General Industrial Equipment	120	100	1	128
Sweeper/Scrubbers	250	180	1	150

4.4 Cargo Handling Equipment Emission Results

Using the surveyed equipment population, activity, and other input data, Port of San Francisco CHE emissions were estimated using the CHE emissions spreadsheet model provided to M&N/ENVIRON by ARB (ARB, 2007). Table 4-3 and Table 4-4 present emission results for the CHE based on surveys at the Port of San Francisco by equipment type and by fuel type respectively.

Table 4-3. CHE Emissions by Equipment Type (tons in 2005)

Equipment Type	ROG	CO	NOx	SO_2	PM10
Forklift	1.389	6.683	14.238	0.076	0.649
Other General Industrial Equipment	0.015	0.148	0.076	<0.001	<0.001
Sweeper/Scrubbers	0.007	0.021	0.131	0.001	0.003
Tractor/Loader/Backhoe	1.692	6.166	25.871	0.239	0.850
Total	**3.103**	**13.018**	**40.315**	**0.316**	**1.503**

Table 4-4. CHE Emissions by Fuel Type (tons in 2005)

Fuel Type	ROG	CO	NOx	SO_2	PM10
LPG	0.236	2.317	0.898	<0.001	0.006
Diesel	2.867	10.701	39.417	0.316	1.497
Total	**3.103**	**13.018**	**40.315**	**0.316**	**1.503**

5. HEAVY DUTY ON-ROAD VEHICLES

This section describes the typical annual on-road vehicle activity demands, average vehicle characteristics and travel modes, and estimates spatially allocated emissions for activity that occurred at the Port of San Francisco in 2005. It was beyond the scope of this report to develop specific travel demand models or collect specific activity data, including determining routes of individual vehicle trips, and ultimate destinations for each vehicle.

Port of San Francisco maritime related operations create a demand for truck trips transporting aggregate materials and other cargo between marine terminals and the freeways and buses which transport people to and from the port as part of cruise and excursion vessel operations.

Activities considered in this category were heavy-duty trucks and buses traveling to and from the terminal to the nearest freeway entrance or within city or from one terminal to another terminal or to nearby parking lots. The on-road vehicles depart from the Port area via Highway 101, the Bay Bridge, or by using city interchanges. The project team therefore defined the study area for this air emissions inventory to include on-road vehicle routes between the marine terminals and freeway or city local interchanges.

The on-road fleet activity and the ARB EMFAC model were used to estimate emissions from on-road vehicles, idling and moving in the Port area. The most recent version of the EMFAC2007 model (version 2.3) available at the time of this study was used to estimate emissions.

5.1 Emission Calculation Methodology

The general approach used to estimate emissions from on-road vehicles was by characterizing the trips to and from the marine terminals. Survey data was collected for gate counts along with estimates of trip mileage, average speed for vehicles within the terminal, idle time within the terminal, count of buses moving through the terminal and route to and from the terminal to the point at which it is no longer possible to estimate the route (typically the nearest freeway interchange). The on-road vehicle emissions were estimated using the following equation.

$$E_p = n_{\text{on-road vehicle Trip}} * Miles_{Trip} * EF_p$$

where: E_p = emissions of pollutant "p"
n = number of trips
Miles = trip mileage or hours at idle
EF = emission factor (g/mile, g/hour) for pollutant "p"
(Requires trips to be defined by speed)

The input activity data were gathered from several distinct sources. The trips were determined for each terminal and applied to routes within the Port area. The necessary input data were as follows:

1. Trips
   a) Truck trips (to and from freeway)
   b) Bus trips (to and from freeway)

2. Trip mileage (routes)
   a) Outside of the terminals
   b) Within the terminal

3. Idle time (for transport trucks only)
   a) Outside terminals entrance queues
   b) Within terminal

4. Emission factors derived from the EMFAC2007 model based on
   a) Vehicle type
   b) Age distribution
   c) Average trip speed
   d) Idle emission rate

5.2 Trip Counts

The most basic measure of truck activity is the number of truck trips through each terminal facility, where a trip includes both an entrance and an exit by the vehicle/truck. A survey was provided to the Port of San Francisco terminal operators included in this study, which asked the operators to provide all data necessary to estimate truck trips and within-terminal mileage and idling. The operators provided gate counts indicating the number of trucks entering the facility and the number of trucks exiting the facility in 2005. The number of trucks entering and leaving each facility was equivalent, and therefore, the number of truck trips was determined to be equivalent to the number of entering and exiting trucks.

The operators also provided a count of buses which were use to transport people to and from the terminal as part of cruise and excursion vessel operations.

Some operators provided trip count for the calendar year other than 2005. For those instances, the trip counts were adjusted by applying the ratio of the tonnage throughput in 2005 to the provided calendar year. The total number of truck and bus trips obtained from operator surveys is summarized in Table 5-1.

Table 5-1. Total Truck and Bus Trips, 2005

Vehicle Type	Trips
Heavy-Heavy Duty Trucks	105,740
Buses	2,923

5.3 Terminal to Freeway Route

Terminal operators provided average speed and distance traveled by a typical truck and bus within the terminal. For the trucks and buses where average speed, idle time and distance within the terminal is not provided, ENVIRON used average speed, idle time and distance provided by other operators. The truck and bus movements occurred at Pier 30-32, Pier 35, Pier 39, Pier 43$^{1/2}$, Pier 80, Pier 92, and Pier 94. Operators provided truck and bus off-site travelling routes and where not provided, ENVIRON assumed on-road vehicles will travel to the nearest freeway entrance.

Google earth was used to estimate the total distance from the terminal gate to the freeway interchange for trucks and buses and composite speeds through the routes were estimated using the total mileage of the entire route divided by the total time from start to end destination obtained from Google Maps. The off-site distance travelled by truck from each terminal and composite speed through the routes are summarized in Appendix B. The emission rates estimated by EMFAC at the estimated average speed are meant to approximate emissions rates over the route, but do not account for speed fluctuations. The maps showing the route for on-road vehicles travelling from different terminals to off-site are reported under Appendix B.

5.4 Emission Factors

The EMFAC2007 model was used for this analysis because this is the approved model for on-road emission analysis. Emission rates from on-road vehicles depend on the age distribution of the transport vehicles as well as site-specific conditions such as humidity, temperature, and, especially, average speed. Age distribution plays a significant role because of recent regulations that significantly reduce criteria pollutant emissions from the newer fleet. In particular, for heavy-duty trucks of model years 1991 to 2003, steep declines in NOx and PM emission rates occurred.

Figure 5-1 shows a sample of the emission factors (specific for 10 mph average speed) by model year for heavy-duty trucks. It is evident that the age distribution of the fleet of vehicles affects the emissions of the truck fleet serving Port terminals because older model year trucks have significantly higher emissions. Port of San Francisco was not able to provide facility-specific age distribution; hence the EMFAC2007 default age distribution for San Francisco County was used.

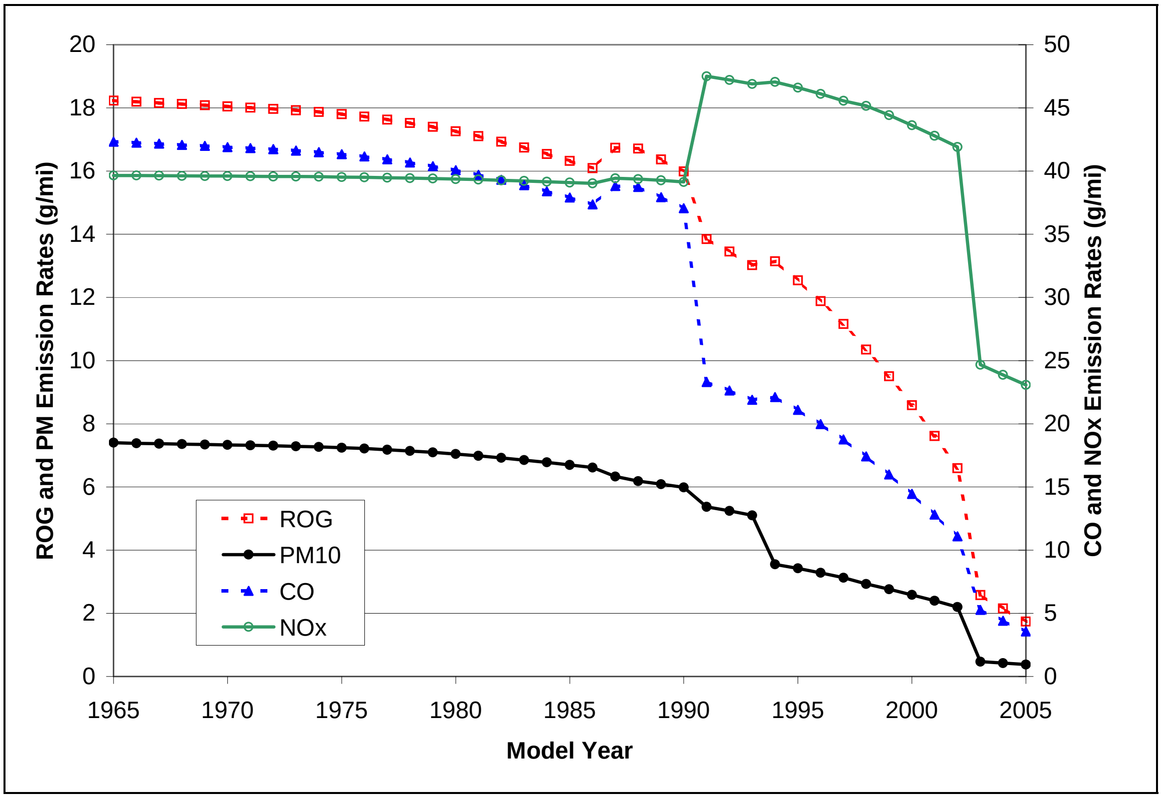


Figure 5-1. Truck emission factors at 10 mph in 2005 as modeled by EMFAC2007

The project team used ROG, CO, NOx, PM, and SO_2 EMFAC2007 emission factors estimates in grams per mile (or grams per hour for idling) for various vehicle speeds. The emission factors by model year were determined by running the model in "burden mode." The burden mode generates the total San Francisco County emissions inventory, population, and VMT. The emission factors are back calculated from these using area-wide emissions and activity totals. These emission factors were calculated using the average of all conditions over the year. The emission factor results used were for calendar year 2005 and included all model years from 1965 to 2005. Table 5-2 shows the average emission factors for trucks and buses travelling at the Port of San Francisco in 2005.

Table 5-2. Average Truck and Bus Emission Factors

Speed (mph)	Emission Factors (g/hour or g/mile)				
	ROG	CO	NOx	PM10	SO_2
Heavy Heavy Duty Trucks					
Idle	12.82	51.51	108.85	2.12	0.58
3	13.00	20.91	49.38	3.84	0.34
5	13.00	20.91	49.38	3.84	0.34
6	12.40	20.42	47.64	3.77	0.34
10	9.98	18.49	40.69	3.19	0.28
12.4	7.73	16.48	34.60	2.74	0.26
15	5.30	14.30	28.00	2.19	0.23
16.6	3.87	12.65	24.85	1.80	0.22
21	2.30	10.60	21.47	1.36	0.19
24	1.86	9.41	20.76	1.22	0.18
25.2	1.70	8.95	20.50	1.17	0.18
Buses					
7	4.59	37.04	38.36	0.86	0.23
21	1.98	14.52	22.37	0.42	0.23
21.8	1.90	13.95	21.92	0.41	0.23
36	1.00	7.51	17.58	0.24	0.23

5.5 On-Road Truck and Bus Emissions Results

Total emissions for the calendar year 2005 for trucks and buses that traveled within the terminal and off-site are presented in Table 5-3.

On-road trucks and buses travelling within the Port of San Francisco terminals emitted approximately 14.1 tons of NOx and 0.9 tons of PM within the Port area. The in-terminal truck emissions for all pollutants are slightly lower than the off-site emissions from the trucks and buses traveling from the Port to off-site. For PM emissions, idling plays a minor role. Emissions from off-site travel of buses and trucks represent about 66% of the PM emissions and 65% of the total NOx emissions.

Table 5-3. Emission Results for Trucks and Buses (tons in 2005)

Emission Category	Emissions				
	ROG	**CO**	**NOx**	**PM10**	**SO_2**
Heavy Heavy Duty Trucks					
Within terminal driving	0.804	1.416	3.195	0.250	0.022
Within terminal idling	0.234	0.939	1.984	0.039	0.011
Outside terminal idling	0.008	0.031	0.065	0.001	<0.001
Travel from Port of freeway	0.983	3.848	7.970	0.522	0.070
Trucks Totals	2.028	6.234	13.214	0.812	0.103
Buses					
Bus pick-up and drop-off	0.034	0.252	0.391	0.007	0.004
Buses total	**0.034**	**0.252**	**0.391**	**0.007**	**0.004**
Total	2.063	6.486	13.605	0.820	0.107

6. TRANSPORTATION REFRIGERATION UNITS

This section describes the typical annual transportation refrigeration unit (TRU) emissions for activity that occurred at the Port of San Francisco in 2005. Transportation refrigeration units are used to regulate temperature during transport for products with temperature requirements.

6.1 Emission Calculation Methodology

2005 TRU emissions were estimated in accordance with the methodology used in the ARB OFFROAD 2007 model. The number of TRU containers entering or handled by the facility and hours of operation estimates were derived from terminal surveys provided to the contractor by the Port of San Francisco maritime facility operators. These activity data were used to estimate TRU emissions along with ARB default age, horsepower, load factor and emission factors.

All TRUs are assumed to use diesel fuel and be within the 25 to 50 horsepower range. The surveys indicated that in 2005, 120 TRU containers entered or were handled at POSF facilities with each TRU spending an average of three hours onsite.

TRU emissions were calculated using the following equation:

$$E_p = EF_p * LF * n * hp * hrs$$

where: E_p = annual emissions of pollutant "p"
EF = emission factor (g/hp-hr)
LF = load factor (average load expressed as a % of rated power)
n = number of TRU
hp = rated power (hp)
hrs = hours of activity per year per TRU (hr/year/TRU)
p = pollutant species (ROG, CO, NOx, PM, SO_2)

6.2 TRU Emissions Results

Emissions from transportation refrigeration units at the Port of San Francisco are shown in Table 6-1.

Table 6-1. Emission Results for TRUs (tons in 2005)

TRUs	ROG	CO	NOx	SO_2	PM10
Total	**0.024**	**0.055**	**0.048**	**0.001**	**0.006**

7. LOCOMOTIVES

The harbor craft emissions estimates were performed by the Bay Area Air Quality Management District as their in-kind contribution to this inventory effort. They provided a stand-alone report for harbor craft emissions estimates methodology, calculations, and results. The BAAQMD locomotive report is included as Appendix C of this report.

The main results are presented here in Table 7-1 for easy reference.

Table 7-1 Emission Results for Locomotives (tons in 2005)

	ROG	CO	NOx	PM10	SO_2
Total	**0.04**	**0.07**	**0.16**	**0.02**	**0.00**

8. SUMMARY OF RESULTS

The Port of San Francisco was part of a cooperative effort to create emissions inventories for the major public ports in the San Francisco Bay Area. The project was spearheaded by the Bay Planning Coalition and done in close partnership with the Bay Area Air Quality Management District under the terms of a Memorandum of Agreement. The other ports involved were Benicia, Richmond, Redwood City, and Oakland. The Port of Oakland had already completed a 2005 inventory prior to this multi-port effort. This inventory, and those of the other participating ports, was done using the same methodology and factors as the Port of Oakland inventory in order to be consistent with Oakland's inventory. By using a consistent approach for all five ports' inventories, a broader understanding of the maritime activities in the Bay Area can be realized.

The following table, Table 8-1, summarizes the 2005 emissions from the Port of San Francisco's maritime activities.

Table 8-1. Summary of Emission Results for Port of San Francisco (tons in 2005)

Source Category	**ROG**	**CO**	**NOx**	**PM10**	**SO_2**
Ocean-Going Vessels (OGV)	7.6	19.9	246.1	25.5	195.5
Harbor Craft (HC)	31.1	96.4	361.8	14.8	4.1
Cargo Handling Equipment (CHE)	3.1	13.0	40.3	0.3	1.5
Heavy Duty On-Road Vehicles (HDV)	2.1	6.5	13.6	0.8	0.1
Transportation Refrigeration Units (TRU)	0.0	0.1	0.0	0.0	0.0
Rail Locomotives (RL)	0.0	0.1	0.2	0.0	0.0
Total	**43.9**	**136.0**	**662.0**	**41.5**	**201.2**

The same results are shown graphically in Figure 8-1. The TRU emissions are not shown in the graph because they are so small.

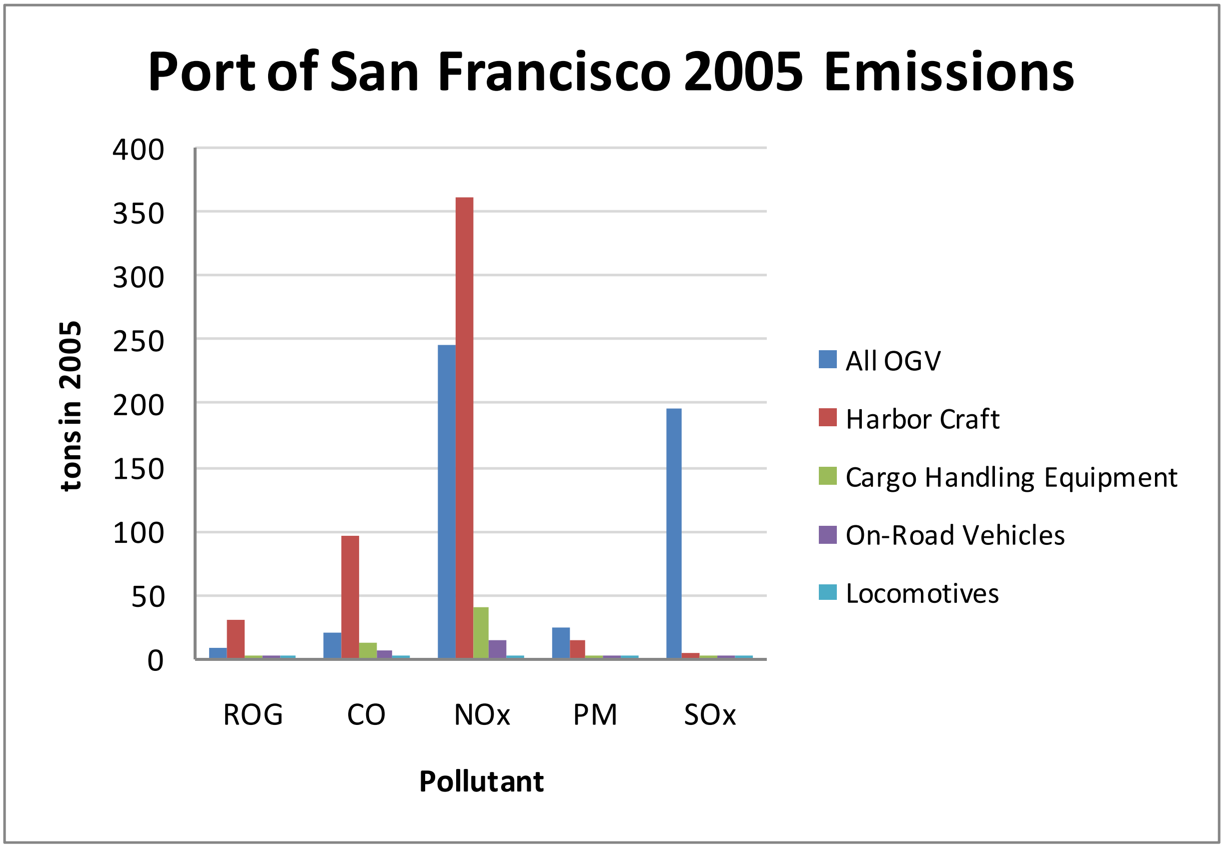


Figure 8-1. Summary Results for Port of San Francisco, by Source and Pollutant

This graph clearly shows that the bulk of San Francisco's emissions (between 86% and 99% depending on the pollutant) are produced on the waterside. Harbor craft are the major source for ROG and CO (71% for each). They produce about 55% of the Port's NOx, 36% of the Port's PM, and 2% of SOx. Ocean going vessels produce almost all (97%) of the Port's SOx.

The OGV emissions are shown in more detail in Figure 8-2 by ship type.

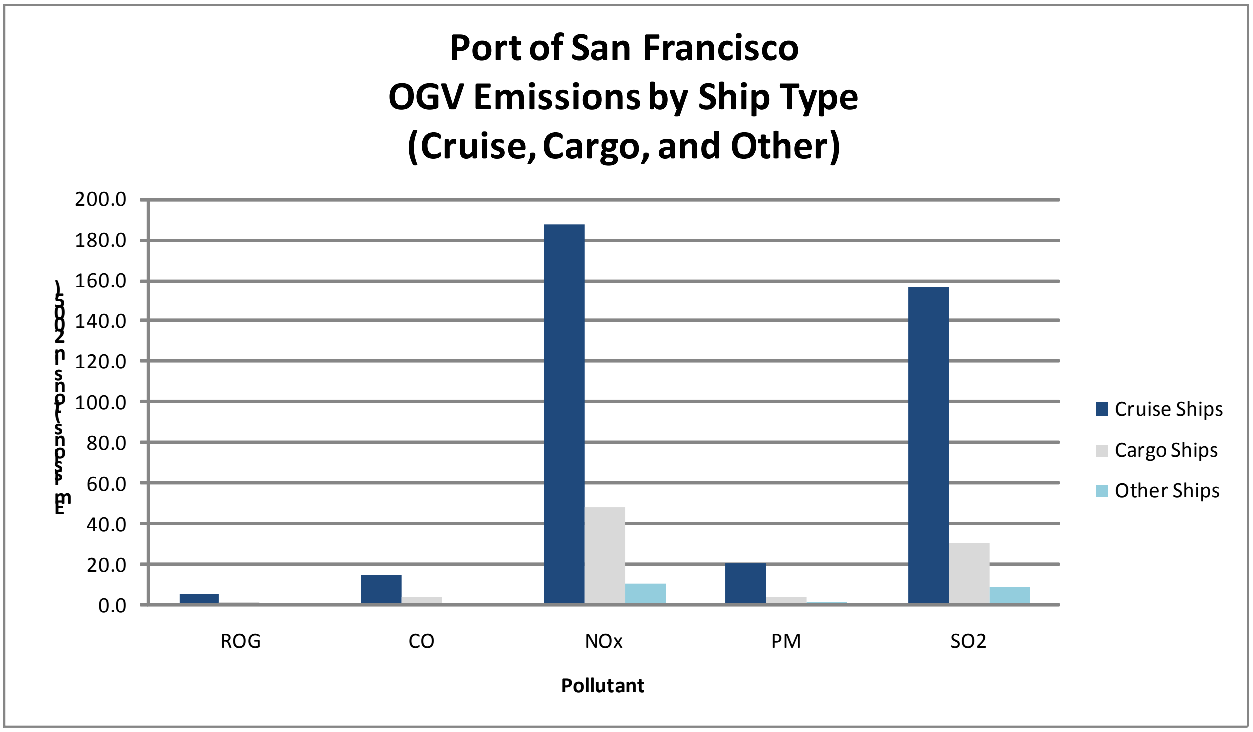


Figure 8-2. Port of San Francisco OGV Emissions by Ship Type

Cruise ships are by far the biggest emitters of all the ship types calling in San Francisco. Cruise ships produce about 75-80% of the OGV emissions at San Francisco for all the different criteria pollutants. Over half of cruise ship emissions occur while at berth hotelling, as can be seen in the next graph.

Figure 8-3 below shows cruise ship emissions by operating mode.

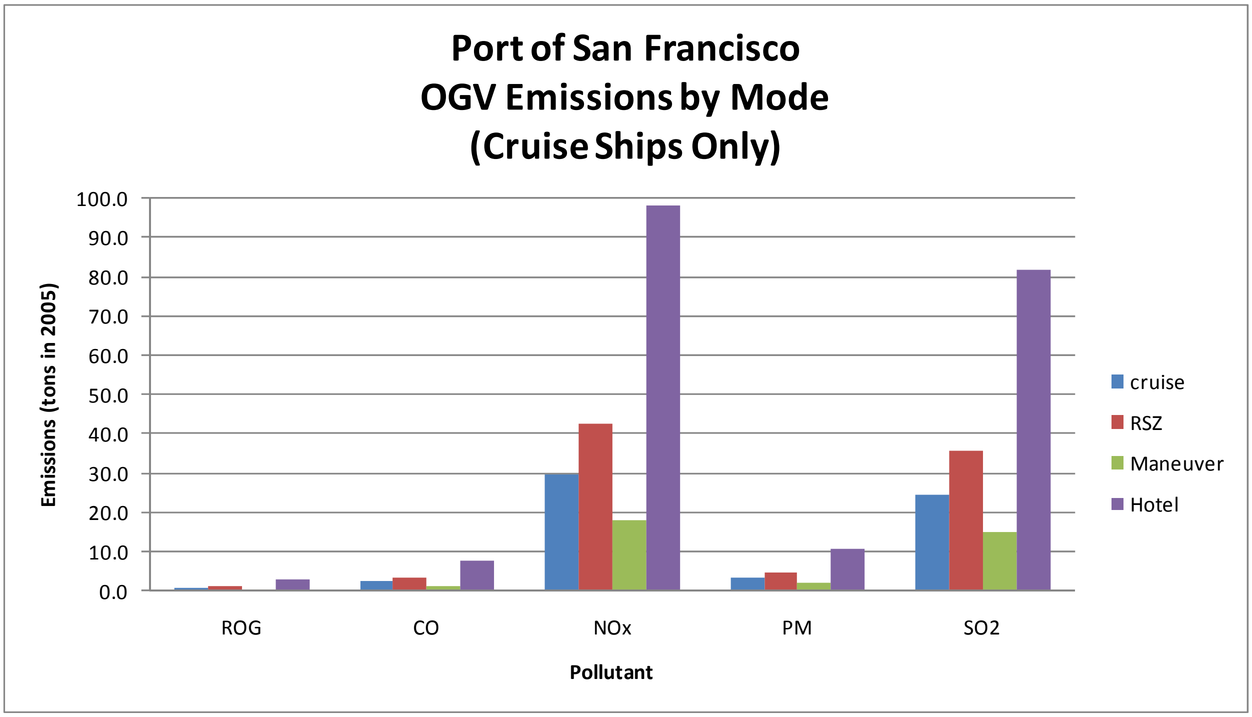


Figure 8-3. Summary of Cruise Ship Emissions by Operational Mode

It is important to note that this inventory was deliberately kept consistent with Oakland's inventory even though Oakland's inventory was conducted two years prior to this one. The science guiding emission estimating methodologies is rapidly evolving as new studies are completed and as CARB updates their emission factors and load factors to reflect better understanding of the sources and modes.

If this were a brand new stand-alone inventory, the estimates would have been done using the latest published guidance documents from CARB instead of using those available at the time Oakland was developing their inventory. Table 8-2 below compares some of the factors that have changed since Oakland's inventory was completed. This is not meant to be an exhaustive list of everything that would be different, it merely points out some notable changes. The differences mainly lie in the waterside emission factors. Landside emissions have been better understood for a long time, but the methodology for estimating emissions from marine engines is rapidly evolving as CARB and other entities undertake and complete more detailed studies.

Table 8-2. Factors Updated Since Oakland's 2005 Inventory

Factor	Value Used in Oakland 2005 Inventory	Current Value	Effect on Emission Results
OGVs: converting reported ship power to "maximum" ship power	0.968	1	Small decrease, all pollutants
OGVs: converting reported design speed to "maximum" speed	0.968	1	Small decrease, all pollutants
OGVs: main, auxiliary, and boiler engine emission factors have been updated	See Table 2-10 and Table 2-12 of this report	See CARB 2008 fuel sulfur rule Initial Statement of Reasons, Appendix D Table II-6	Small increase in HC (or ROG), small decrease in aux engine SOx, and a decrease in boiler PM
OGVs: low load adjustment factors for main engines	See Table 2-11 of this report	See POLA 2008 Emissions Inventory (Starcrest, LLC) Table 3.10	Decrease in HC, decrease in CO at lower loads (2-4%), increase at higher loads, increase in PM at lower loads (2-3%) increase at higher loads
HC: tug fuel sulfur content	225 ppm	330 ppm	Increase in SOx
HC: tug auxiliary engine load factor in assist and transit modes	0.43	0.31	Decrease, all pollutants

In instances where there was no Oakland precedent to refer to for emission and load factors, such as excursion boats and tugs towing barges, the latest guidance documents were followed.

9. REFERENCES

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Appendix A: Harbor Craft Emissions by BAAQMD

BAY AREA AIR QUALITY MANAGEMENT DISTRICT

2005 Bay Area Seaports Air Emissions Inventory
Port of San Francisco Commercial Harbor Craft Emissions

Introduction

This section describes the methodology used in estimating emissions from commercial harbor craft. The emission estimate is based on information taken from the "San Francisco Bay Area Seaports Air Emission Inventory Work Plan" (Moffatt & Nichol/ENVIRON, 2008). Harbor craft emissions from private berths as well as commuter ferries, fishing boats, pleasure craft and dredging activities are not included in this report.

The 2005 Port of San Francisco harbor craft emissions are derived from tug assist, excursion, and pilot boat activities. Tug assist emissions result from the running of the tug's engine while assisting ocean-going vessels (including barges) during arrivals and departures at the berths. Excursion and pilot boat emissions result from the running of the boat's engine during excursion and pilot outings.

Typically, tugs are utilized in assisting ocean-going vessels (OGVs) to dock and undock from the berths at the Port of San Francisco. These tugs rendezvous with OGVs two to three miles from berth and ensure the safe navigation of those vessels to their destinations. The emissions in this document account for two types of tug assist operations: (1) the actual vessel assist operation, and (2) the tug's transit trip to meet the vessel it is assisting and its return back to base.

For excursion boats and pilot vessels, it is assumed that all emissions occur within the San Francisco Bay, since most of the vessels operate inside the Bay Area waters. Usually the excursion boats leave their berths and head north, either to Alcatraz (for Alcatraz tours) and/or around the Golden Gate Bridge and Fisherman's Wharf (dinner cruises) and back to their berths. However, some boats transit to Marin, Napa, and/or Alameda County destinations. Pilot boats generally head out from their berth and rendezvous with OGVs at the sea buoys outside of the Golden Gate Bridge. Excursion and pilot vessel emissions are estimated based on their engine operating hours as reported by the boat operators.

Methodology

The methodology used to calculate harbor craft emissions at this port follows the California Air Resources Board (CARB) 2007 report, "Emissions Estimation Methodology for Commercial Harbor Craft Operating in California**"** (CARB, 2007). The CARB methodology requires the use of emission factors specific to the main propulsion and auxiliary engine model year and applies both a deterioration rate and a fuel correction factor. Since harbor craft specific data is not available, state-wide and Bay Area average factors are utilized in the emission calculations.

The equation used for estimating emissions on commercial harbor craft engines is:

$$\mathbf{E = EF_o \times F \times (1+D \times A/UL) \times HP \times LF \times Hr}$$

Where:

- **E** is the amount of emissions of a pollutant (NO_x, PM, ROG, and CO) emitted during one period;
- **EF_o** is the model year, horsepower and engine use (propulsion or auxiliary) specific zero hour emission factor (when engine is new);
- **F** is the fuel correction factor which accounts for emission reduction benefits from burning cleaner fuel;
- **D** is the horsepower and pollutant specific engine deterioration factor, which is the percentage increase of emission factors at the end of the useful life of the engine;
- **A** is the age of the engine when the emissions are estimated;
- **UL** is the vessel type and engine use specific engine useful life;
- **HP** is rated horsepower of the engine;
- **LF** is the vessel type and engine use specific engine load factor;
- **Hr** is the number of annual operating hours of the engine.

Total annual NO_x, PM, ROG, and CO emissions are calculated by multiplying the emissions rates, average emissions per engine per year, and the annual operating hours along with the various factors above.

SO_x emissions are calculated based on total fuel usage along with an average sulfur mass content of fuel used at the time. The following equation is used to calculate total fuel usage.

$$\mathbf{F_c = HP \times LF \times Hr \times BSFC}$$

Where

- **F_c** is fuel consumed per year;
- **HP** is rated horsepower of the engine;
- **Hr** is the number of annual operating hours;
- **LF** is the load factor;

- **BSFC** is brake specified fuel consumption rate.

An assumed EPA on-road diesel fuel of 225 parts per million sulfur content was used on all San Francisco Bay Area harbor craft in year 2005. This number is based on the Port of Oakland Maritime Emissions Report (Port of Oakland, 2005).

Data Collection and Operating Activity

1. Data Collection

For OGVs, the Port of San Francisco handles passenger cruises and the import and export of bulk materials. Most of the port's OGV calls are from cruise ships and cargo and bulk carriers. The port's major tenants in 2005 included Metro Cruise Services, MTC, Darling International, Bode Gravel, and Hanson Aggregates. According to the report (Moffatt & Nichol/ENVIRON, 2008), there were 392 OGV calls (including barges) in year 2005. From this total and given the requirement of tug assists per vessel call, it was estimated a total of 912 tug assists took place at the Port in 2005 (see Table 1).

Table 1. Total Number of Tug Assists by Vessel Call.

Vessel Type	No. of Vessels	Assist Tug Requirement per Call		Assist Tugs[1]
		Incoming	Outgoing	
Vessels				
General Cargo	58	0-1 [a]	0-1 [a]	58
Dry Bulk	27	1-2 [b]	1-2 [b]	81
Liquid Bulk	10	1	1	20
Cruise	74	2	1-2 [b]	259
Others				
Dry Dock	9	2	2	36
MARAD	3	2	2	12
Jeremiah O'Brien	6	2	1-2 [b]	21
Barge (Operator):				
Bode	68	1	1	136
Hanson (Pier 92)	72	1	1	144
Hanson (Mission Valley Pier)	55	1	1	110
Total	**382**			**877**

[1] *Total for incoming and outgoing*
[a] *Assume 0.5 per call*
[b] *Assume 1.5 per call*

For marine excursion vessels, the port is home to three major excursion fleet operators: (1) the Red and White Fleet, (2) the Blue and Gold Fleet, and (3) the Hornblower Fleet. A small excursion cruise ship, the Yorktown Clipper, also hosts excursion cruises at the port. The port is also home to the bar pilots. The bar pilots have a fleet of vessels which carry the pilots to the OGVs during the assistance and piloting phase. All these vessels operate at the port on a consistent basis.

Data that identified the port individual vessels and activities was not available at the time of this report. In the absence of this data, statistical data was used in the emission estimates. For OGV assist tug boats (excluding barge assist tugs), Bay Area specific OGV tug assist data was obtained from the Port of Oakland Report (Port of Oakland, 2005). The data obtained from this report and used to estimate OGV tug assist emissions include adjusted emission factors for class A and B tugs along with corresponding total average engine power and load factors. Based on correspondences with Bay Area tug operators (Bay Delta et al, 2009), it was estimated that 75% of OGV assist tugs are Class A and 25% are of Class B Bollard Pull rated tugs. A summary of the data is given below in Table 2.

Table 2. Summary of Class A and B Main and Auxiliary Engine Horsepower, Adjusted Emission Factor, Tug Assist, and Tug Transit Load Factors.

Type of Vessel	Engine	Total Average	Adjusted Emission Factor: (AEF) - Efo x F x (1+D x A/UL)					Tug-assist	Tug-in-transit
		Horsepower (HP)	NOx	ROG	CO	SO2	PM	Load Factor (LF)	Load Factor (LF)
Tug Boat - Class A	Main	4,344	11.41	0.69	2.82	0.09	0.44	0.31	0.50
Tug Boat - Class A	Auxiliary	128	11.13	0.85	3.30	0.09	0.59	0.43	0.43
Tug Boat - Class B	Main	3,125	11.30	0.72	2.79	0.08	0.48	0.31	0.50
Tug Boat - Class B	Auxiliary	110	11.27	0.98	3.25	0.08	0.67	0.43	0.43

Source: Port of Oakland (2008) where AEF units are in grams/(hp-hr)

For other commercial harbor craft, CARB data sources were used in the emission estimates. One source of data comes from the CARB report, "Emission Estimation Methodology for Commercial Harbor Craft Operating in California" (CARB, 2007). In this report, state-wide average data was gathered for harbor craft. These data include emission factors, load factor, deterioration factor, average number of engines per vessel, engine useful life, and fuel correction factors. The second source of data comes from CARB's state-wide commercial harbor craft survey report, "Statewide Commercial Harbor Craft Survey Final Report" (CARB 2004). In this report, Bay Area specific data on main and auxiliary engines for a harbor craft vessel type were gathered to perform the emission estimates. Table 3 and 4 below present a summary of the data used in the emission estimates from these two reports.

Table 3. Summary of Commercial Harbor Craft Average Horse Power, Emission Factor, Fuel Correction Factor, and Specific Engine Deterioration Factor

Type of Vessel	Engine	Horsepower (HP)[a]	NO_x			PM			ROG			CO		
			EF	F	D	EF	F	D	EF	F	D	EF	F	D
Tug Boat[b]	Main	1,274	12.98	0.93	0.21	0.50	0.75	0.67	0.90	1.00	0.44	3.07	1.00	0.25
Tug Boat[b]	Auxiliary	111	13.00	0.93	0.14	0.71	0.75	0.44	1.71	1.00	0.28	4.94	1.00	0.16
Excursion Boat	Main	733	12.98	0.93	0.21	0.50	0.75	0.67	0.84	1.00	0.44	2.99	1.00	0.25
Excursion Boat	Auxiliary	94	13.00	0.93	0.14	0.71	0.75	0.44	1.71	1.00	0.28	4.94	1.00	0.16
Work Boat	Main	239	12.98	0.93	0.14	0.52	0.75	0.44	0.88	1.00	0.28	3.07	1.00	0.16
Work Boat	Auxiliary	101	13.00	0.93	0.14	0.71	0.75	0.44	1.71	1.00	0.28	4.94	1.00	0.16
Pilot Vessel	Main	408	12.98	0.93	0.21	0.50	0.75	0.67	0.90	1.00	0.44	3.07	1.00	0.25
Pilot Vessel	Auxiliary	30	6.90	0.93	0.06	0.64	0.75	0.31	2.19	1.00	0.51	5.15	1.00	0.41

Where:
[a] Average horsepower for one engine. Total horsepower is the number of engines per vessel times the average horsepower of one engine.
[b] Data used to estimate emissions for tug boat assisting barges.

- EF is the model year, horsepower and engine use (propulsion or auxiliary) specific zero hour emission factor (when engine is new). Units are in **grams/(hp-hr**)
- F is the fuel correction factor which accounts for emission reduction benefits from burning cleaner fuel.
- D is the horsepower and pollutant specific engine deterioration factor, which is the percentage increase of emission factors at the end of the useful life of the engine. F is the fuel correction factor which accounts for emission reduction benefits from burning cleaner fuel.

Table 4. Summary of Commercial Harbor Craft Useful Life, Load Factor, Average Number of Engines Per Vessel and Average Age by Engine Type.

Type of Vessel	Engine	Useful Life (UL)	Load Factor (LF)	Number of Engines Per Vessel	Age
Tug Boat[1]	Main	21	0.50	1.92	17.8
Tug Boat[1]	Auxiliary	23	0.31	1.59	18.8
Excursion Boat	Main	20	0.42	2.01	13.8
Excursion Boat	Auxiliary	20	0.43	1.23	12.7
Work Boat	Main	17	0.45	1.46	14.0
Work Boat	Auxiliary	23	0.43	0.32	17.4
Pilot Vessel	Main	19	0.51	see note	15.6
Pilot Vessel	Auxiliary	25	0.43	see note	24

Note : Pilot Vessel actual engine hours were used for emissions calculations.
[1] Data used to estimate emissions for tug boat assisting barges.

2. Operating Activity

The average tug assist operational time at the Port of San Francisco occurred in 55 minute cycles based on correspondence with a tug operator (Bay Delta, 2008). The time for tugs transiting to the OGV meeting location and from berth back to base was estimated to occur in 30 minute cycles. This short duration of time is due on the close proximity of the Port of San Francisco relative to Bay Area tug operators. The transit assist time for tugs assisting barges occurs in four hour cycles from the time it enters the county line (or 3 miles from Golden Gate Bridge for OGV barges) to berth and vice versa. The transit time for tugs assisting barges is also an estimated value based on the average distance from berth to the San Francisco county boundary divided by the average transit speed of the tug assisting the barge (Westar, 2009). The 2005 annual operating hours for each vessel mode and engine type are summarized in Table 5 below.

While hotelled/parked at dock, commercial harbor craft often run their auxiliary engines to power ancillary sources such as lights and refrigeration. However, at the Port of San Francisco, harbor craft are able to use electrified berths. Instead of running their auxiliary engines, the tugs and other vessels use the electricity at the dock to power their ancillary sources. The only auxiliary engine emission accounted for during berthing is the Yorktown Clipper excursion boat, which temporarily parks at a berth a few times a year to pick up passengers. Since it is only making a temporary stop to pick up passengers, it is assumed that the vessel runs it auxiliary engine the entire time it is at berth or 164 hours per 2005 year.

The operating time for the fleet of tug boats (for tugs not making OGV assist calls to the Port of San Francisco) is not considered in the estimates. The transit time for the tugs is already considered in estimates elsewhere based on the vessel port of call that the tug is assisting. Taking account the tug fleet transit time would double count the emissions.

With the exception of the Hornblower excursion fleet, all excursion boat operating time (including Bar Pilot vessels) used in the emission estimate is taken from the CARB database (CARB, 2009). The data in this database is based on the 2002 California Harbor Craft Survey and reflects the total operating hours of the vessel engine(s). In the absence of 2005 data, it is assumed that the operating time in 2005 is similar to that of 2002. The Hornblower 2005 data is taken directly from the operator (Hornblower, 2009).

Table 5. Annual Operating Hours by Vessel Mode and Engine Type.

Vessel Mode	In Transit		Hotelling
	Main Engine (hrs)	Auxiliary Engine (hrs)	Auxiliary Engine (hrs)
Tug Assist – OGV	446	446	--
Tug-in-Transit (OGV)	221	221	--
Tug Assist – Barges	1449	1449	--
Excursion Boat (Hornblower)	1821	1821	--
Excursion Boat (Red & White, Blue & Gold) *	43,045	27,289	--
Excursion Boat (Yorktown Clipper)	18	18	164
Pilot Boat*	25,200	11,600	--

* Total actual engine hours

Summary

The annual operating times of each vessel modes multiplied by the emission factors, total vessel horsepower (or single engine horsepower if total actual engine hours are given), fuel correction factors, deterioration factors, and other factors give us the estimated emissions. The SO_x emissions are estimated based on the mass based sulfur content of fuels. Table 6 summarizes the emissions associated with harbor craft activities at the Port of San Francisco.

Table 6. 2005 Port of San Francisco Harbor Craft Annual emissions (tons per year)

	Emissions (tons/year)				
	ROG	CO	NO_x	PM	SO_x
Tug Assist					
Main Engines	0.43	1.73	7.00	0.28	0.05
Auxillary Engines	0.02	0.09	0.29	0.02	0.00
Tug In-Transit	-	-	-	-	-
Main Engines	0.34	1.38	5.60	0.22	0.04
Auxillary Engines	0.01	0.04	0.14	0.01	0.00
Barge Tugs	-	-	-	-	-
Main Engines	2.41	7.25	27.71	1.15	0.16
Auxillary Engines	0.18	0.49	1.17	0.06	0.01
Excursion Vessels	-	-	-	-	-
Main Engines	17.33	55.49	218.76	8.68	2.71
Auxillary Engines	2.66	7.20	17.42	0.90	0.09
Pilot Boats	-	-	-	-	-
Main Engines	7.07	21.34	81.63	3.35	1.00
Auxillary Engines	0.54	1.18	1.12	0.10	0.05
Total	31.05	96.43	361.79	14.80	4.13

* SO_x emission is based on total fuel consumption.

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Appendix B: Aerial Images Showing Truck Routes

Table B-1 On-Road Vehicle Off-Site distance and Composite Speed by Trip Route

Route	One-Way Distance (miles)	Speed Through Route (miles/hr)
Heavy Heavy Duty Trucks Off-site Routes		
Pier 94 to U.S Highway 101 North Entrance	1.41	21.00
Pier 92 to U.S Highway 101 North Entrance	1.99	25.20
Pier 92 to City Local*	1.99	25.20
Pier 80 to U.S Highway 101 North Entrance	1.23	24.00
Pier 94 to Nearby Off-Site Parking Lot Entrance	0.65	12.40
Within Pier 94 Off-site Travel	0.30	15.00
Within Pier 92 Off-site Travel	0.20	15.00
Pier 92 to U.S Highway 101 North Entrance	3.14	21.00
Buses Off-Site Routes		
Pier 30-32 to Nearby Parking Lot on Embarcadero	0.10	7.000
Parking Lot on Embarcadero nearby Pier 30-32 to SF Oakland Bridge Freeway Entrance	0.61	36.00
Pier 39 to U.S Highway 101 North Entrance	2.70	21.00
Pier 35 to U.S Highway 101 North Entrance	3.14	21.00
Pier $43^{1/2}$ to U.S Highway 101 North Entrance	2.61	21.75

*Due to lack of information on this truck route, it was assumed that the truck traveling from Pier 92 to City local would take similar route as Pier 92 to U.S Highway 101 North Entrance.

Heavy Heavy Duty Trucks Off-Site Routes

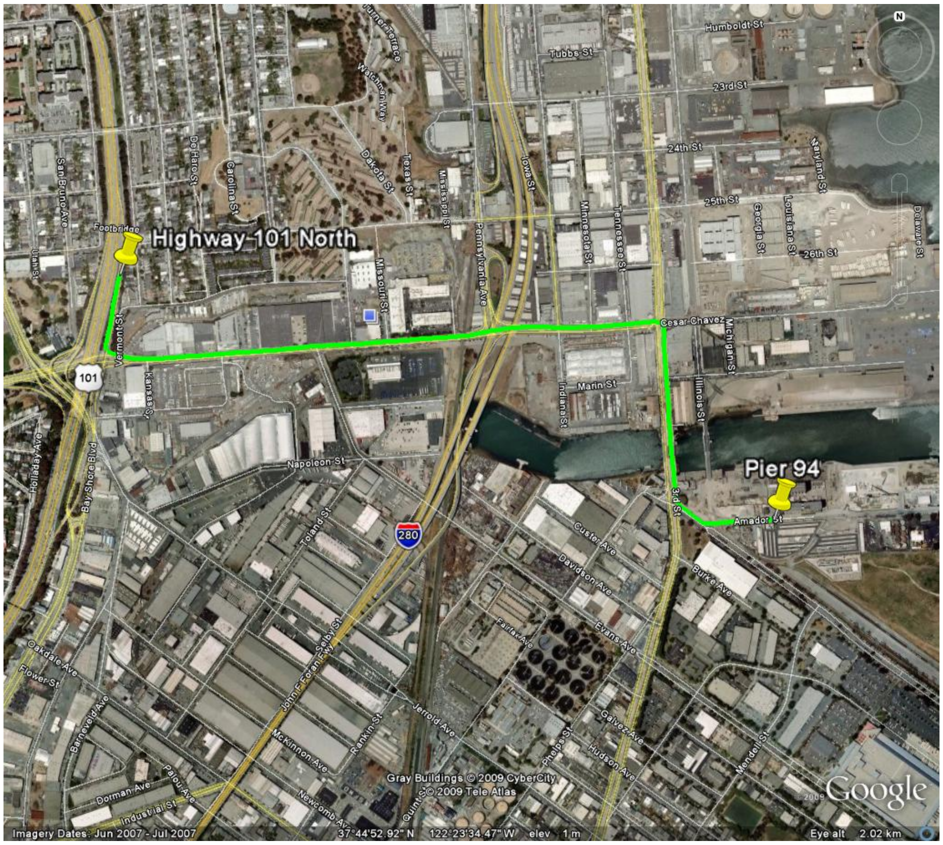

Figure B-1 Pier 94 to U.S Highway 101 North entrance (green highlighted route)

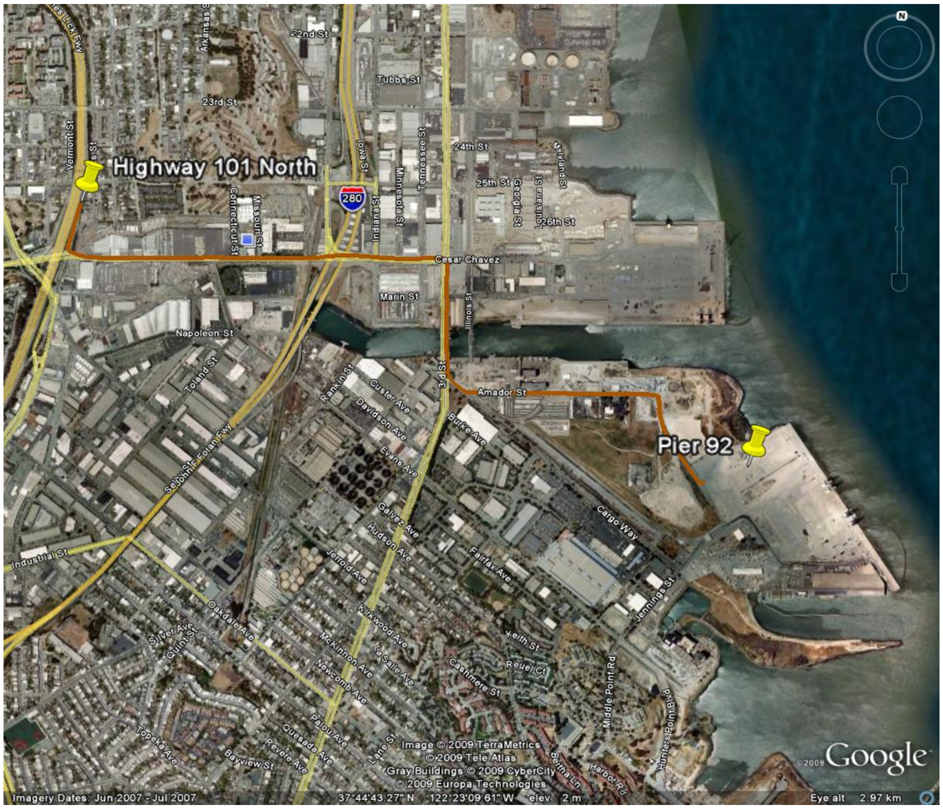

Figure B-2 Pier 92 to U.S Highway 101 North entrance and City Local (orange highlighted route)

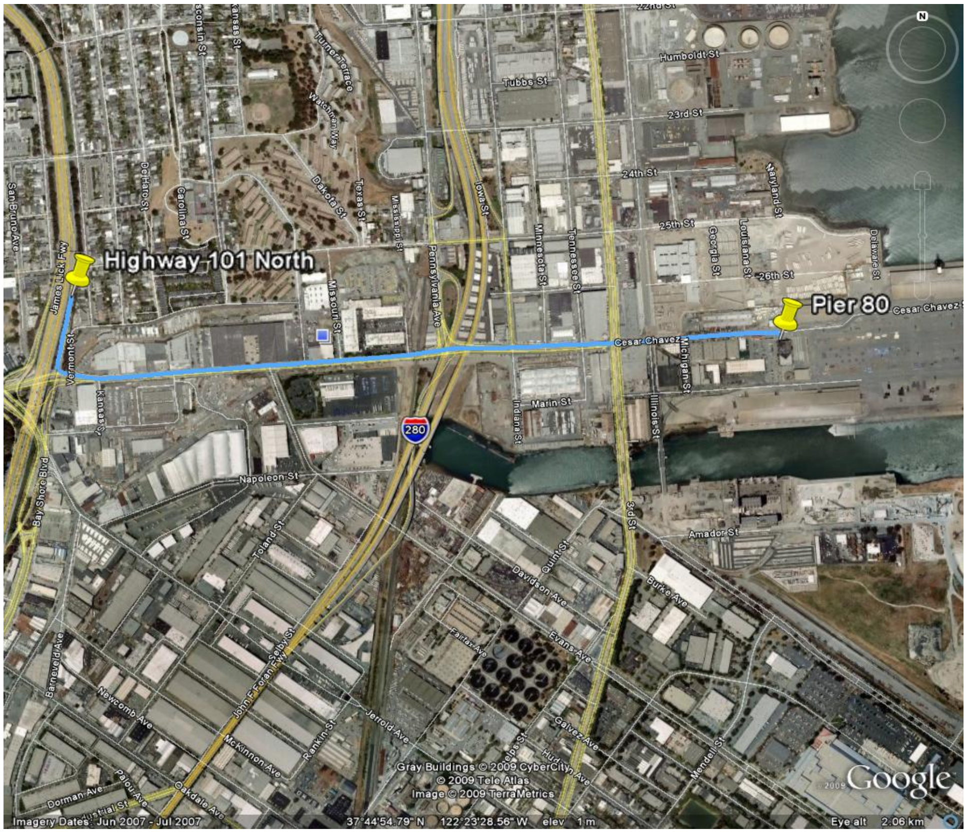

Figure B-3 Pier 80 to Highway 101 North entrance (sky-blue highlighted route)

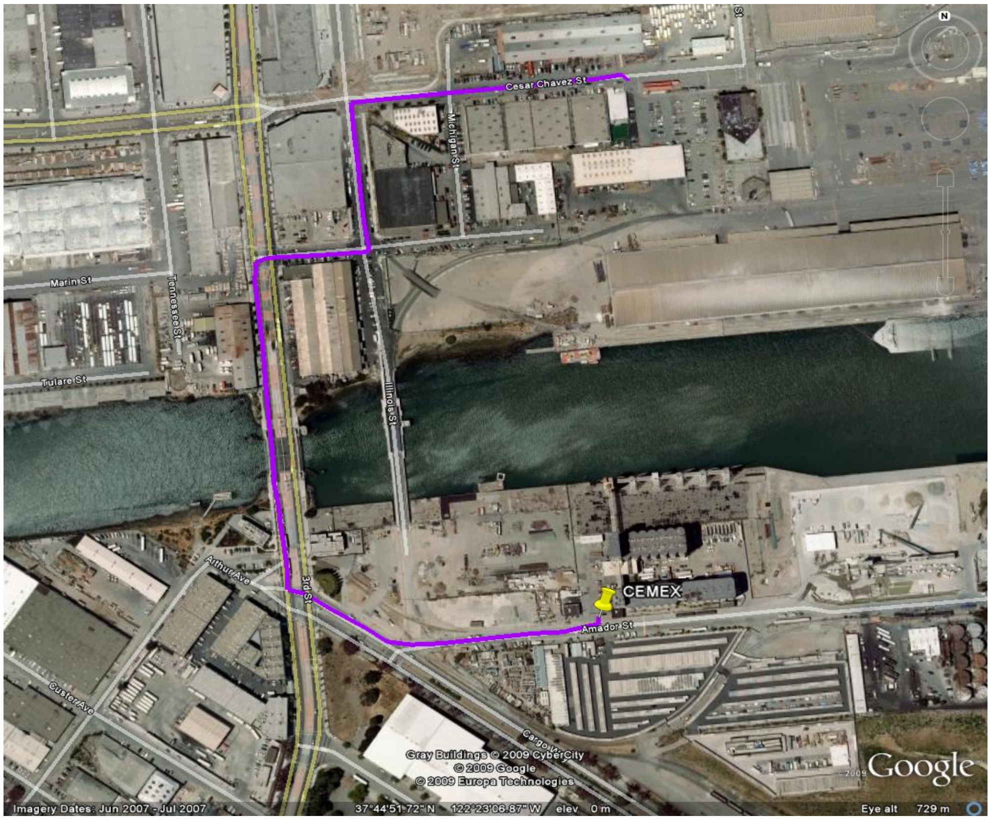

Figure B-4 Pier 94 to nearby off-site parking lot (purple highlighted route)

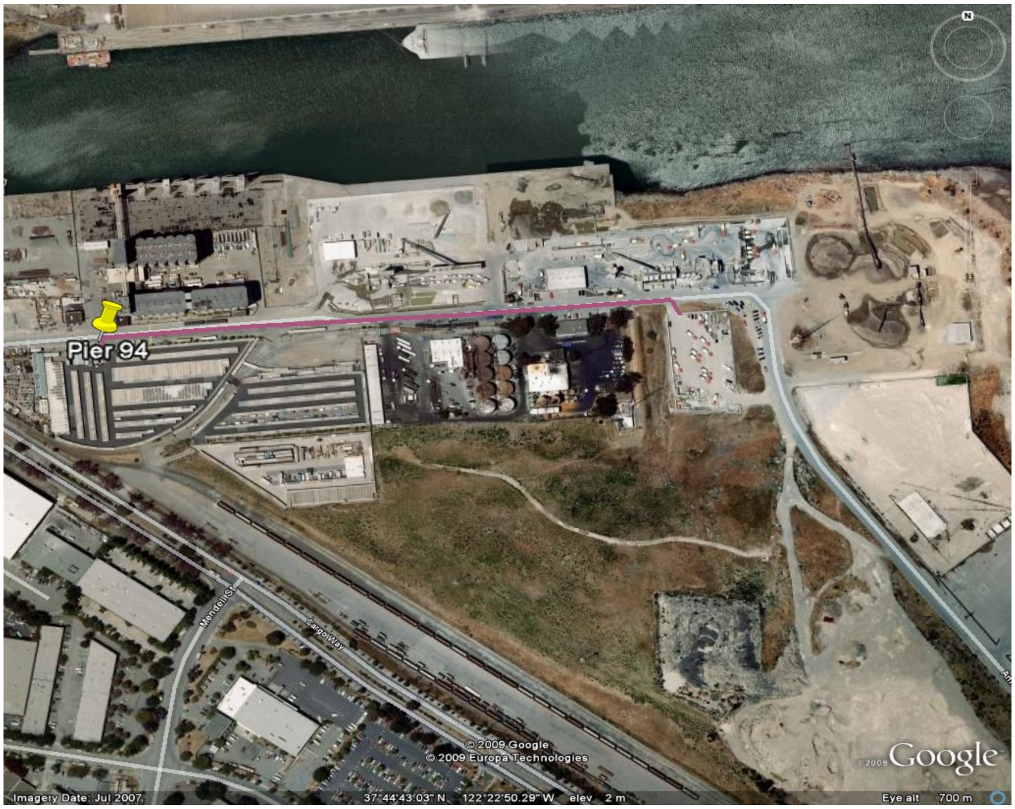

Figure B-5 Within Pier 94 off-site travel (purple highlighted route)

Figure B-6 Within Pier 92 off-site travel (green highlighted route)

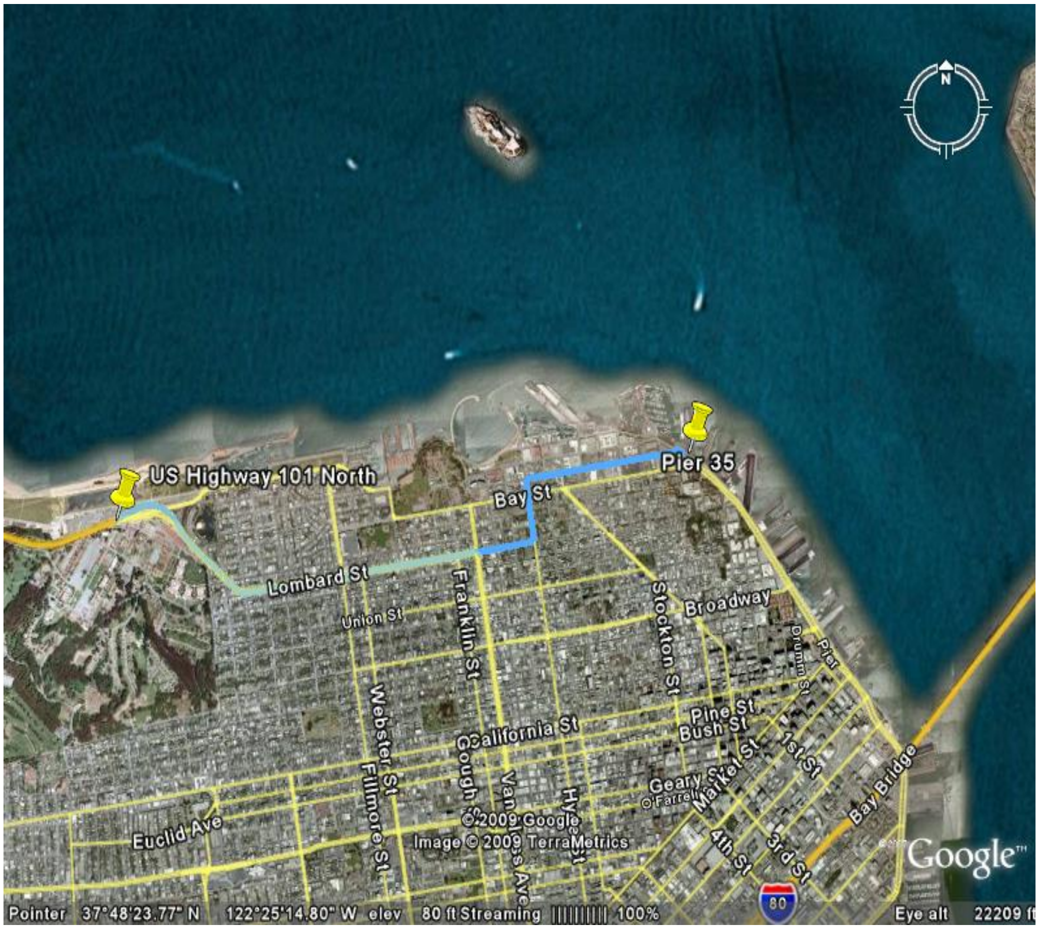

Figure B-7 Pier 35 to U.S Highway 101 North entrance (sky-blue highlighted route)

Cruise and Excursion Buses Off-Site Routes

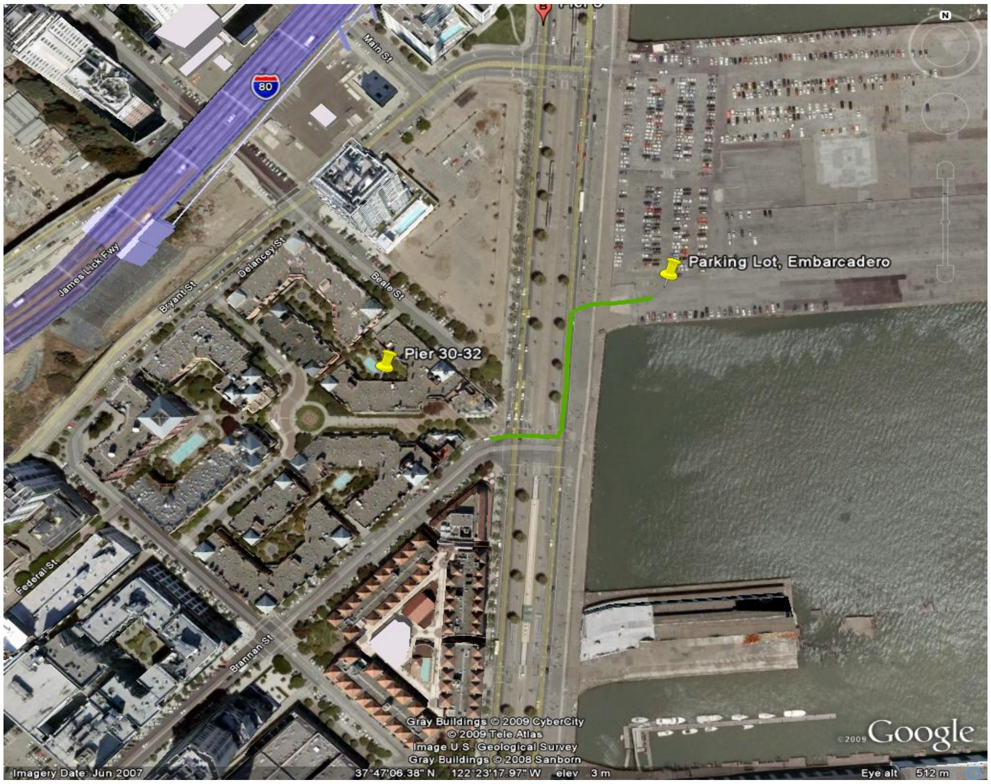

Figure B-8 Pier 30-32 to near by parking lot on Embarcadero (green highlighted route)

Figure B-9 From a parking lot near by Pier 30-32 to SF Oakland Bridge Freeway Entrance (maroon highlighted route)

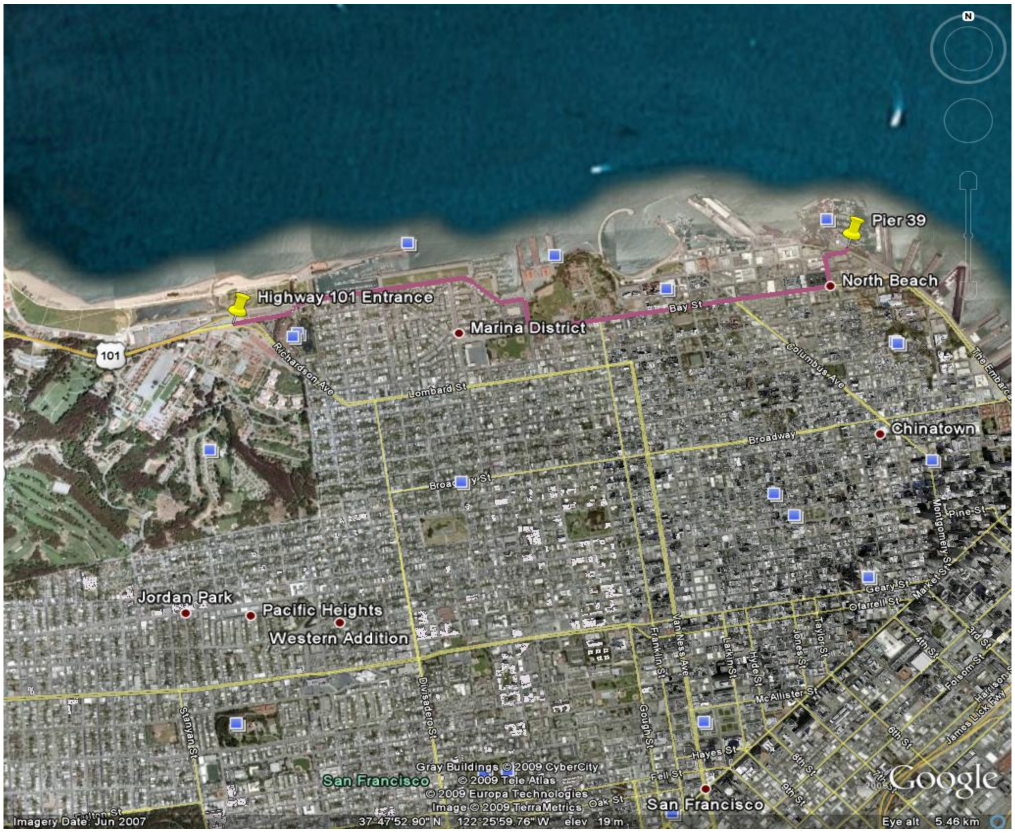

Figure B-10 Pier 39 to U.S Highway 101 North entrance (pink highlighted route)

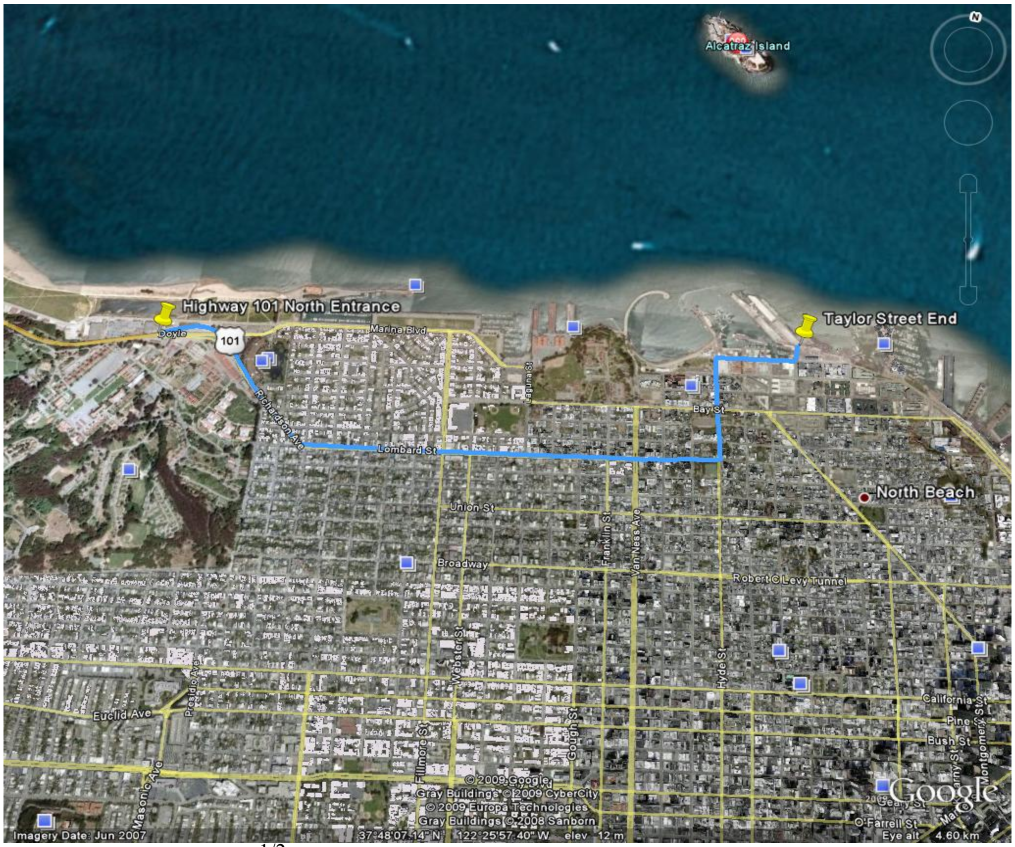

Figure B-11 Pier 43$^{1/2}$ to Highway 101 North entrance (blue highlighted route)

Appendix C: Locomotive Emissions by BAAQMD

2005 Bay Area Seaports Air Emissions Inventory
Port of San Francisco Locomotive Emissions

This document describes the data and methods used in estimating emissions from locomotives at the Port of San Francisco. The San Francisco Bay Railroad (SFBR) operates two small switch engines at the Port of San Francisco. In 2005, these switch engines reportedly burned approximately 450 gallons of locomotive diesel fuel per quarter or around 1800 gallons of diesel fuel per year.

The methodology used to calculate locomotive emissions at the Port of San Francisco is based on the fuel consumption method. This methodology takes into account total fuel consumed along with engine-specific and generalized emission factors.

1. Summary of Emission Factors

With the exception of SOx and CO, emission factors used in the calculation of emissions were provided by Environ (Environ, 2009) and are based on the "San Francisco Bay Railroad Biodiesel Test Study Report" (CARB, 2008). SOx emission factor is based on the sulfur content used in locomotive fuel in 2005. The sulfur content is assumed to be 221 parts per million by weight. CO emission factor is taken from the "Locomotive Emission Study Report" prepared by Booz, Allen and Hamilton (BAH, 1991). These emission factors are given in Table 1-1 below.

Table 1-1. Locomotive – Emission Factors for San Francisco Rail Operations (Pounds per 1000 Gallons of Fuel).

Train Type	PM	HC	NOx	SOx	CO
Alco S-2 Switch Locomotive	23.3	54	172	3	80.6

Note: to convert HC to ROG (x .836)

2. Summary of Locomotive Emission Estimates for Port of San Francisco

The annual amount of fuel multiplied by the emission factor gives the estimated annual emissions. The emissions associated with locomotive activities at the Port of San Francisco in 2005 are summarized below in Table 1-2.

Table 1-2. Locomotive – Estimated Annual Emissions Associated with Locomotive Activities at the Port of San Francisco in 2005.

	ROG	CO	NOx	PM	SOx
grams	36892	65866	140558	19041	2511
tons	0.041	0.073	0.155	0.021	0.003

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PORT OF SAN FRANCISCO LOCOMOTIVE

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