SF Bay Area Seaports Air Emissions Inventory

Port of Benicia 2005 Emissions Inventory

Prepared for: Bay Planning Coalition

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ENVIRON

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- Port of Redwood City, a California municipal corporation
- Port of Benicia, a private corporation

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LIST OF ABBREVIATIONS

BAAQMD – Bay Area Air Quality Management District
BPC – Bay Planning Coalition
CARB – California Air Resources Board
CHE – Cargo Handling Equipment
CO – Carbon monoxide
HC – Harbor Craft
HC – hydrocarbons
HDV – Heavy Duty Vehicles
HHDT – Heavy Heavy Duty Vehicles
LPG – Liquid Petroleum Gas
M&N – Moffatt & Nichol
NOx – Nitrogen oxides
OGV – Ocean-Going Vessels
PM – Particulate matter
RL – Rail Locomotives
ROG – Reactive Organic Gases
RSZ – Reduced Speed Zone
SF – San Francisco
SO2 – Sulfur dioxide
SOx – Sulfur oxides
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 to transfer cargo or containers. Cargo handling equipment is used to move containers from one mode of transportation to another, or from a storage area to a truck chassis, for example. Typical cargo handling equipment found at ports include yard trucks, rubber-tired gantry (RTG) cranes, top and side picks, 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 run below 250 rpm.

Standard fuel oil consumption (SFOC): See brake specific fuel consumption (BSFC).

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 Benicia (Port) 2005 Seaport Air Emissions Inventory (emissions inventory) identifies and quantifies air emissions from the Port's maritime activities, 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 Bay Planning Coalition and involved active participation during all stages by the Bay Area Air Quality Management District. 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 B. The results from their analysis are included in the summary results tables and graphs.

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 Port is committed to conducting its operations in the most sustainable and environmentally sensitive manner possible.

Purpose

The purpose of this inventory is to better understand the 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 Benicia Operations

The primary tenant at the Port of Benicia is AMPORTS. They import new vehicles using auto carriers. A second tenant, Kinder Morgan, leases a small terminal on the port, including a silo and some rail tracks, for their petroleum coke export business. There are two other tenants on the port property, Suba Manufacturing and Greenbrier, both of whom conduct non-maritime operations. The non-maritime operations were not included in this inventory.

The Port of Benicia has a significant amount of tug boat lay berthing. The tug boats that lay over at Benicia are from all different companies operating in the bay. A typical scenario would be a tug who's home berth is somewhere in the central part of the bay who has multiple jobs to do in the north bay and needs a place to tie up between jobs to avoid excess traveling.

Figure ES-1 shows an aerial view of the Port of Benicia, with the property boundaries shown in white. The tenants are labeled with the number of ship calls on each berth in 2005.

Figure ES-1. Aerial Image of Port of Benicia

The outlined areas indicate areas of maritime activity.

Figure ES-2 is a schematic summary of the amount of cargo, the direction of cargo flow, and the number of ship calls for Benicia in 2005.

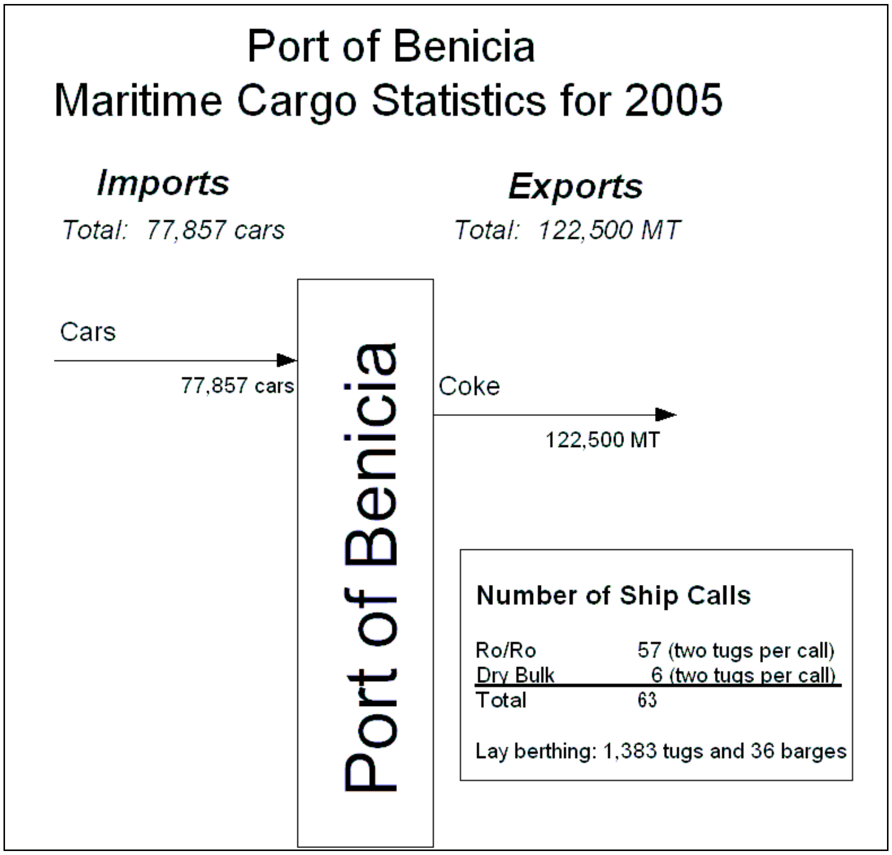

Figure ES-2. Schematic of the Port of Benicia Cargo Flow

The diagram in Figure ES-3 lists the tenants at the Port of Benicia, and shows the mode of both waterside and landside transport along with the arrows which indicate the direction of flow of the commodity. The two tenants shown in orange were included in the inventory. The two tenants in blue were not included in the inventory because they are privately owned terminals or they are not conducting maritime business, or both.

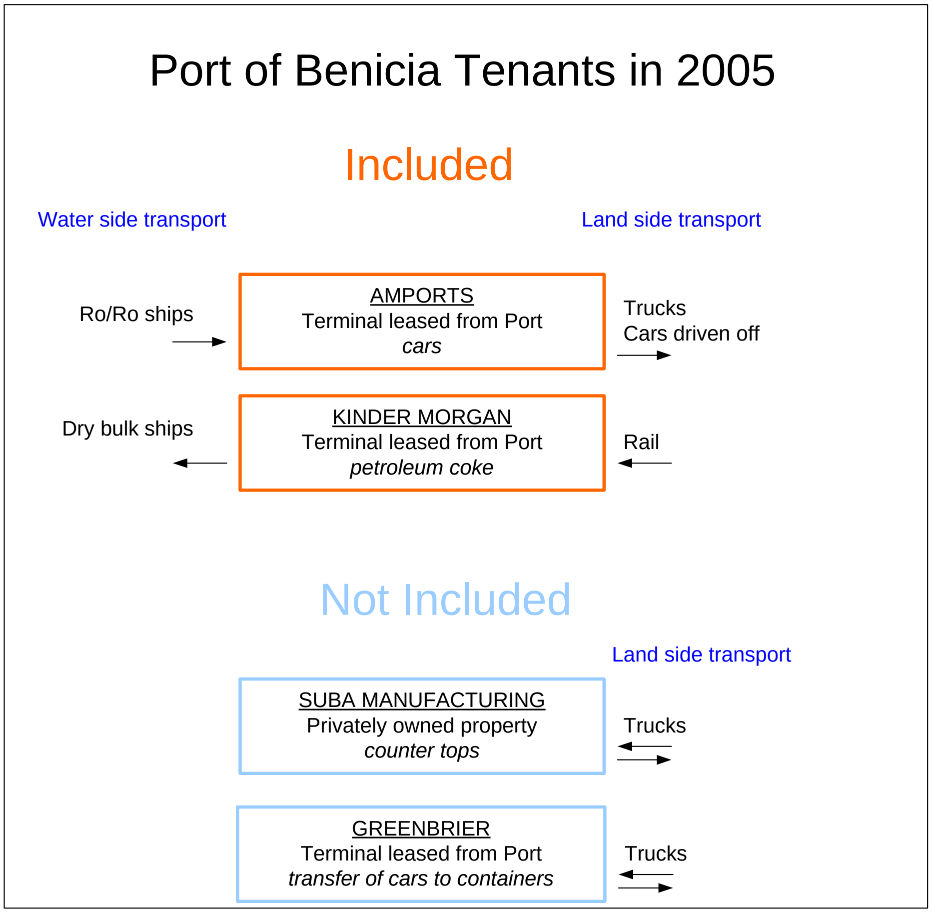

Figure ES-3. Terminals and Commodity Flow Modes at the Port of Benicia

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 back and forth between the outer buoys west of the Sea Buoy (approximately 17 miles west of the Golden Gate Bridge) and the berths at Benicia.

On the landside, 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.

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: Smaller marine vessels are included in this category. Vessels in this category are associated with Port maritime operations and consist primarily of assist tugs. One or two tugs assist all vessels during the maneuvering mode as they enter and leave the Port. Many different tug companies provided assist services.

The inventory includes tug emissions estimates in two operating modes, vessel assist and transit to and from the vessel assist point. Emissions sources include tug main propulsion and auxiliary diesel engines. Hotelling hours (auxiliary engines only) for tugs laying over at Benicia are also included in this inventory.

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 Benicia 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, backhoes, and sweepers.

Heavy Duty On-Road Vehicles: The on-road vehicles at Benicia include the trucks used to transport new vehicles off the port. The emissions from the new vehicles as they are driven off the ships and parked on port property are also included in this inventory.

Locomotives: There are no locomotives operating on Port of Benicia property. Therefore, the locomotive emissions in this inventory are zero.

Results

The results of the Port of Benicia Seaport Air Emissions Inventory are given in Table ES-1. The same results are presented graphically in Figure ES-4.

Table ES-1. Port of Benicia Emissions Summary by Source – tons in 2005

Source Category	ROG	CO	NOx	PM10	SO_2
Ocean-Going Vessels (OGV)	1.47	3.82	45.63	4.08	29.28
Harbor Craft (HC)	1.47	5.80	22.34	0.97	0.17
Cargo Handling Equipment (CHE)	0.08	1.69	0.27	0.01	0.00
Heavy Duty On-Road Vehicles (HDV)	0.07	0.49	0.40	0.04	0.01
Rail Locomotives (RL)	n/a	n/a	n/a	n/a	n/a
Total	**3.1**	**11.8**	**68.6**	**5.1**	**29.5**

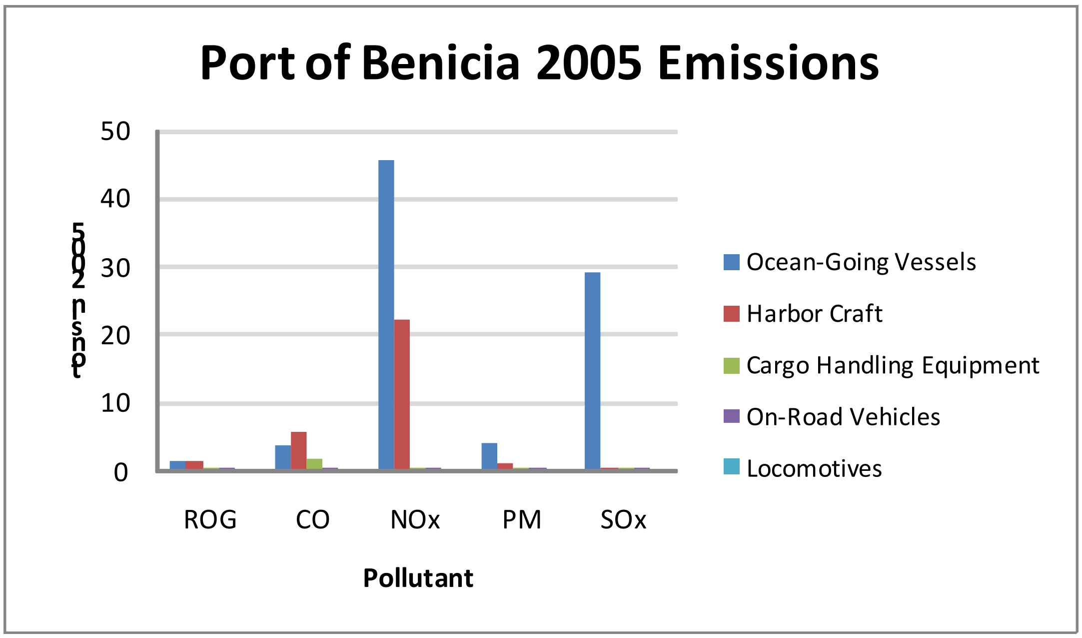

Figure ES-4. Summary of Port of Benicia 2005 Emissions by Source & Pollutant

Ocean-going vessels are the largest source for all pollutants, producing 67% of NOx emissions, 80% of particulate matter, and 99% of estimated SOx emissions, and the major portion of other pollutants within the scope of this emissions inventory. Table ES-2 shows a more detailed assessment of ocean-going vessel emissions by mode of operation.

Table ES-2. Port of Benicia OGV Emissions Summary – tons in 2005

Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.22	0.62	7.91	0.70	5.02
Reduced Speed Zone	0.85	2.11	25.06	2.26	15.56
Maneuver	0.13	0.15	1.16	0.11	0.44
Hotel	0.27	0.95	11.51	1.01	8.26

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 problems.

1. INTRODUCTION

1.1 Purpose

The Port of Benicia (Port) prepared this 2005 Seaport Air Emissions Inventory (emissions inventory) for the purpose of identifying and quantifying the air quality impacts from the maritime operations of the Port and its tenants. With a baseline inventory, the Port will be better able to target potential air quality improvement measures at emissions reductions within the major categories of maritime equipment:

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

The Port of Benicia, operated by AMPORTS, 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 Redwood City, Richmond, and San Francisco. The Port of Oakland conducted their inventory prior to this project. The methodology used in Oakland's inventory formed the basis for the other public ports. The goal was to have a consistent set of inventories for all the seaports in the region.

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 Bay Planning Coalition and involved active participation during all stages by the Bay Area Air Quality Management District. 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 B (unless there are no locomotives, as for Benicia, in which case Appendix B is omitted). The results from their analysis are included in the summary results tables and graphs.

This emissions inventory highlights the Port's commitment to improve understanding of the emissions from its maritime-related operations.

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 participate in managing 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 M&N/ENVIRON to assist in the effort to create a regional air emissions inventory for the 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 inventory as much as possible. It was also agreed that BAAQMD's potential 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 or 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 acceptance 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.

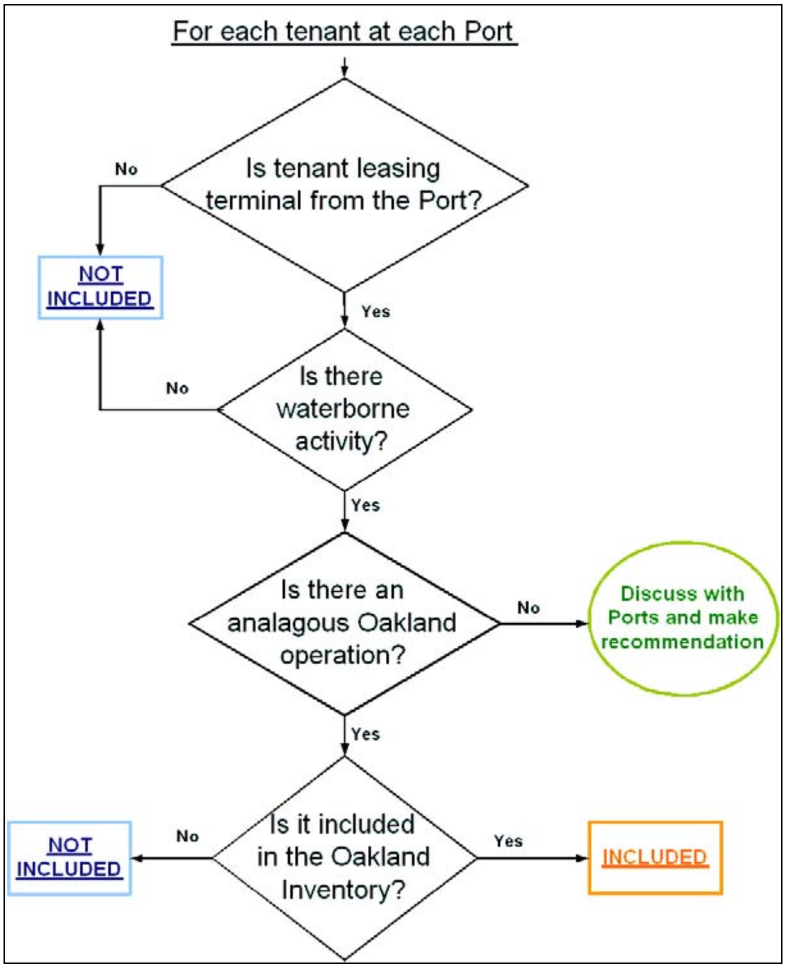

Figure 1-1. Decision-Making Flow Chart

The Port of Oakland inventory established two major precedents for exclusion. The first is that privately owned terminals (such as Schnitzer Steel) 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 boat terminal.

The primary tenant at the Port of Benicia is AMPORTS. They import new vehicles using auto carriers. A second tenant, Kinder Morgan, leases a small terminal on the port, including a silo and some rail tracks, for their petroleum coke export business. There are two other tenants on the port property, Suba Manufacturing and Greenbrier, both of whom conduct non-maritime related operations.

The Port of Benicia has a significant amount of tug boat lay berthing. The tug boats that lay over at Benicia are from all different companies operating in the bay. A typical scenario would be a tug who's home berth is somewhere in the central part of the bay who has multiple jobs to do in the north bay and needs a place to tie up between jobs to avoid excess traveling.

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 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.

<u>Scope</u>

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, 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.

On the landside, 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.

Figure 1-2 shows the boundary of the landside property for the Port of Benicia. A larger version of this aerial image is shown on page ES-1 of this report.

(Source: Google Earth)
Figure 1-2. Port of Benicia Aerial Image

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

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

	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 and nitrogen dioxide. 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.

1.6 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. They 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
- Section 6 summarizes the locomotive emissions estimate results. For Benicia, there was zero locomotive activity on Port property. This section is left in as a place-holder, to be consistent with the other ports' inventories.
- Section 7 contains the summary and results of the report.
- Section 8 provides the references used in developing the emissions inventory.
- Appendix A provides the BAAQMD independent emissions analyses for harbor craft activity.

2. OCEAN-GOING VESSELS

2.1 Ocean-Going Vessel Activity and Inventory

This section documents the emission estimation methods and results for large ocean-going vessels calling at the Port of Benicia 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 primary water-borne freight that moves through the Port of Benicia is new automobiles and light-duty trucks. There is also a small petroleum coke operation. The two types of OGVs calling at Benicia, therefore, are car carriers and bulk carriers.

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 Schedule</u>

The Port of Benicia provided complete vessel call data for 2005. The data included arrival date, arrival time, departure date, departure time, vessel name, vessel operator, ship type, arrival berth, and amount of cargo transferred. Figure 2-1 shows a schematic summary of the amount of cargo, the direction of cargo flow, and the number of ship calls for Benicia in 2005.

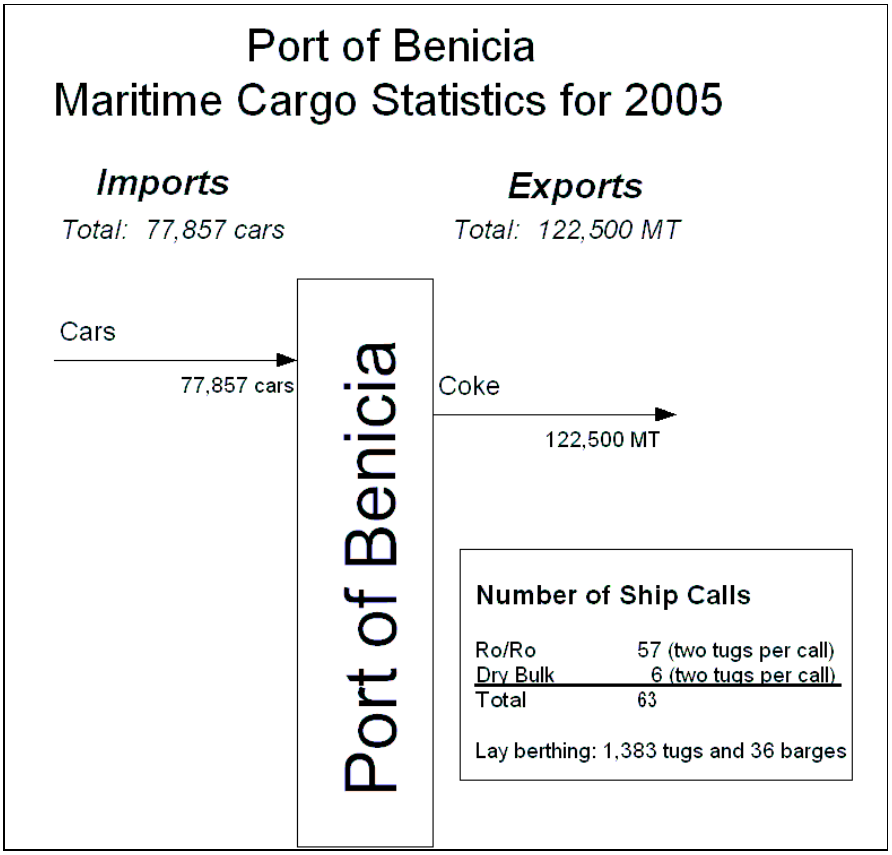

Figure 2-1. Schematic of the Port of Benicia Cargo Flow

The 63 vessel calls at the Port of Benicia in 2005 were primarily auto carriers (57 calls) with a handful of bulk carriers (6 calls). The 57 auto carrier calls at Benicia were made by 46 unique vessels. Two vessels called five times each, one called three times, four called two times, and 36 ships called only one time in 2005. The six bulk carrier calls were made by six different vessels.

Vessel Information Lookup

A list of vessels calling the SF Bay in 2005 was given to BAAQMD to look up 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 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 sizes, 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 in 8% of the vessel lookups.

Vessel Characteristics

Table 2-1 and Table 2-2 summarize some of the characteristics of the two types of vessels calling at Benicia.

Table 2-1. Auto Carrier Vessel Characteristics

	LOA (ft)	DWT	Main Engine (kW)	Design Speed (knots)	Age (yrs)
Minimum	455	7,351	7,867	15	4
Maximum	656	42,424	17,487	21	33
Average	606	16,793	11,531	19	22

Table 2-2. Bulk Carrier Vessel Characteristics

	LOA (ft)	DWT	Main Engine (kW)	Design Speed (knots)	Age (yrs)
Minimum	555	22,056	5,965	14	12
Maximum	609	45,248	9,028	15	14
Average	581	30,789	7,138	14	13

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 car carriers and the red represent bulk carriers. All five bulk carriers for which build year data were available were 10 to 15 years old.

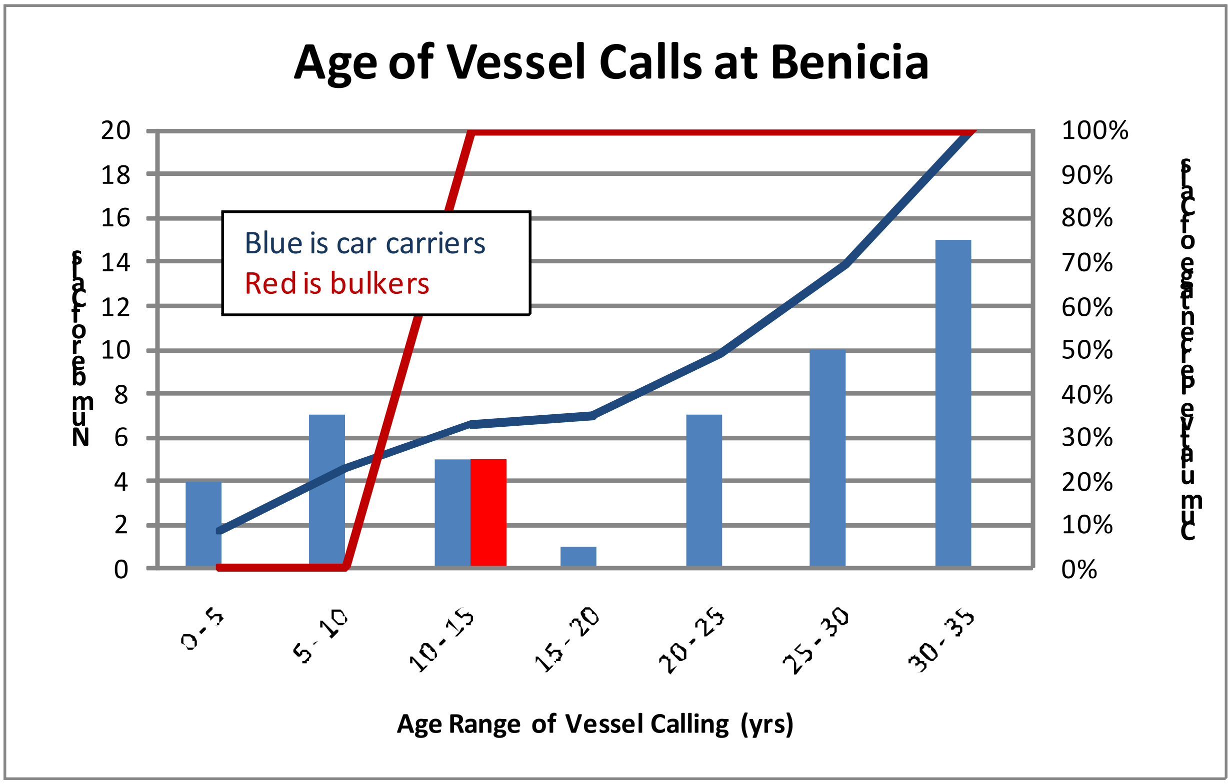

Figure 2-2. Age Distribution of OGV Calls at Benicia

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[2], 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

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

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 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. Some anchoring is done so ships can bunker, make repairs, or wait for fog to clear before leaving the bay. But, according to a terminal operator from Benicia, it is common for the bulk carriers to go to anchorage for a holds inspection prior to berthing[3]. 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.

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3 Information on common anchorage practice for Benicia from Ron Chamberlain private email sent 7/30/2009.

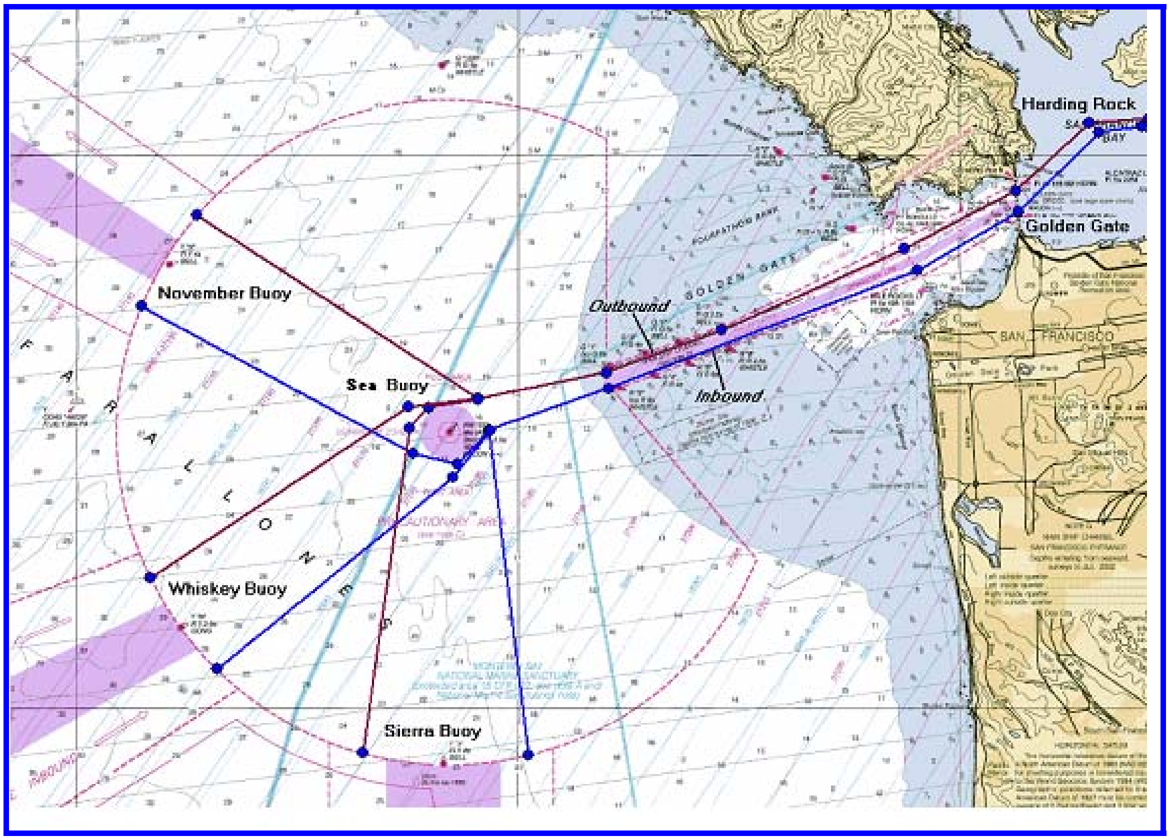


Figure 2-3. Ship Routes Outside of Golden Gate to the Outer Sea Buoys

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.

For Benicia, 86% of auto carrier calls reported by the port had corresponding calls in the SLC database that included previous port information (48 of the 57 calls). Eighty percent (45 of the 57 calls) had next port information. Table 2-3 and Table 2-4 below summarize the previous and next port directional information found using the SLC database combined with the port-provided data. The highlighted directions were used for calls where no other data were available.

Table 2-3. Benicia Car Carrier Previous and Next Port Information from SLC Database

Direction of Previous Port	No. of Calls	Percent of Calls
North	33	69%
West	1	2%
South	6	13%
Within SF Bay	8	17%
	48	100%

Direction of Next Port	No. of Calls	Percent of Calls
North	23	51%
West	0	0%
South	20	44%
Within SF Bay	2	4%
	45	100%

The same information is presented below for the bulk carriers at Benicia. For bulk carriers, six of the seven calls recorded by the Port had matching calls in the SLC database.

Table 2-4. Benicia Bulk Carrier Previous and Next Port Information from SLC Database

Direction of Previous Port	No. of Calls	Percent of Calls
North	2	33%
West	0	0%
South	2	33%
Within SF Bay	2	33%
	6	100%

Direction of Next Port	No. of Calls	Percent of Calls
North	4	67%
West	0	0%
South	1	17%
Within SF Bay	1	17%
	6	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 car carriers and cruise ships is around 20 knots 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. For Benicia, car carriers go 15 knots east of the Sea Buoy and bulk carriers go 12 knots. Starting about 2.5 nautical miles west of Benicia, all vessels slow to 7 knots. The RSZ mode is similar in reverse order for ships leaving the Port. The total transit distance inside the Golden Gate is about 30 nautical miles and takes between two hours and fifteen minutes to almost three hours.

- 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 pilot 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 15 knots to 3 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[4] to Benicia are shown in green 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 the SF Bar Pilots, car carriers travel at 15 knots for most of the transit to Benicia, but bulk carriers in general can only go 12 knots. About 50% of vessels take the route north of Harding Rock and 50% take the route south of Alcatraz, depending on other vessel traffic in the area. The average time for the two routes was used to calculate transit emissions.

The black dashed line on the chart shows the route and speed to Anchorage 9. Seven of Benicia's calls spent time at anchorage in 2005, five of which were bulk calls. Transit to anchorage was assumed to be at the slower speed used for bulkers – 12 knots – even for the two car carriers that anchored.

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

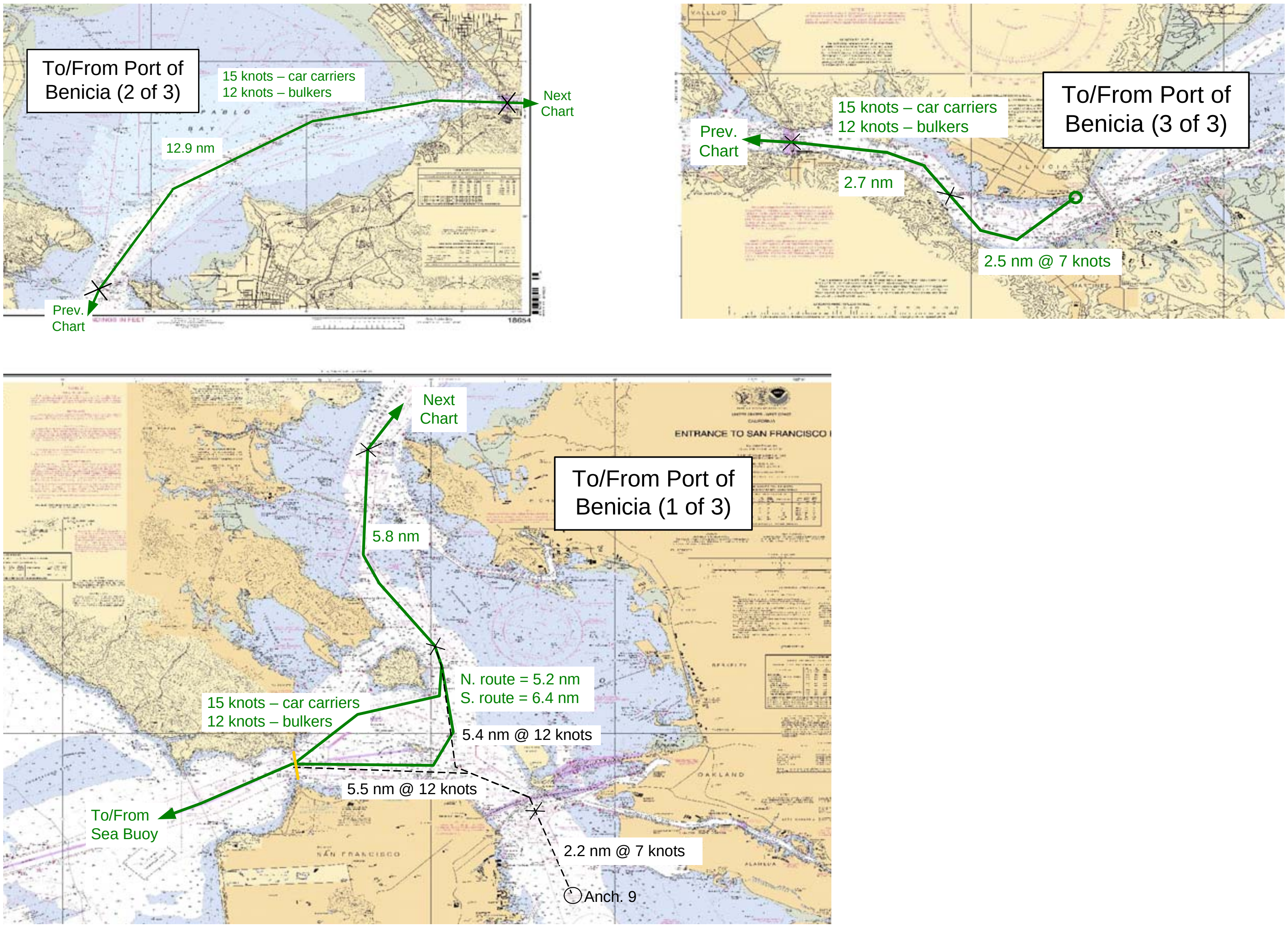


Figure 2-4. Ship Routes Inside of Golden Gate to Benicia

Table 2-6 and Table 2-7 summarize the information presented graphically on the nautical charts. The first table describes the links for ships going straight to berth; the second table describes the links for the handful of ships that went to anchorage first. Car carriers go faster than bulkers, so the speed and duration for both types of ships are listed, separated by a "/".

Table 2-6. Summary of Transit Links from Golden Gate to Benicia – No Anchorage

Link Description	Distance (nm)	Speed (knots)	Duration (hrs)
Outer ring of sea buoys to Sea Buoy (Distance: north buoy/west buoy/south buoy) (Speed & Duration: car carrier/bulker)	7.2/6.5/5.8 avg = 6.5	15/12	0.43/0.54
Pilot Boarding Activity	1.7	8	.21
Sea Buoy to Golden Gate	8.7	15/12	0.58/0.73
Total outside Golden Gate*	**16.9**		**1.2/1.5**
Golden Gate to point east of Angel Island: route going north of Harding Rock – about 50% of calls (Speed & Duration: car carrier/bulker)	5.2	15/12	0.35/0.43
Golden Gate to point east of Angel Island: route going south of Alcatraz – about 50% of calls (Speed & Duration: car carrier/bulker)	6.4	15/12	0.43/0.53
Point east of Angel Island (where north and south routes meet up), past Carquinez Bridge, to east end of Carquinez Strait (point due west of Benicia marina) (Speed & Duration: car carrier/bulker)	21.4	15/12	1.43/1.78
East end of Carquinez Strait to berth	2.5	7	0.36
Total inside Golden Gate**	**29.7**		**2.2/2.6**
* Calculated using average of three outer buoys. **Calculated using the average for north and south routes.			

Table 2-7. Summary of Transit Links from Golden Gate to Benicia – 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) (Speed & Duration: car carrier/bulker)	7.2/6.5/5.8 avg = 6.5	15/12	0.43/0.54
Pilot Boarding Activity	1.7	8	.21
Sea Buoy to Golden Gate (Speed & Duration: car carrier/bulker)	8.7	15/12	0.58/0.73
Total outside Golden Gate*	**16.9**		**1.2/1.5**
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 spent at anchor--	na	na	na
Center of Anchorage 9 to point south of Bay Bridge	2.2	7	0.31
Point south of Bay Bridge to point east of Angel Island (where north and south routes meet up, see table above)	5.4	12**	0.45
Point east of Angel Island (where north and south routes meet up), past Carquinez Bridge, to east end of Carquinez Strait (point due west of Benicia marina) (Speed & Duration: car carrier/bulker)	21.4	15/12	1.43/1.78
East end of Carquinez Strait to berth	2.5	7	0.36
Total inside Golden Gate	39.2		3.3/3.7

* Calculated using average of three outer buoys.
**A simplifying assumption was made that all ships transiting to anchor travel at the bulker speed of 12 knots. Five of the seven Benicia calls that anchored in 2005 were bulkers

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, described individually here.

Ten calls in 2005 visited both PPMT in Richmond and Benicia. None of these calls went to anchor during the visit. The transit emissions for these ten calls were divided equally between Richmond and Benicia. The hotelling emissions are attributed to each port accordingly.

One Benicia call, the *Armstrong* on 2/28/05, was reported to have come from San Francisco and sailed to Nagoya. This call included anchorage time. There was no corresponding call by the *Armstrong* reported by San Francisco near that date, so it is unlikely that the ship actually came from the Port of San Francisco. In this case, it was assumed that the vessel came from the north through the Golden Gate (the default direction for Benicia bulk carriers if no other information is available), then went to anchor, then called at Benicia, and then left to the north to Nagoya.

Two calls to Benicia included a visit to a second Bay Area port which is not part of this inventory. One call, the *Beaumont* on 8/26/05, was reported to have come from Stockton and sailed to Italy. Another call, the *Great Happy* on 11/22/2005, was reported to have come from Manzanillo and sailed to Carquinez. It is not clear what is meant by Carquinez. For these two calls, the transit emissions were included only for the leg between the sea buoys and the Port of Benicia (either inbound or outbound), not to or from the other Bay Area port or between the other port and the sea buoys. The hotelling emissions while at Benicia for these two calls were included in Benicia's inventory.

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.

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

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 2-8 were used in this study, consistent with the Oakland inventory.

Table 2-8. 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

Source: CARB, 2005a

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 the Port of Benicia were mostly slow speed engines. Ten vessels had 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 2-9.

Table 2-9. 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% sulfur)	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 2-9. 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:

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

Fuel Types

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% us 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 2-10 below are the same adjustment factors used in Oakland's inventory.

Table 2-10. Low Load Adjustment Factors for Propulsion Engines

Load %	HC	CO	NOx	PM10*	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	1.4	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. ICF Consulting (2006) provided emission factors for boilers that 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 2-11.

Table 2-11. 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

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 Benicia OGVs are presented in

Table 2-12 through Table 2-15 by each mode (cruise, reduced speed zone, maneuver, and hotel). Main or propulsion engine emissions are presented first, followed by auxiliary engines.

Table 2-14 gives the combined results for main and auxiliary engines. The combined results are included to be consistent with how they were presented in Oakland's inventory report. The last table is for boiler emissions only.

Table 2-12. Emission Results for Main Engines (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.22	0.60	7.66	0.68	4.83
RSZ	0.81	1.96	23.36	2.11	14.29
Maneuver	0.12	0.11	0.63	0.07	0.09
Hotel	0.00	0.00	0.00	0.00	0.00
Total	**1.15**	**2.67**	**31.64**	**2.86**	**19.20**

Table 2-13. Emission Results for Auxiliary Engines (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.01	0.02	0.24	0.02	0.15
RSZ	0.04	0.12	1.65	0.14	1.05
Maneuver	0.01	0.04	0.52	0.05	0.33
Hotel	0.26	0.85	11.25	0.98	7.13
Total	**0.32**	**1.03**	**13.67**	**1.19**	**8.66**

Table 2-14. Emission Results for Main & Auxiliary Engines Combined (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.22	0.62	7.90	0.70	4.98
RSZ	0.84	2.09	25.00	2.26	15.34
Maneuver	0.13	0.15	1.15	0.11	0.42
Hotel	0.26	0.85	11.25	0.98	7.13
Total	**1.46**	**3.70**	**45.31**	**4.04**	**27.87**

Table 2-15. Emission Results for Boilers (tons in 2005)

Operation Mode	ROG	CO	NOx	PM10	SO_2
Cruise	0.00	0.00	0.01	0.00	0.03
RSZ	0.00	0.02	0.05	0.01	0.22
Maneuver	0.00	0.00	0.01	0.00	0.02
Hotel	0.01	0.10	0.26	0.03	1.13
Total	**0.01**	**0.12**	**0.32**	**0.03**	**1.41**

Figure 2-5 and Figure 2-6 show the same results graphically. The first chart shows the emissions by mode (cruise, reduced speed zone, maneuver, hotel). The second shows emissions by source (main engines, auxiliary engines, boilers).

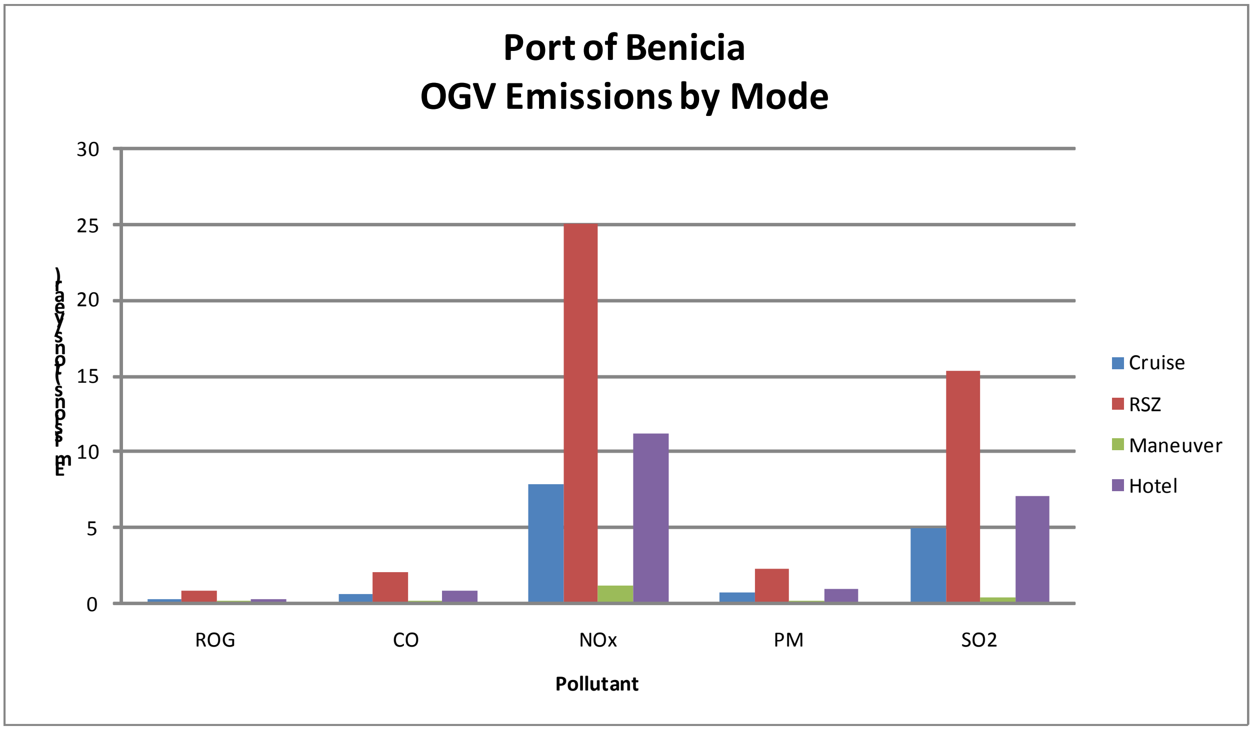


Figure 2-5. Summary of Port of Benicia Emissions Results by Operational Mode

This shows that NOx and SO_2 have the greatest emissions and they are emitted the most while transiting inside the Bay and hotelling.

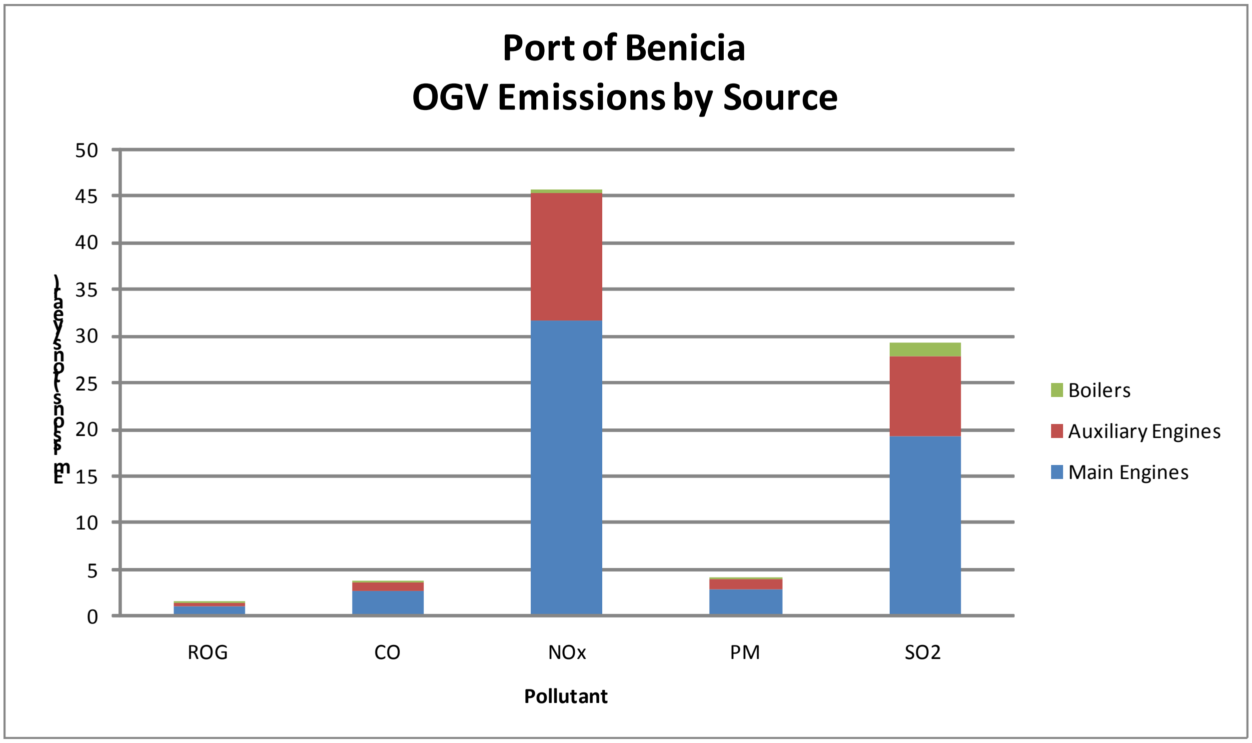


Figure 2-6. Summary of Port of Benicia Emissions Results by Source

This shows the biggest source of emissions is the propulsion engines, which makes sense because Benicia has a long transit to berth.

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	0.22	0.90	3.62	0.14	0.03
Auxiliary	0.01	0.04	0.15	0.01	0.00
Tug Transit					
Main	0.78	3.15	12.75	0.50	0.10
Auxiliary	0.03	0.10	0.33	0.02	0.00
Lay Berthing					
Auxiliary	0.43	1.62	5.49	0.30	0.04
Total	**1.47**	**5.80**	**22.34**	**0.97**	**0.17**

4. CARGO HANDLING EQUIPMENT

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 Benicia 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 (2005b). To date, studies (Starcrest, 2008 and ENVIRON, 2008) have largely focused on equipment primarily used to move containers. The Port of Benicia does not move containers, so the equipment used is atypical of cargo handling equipment. Therefore the approach used in this study was to identify for inclusion in this study all of the off-road equipment used at maritime Port facilities regardless of 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 Benicia 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 Benicia (M&N/ENVIRON, 2008). Per CARB (2005b) 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 Benicia 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 (2005b) was 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 (2005b) 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.

The CHE were grouped into equipment type categories as defined by CARB (2005b). The resulting populations by equipment type for the Port of Benicia are summarized in Table 4-1. Out of 14 total pieces of CHE equipment at the Port of Benicia in 2005, eight were gasoline powered, five were diesel powered, and one was LPG (liquid petroleum gas) powered.

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

Equipment Type	Population	Percentage
Forklift	4	30%
Crane	2	14%
Tractor/Loader/Backhoe	1	7%
Sweeper/Scrubbers	1	7%
Other General Industrial Equipment	6	43%
Total	**14**	**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. Average Horsepower and Operating Hours by Equipment Type

CARB General Equipment Type	Upper End Power Range (hp)	Number of Equipment	Average Power (hp)	Average Annual Operation (hours)
Crane	120	1	105	60
	250	1	214	60
Forklift	120	4	83	545
Other General Industrial Equipment	15	1	10	24
	25	1	14	10
	50	1	34	110
	120	2	97	13
	250	1	212	12
	500	1	415	26
Sweeper/Scrubbers	50	1	37	50
Tractor/Loader/Backhoe	120	1	75	144

4.4 Cargo Handling Equipment Emission Results

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

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

Equipment Type	ROG	CO	NOx	PM10	SO_2
Forklift	0.034	1.036	0.084	0.001	0.000
Other General Industrial Equipment	0.015	0.076	0.071	0.005	0.001
Sweeper/Scrubbers	0.011	0.212	0.008	0.001	0.000
Crane	0.005	0.333	0.021	0.001	0.000
Tractor/Loader/Backho e	0.011	0.034	0.082	0.006	0.000
Total	**0.075**	**1.691**	**0.266**	**0.013**	**0.001**

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

Fuel Type	ROG	CO	NOx	PM10	SO_2
LPG	0.021	0.176	0.061	0.000	0.000
Diesel	0.025	0.077	0.153	0.011	0.001
Gasoline	0.029	1.438	0.053	0.002	0.000
Total	**0.075**	**1.691**	**0.266**	**0.013**	**0.001**

5. HEAVY DUTY ON-ROAD VEHICLES

This section describes the typical annual on-road vehicle activity demands, average vehicle characteristics and travel modes, and presents estimates of spatially allocated emissions for activity that occurred at the Port of Benicia 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 Benicia maritime related operations create a demand for truck trips transporting automobiles offsite. New imported vehicles are driven off of auto carriers and then either driven offsite or transported offsite by truck.

Activities considered in this category were heavy-duty trucks which transport imported vehicles from port facilities as well as imported vehicles. The on-road vehicles depart from the Port area via I-680 freeway interchanges. The project team therefore defined the study area for this air emissions inventory to include on-road vehicle routes between the Port of Benicia and freeway interchanges.

The on-road fleet activity and the CARB 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 were collected which included gate counts along with estimates of trip mileage, average speed for vehicles within the terminal, idle time within the terminal, count of imported passenger vehicles 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 (the nearest freeway interchange). The on-road vehicle emissions were estimated using the following equation:

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

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) Imported passenger vehicle 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 Truck Trip Counts

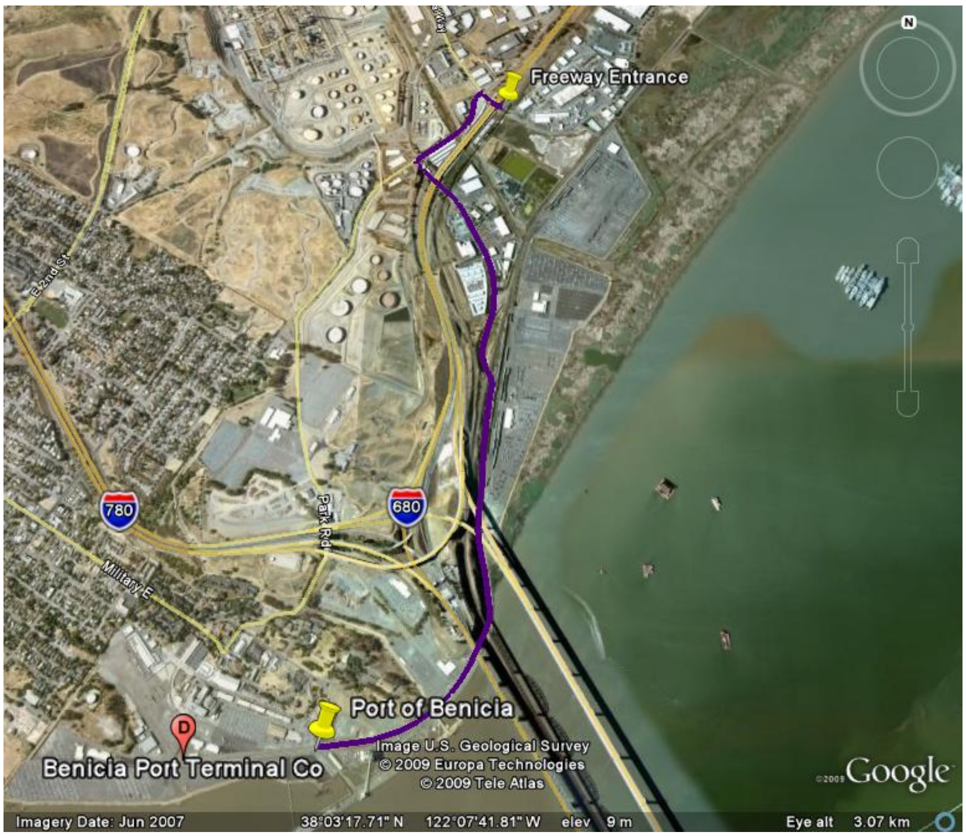
The most basic measure of truck activity is the number of truck trips through each terminal facility, where a trip includes both an entrance and an exit by the vehicle/truck. A survey was provided to the Port of Benicia, which asked the Port to provide all data necessary to estimate truck trips and within-terminal mileage and idling. The Port 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.

Another survey was conducted to determine emissions from imported light duty vehicles. Imported light duty vehicles leave the Port facility in two different ways, via transport truck and by being driven offsite. In order to capture the different imported light duty vehicle activity associated with each type of offsite transport, it was important to account for the number of vehicles leaving the facility by truck and by being driven offsite. Therefore, the survey asked for the number of vehicles and associated activity by the following configurations:

- Passenger vehicles driven offsite
- Passenger vehicles moved offsite by trucks

5.3 Terminal to Freeway Route

Terminal operators provided average speed and distance traveled by a typical truck and passenger vehicle within the terminal. Google Earth was used to estimate the total distance of 2.14 miles one-way from the Port gate to I-680 freeway entrance for trucks and passenger vehicles travelling offsite. This assumed the longest route for traffic heading north on I-680 because the interchange for those headed south would result in a shorter route. A composite speed of 21 miles/hr through the route was estimated using the total mileage of the entire route divided by the total time from start to end destination obtained from Google Maps. 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. Figure 5-1 shows the route for on-road vehicles travelling from the terminal to the freeway entrance.



(Source: Google Earth)
Figure 5-1. Route from Terminal to Nearest Freeway Entrance

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 5-2 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 Benicia was not able to provide facility-specific age distribution. Hence, the EMFAC2007 default age distribution for Solano County was used.

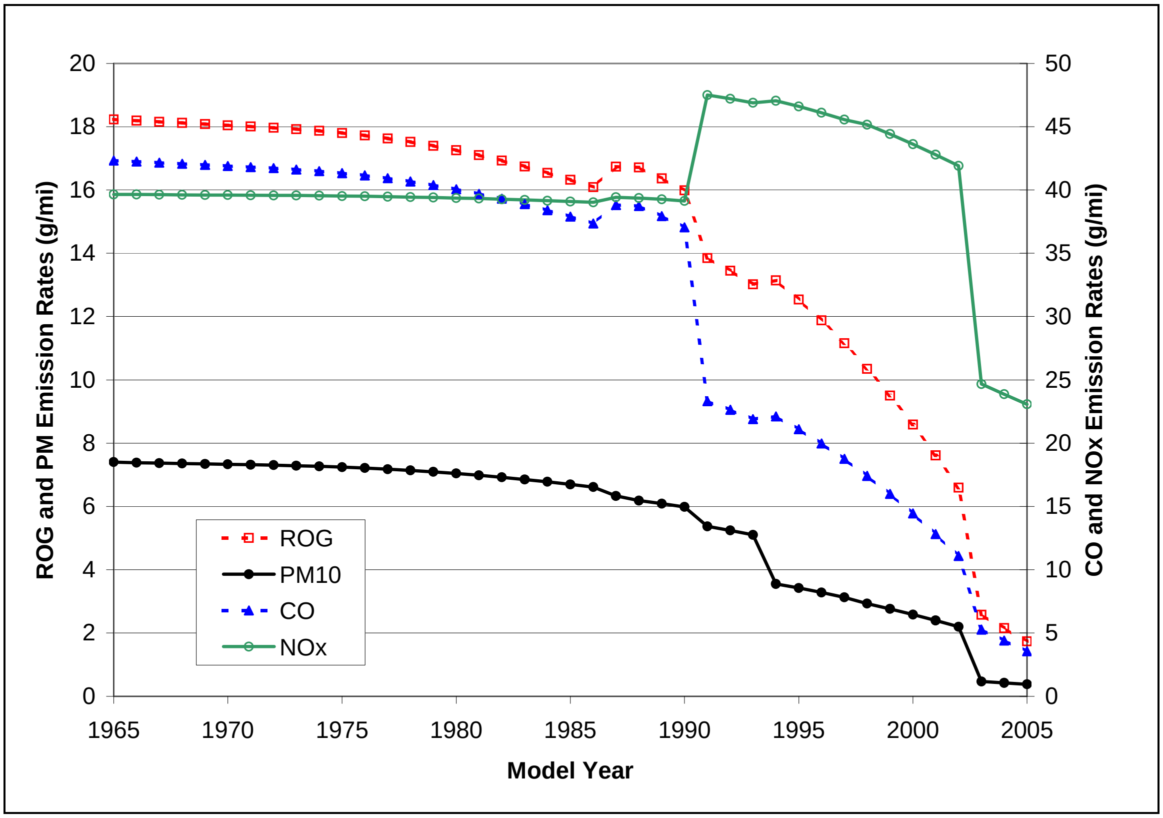


Figure 5-2. EMPFAC 2007 Truck Emission Factors at 10 mph in 2005

The project team used EMFAC2007 emission factor 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 Solano County emissions inventory, population, and VMT; from which the emission factors are back calculated using area-wide emissions and activity totals. These emission factors were calculated using the average of all conditions over the year. For trucks, the emission factor results used were for calendar year 2005 and included all model years from 1965 – 2005. For passenger vehicles, the operator indicated that the vehicles being transported were new vehicles, therefore emission factor results used were for light duty vehicles and light duty trucks, calendar year 2005, and model year 2005.

Table 5-1 shows the average emission factors for trucks and passenger vehicles travelling at the Port of Benicia in 2005.

Table 5-1. Port of Benicia Specific Average Truck and Car Emission Factors

Speed	Emission Factors (g/hour or g/mile)				
	ROG	CO	NOx	PM10	SO_2
Heavy Heavy Duty Trucks					
Idle gram/hour	12.73	51.41	109.09	2.10	0.58
15 miles/hour	7.31	19.68	29.90	2.79	0.23
21 miles/hour	3.17	14.57	22.98	1.79	0.19
Passenger Vehicle					
10 miles/hour	0.04	1.03	0.09	0.03	0.012
21 miles/hour	0.02	0.85	0.07	0.03	0.007

5.5 On-Road Truck and Imported Vehicle Emissions Results

Total emissions for the calendar year 2005 for truck and passenger vehicles that traveled within the terminal and off-site to the nearest freeway are presented in Table 5-2.

Table 5-2. Truck and passenger Vehicle Emission Results (tons in 2005)

Emission Category	Emissions (tons/year)				
	ROG	CO	NOx	PM10	SO_2
Heavy Heavy Duty Trucks					
Within terminal driving	0.017	0.045	0.068	0.006	0.001
Within terminal idling	0.003	0.013	0.027	0.001	<0.001
Travel from Port to freeway	0.040	0.183	0.288	0.022	0.002
Trucks Totals	**0.060**	**0.240**	**0.383**	**0.029**	**0.003**
Passenger Vehicles					
Within terminal driving	0.005	0.132	0.011	0.004	0.002
Travel from Port to freeway	0.002	0.112	0.009	0.003	0.001
Passengers Vehicle Totals	**0.007**	**0.245**	**0.021**	**0.008**	**0.002**
Total	**0.066**	**0.485**	**0.404**	**0.037**	**0.006**

On-road trucks and passenger vehicles travelling to, from, and within the Port of Benicia emitted approximately 0.40 tons of NOx and 0.04 tons of PM10 within the Port area. Trucks contribute the majority of emissions for all pollutants. The in-terminal truck emissions for all pollutants are significantly lower than the off-site truck emissions associated with travel between the Port and the nearest freeway entrance. In-terminal passenger vehicle emissions for all pollutants are higher than the off-site passenger vehicle emissions.

For PM emissions, idling plays a minor role relative to the total PM emissions. Emissions from off-site travel of passenger vehicles and trucks represent about 68% of the PM emissions and 74% of the total NOx emissions.

6. LOCOMOTIVES

The Port of Benicia does not have any locomotive activity occurring on port property. Therefore, their locomotive emissions are zero.

7. SUMMARY OF RESULTS

The Port of Benicia 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 Redwood City, Richmond, San Francisco, and Oakland. Oakland had already completed their 2005 inventory. This inventory was done using the same methodology and factors as much as possible 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 7-1, summarizes the 2005 emissions from the Port of Benicia's maritime activities.

Table 7-1. Summary of Emission Results for Port of Benicia (tons in 2005)

Source Category	ROG	CO	NOx	PM10	SO_2
Ocean-Going Vessels (OGV)	1.47	3.82	45.63	4.08	29.28
Harbor Craft (HC)	1.47	5.80	22.34	0.97	0.17
Cargo Handling Equipment (CHE)	0.08	1.69	0.27	0.01	0.00
Heavy Duty On-Road Vehicles (HDV)	0.07	0.49	0.40	0.04	0.01
Rail Locomotives (RL)	n/a	n/a	n/a	n/a	n/a
Total	**3.1**	**11.8**	**68.6**	**5.1**	**29.5**

The same results are shown graphically in Figure 7-1.

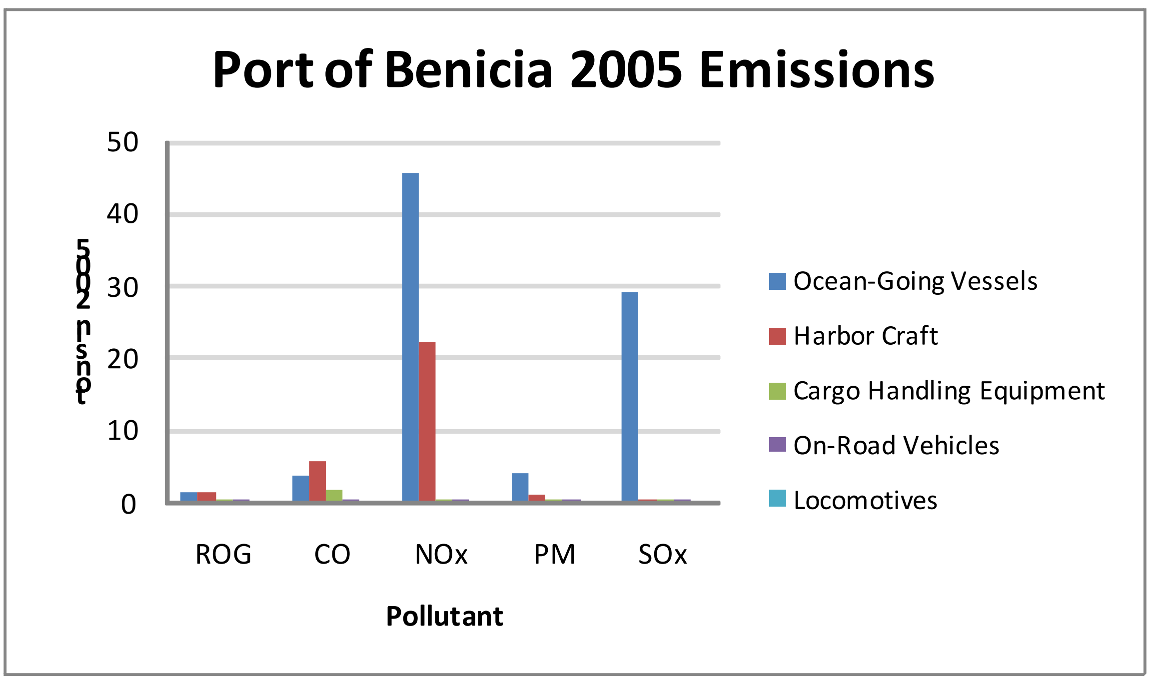


Figure 7-1. Summary Results for Port of Benicia, by Source and Pollutant

It can be seen the biggest emitters by far are the ocean-going vessels, followed next by harbor craft. As expected, cargo handling equipment and on-road vehicles comprise a very small part of the Port's emissions. Locomotive emissions are zero because there is no locomotive activity on Port property.

The OGV emissions are shown in Figure 7-2 by mode. Cruising mode is the short distance between the ring of outer sea buoys and the Sea Buoy. The reduced speed zone is the distance between the Sea Buoy and the area directly in front of the berth. Maneuvering occurs as the vessels move in and out of berth. Hotelling emissions occur both at berth and at anchor as applicable.

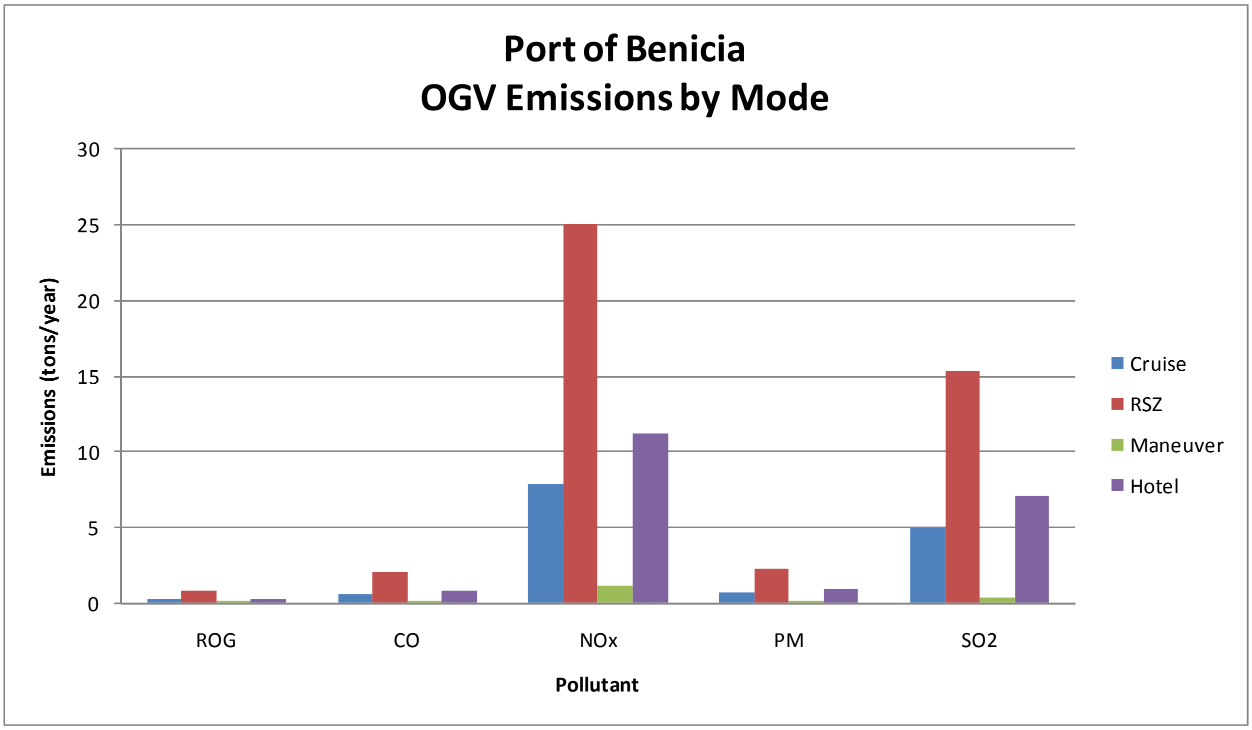


Figure 7-2. Port of Benicia OGV Emissions by Mode

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 7-2 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 7-2. 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.

8. 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 Benicia 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 Benicia harbor craft emissions are derived from tug boat movements that consist of tug assists and tug lay-berthing activities. Tug assist emissions result from the running of the tug's engine while assisting ocean-going vessels (OGVs) during arrivals and departures at the berths. Tug lay-berthing emissions result from the running of auxiliary engines while temporarily parked at a lay-berthing facility awaiting further tug assist jobs.

Typically, tugs are utilized in assisting OGVs to dock and undock from the berths at the Port of Benicia. These tugs rendezvous with OGVs at or near the entrance of the Carquinez Strait to ensure the safe navigation of these vessels to their destinations. The emission in this document accounts for two types of tug assist operations: (1) the actual vessel assist operation, and (2) the tug's trip to meet the vessel it is assisting and its return back to base.

For tug lay-berthing emissions, only auxiliary engine emissions are accounted for while the tug is docked at berth. Most tugs lay berth at the Port of Benicia while in wait and/or in between jobs to avoid excess traveling. Since the tug dock station is not equipped with a power supply, the tugs are assumed to run their auxiliary engines the entire time they are parked at berth.

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, with 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

The Port of Benicia hosts primarily roll/on – roll/off (automobile carrier) ships and dry bulk ships. Its major tenants include Amports which specializes in automobile import, and Kinder Morgan which specializes in petroleum coke export. According to the report (Moffatt & Nichol/ENVIRON, 2008), there were 63 ocean-going vessel (OGV) calls in 2005. Of this number, fifty seven (57) calls were automobile carrier ships and six (6) were dry bulk ships. From this total and given the requirement of tug assists per vessel call, it was estimated a total of 252 tug assists taking place at the Port of Benicia 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 Tugs	Outgoing Tugs	
Vessels				
Roll/On - Roll/Off	57	2	2	228
Dry Bulk	6	2	2	24
Total	**63**			**252**

[1] Total for incoming and outgoing

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 Horsepower (HP)	Adjusted Emission Factor: (AEF) - Efo x F x (1+D x A/UL)					Tug-assist	Tug-in-transit
			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)*	NO_x			PM			ROG			CO		
			EF	F	D	EF	F	D	EF	F	D	EF	F	D
Tug Boat[1]	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[1]	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 time at the Port of Benicia occurred in 55 minute cycles based on correspondence with tug operator (Bay Delta, 2008). The round trip time for tugs transiting to and from their base of operations to the Carquinez Bridge meeting location occurred in two hour cycles. This is an estimated value based on the average distance of a tug home base to the vessel call meeting location divided by the average transit speed of the tug. Lay-berthing annual time is based on an estimate of data provided by the Port of Benicia (Amports, 2008) for a typical one week lay berthing period multiplied by the overall lay berthing instances for year 2005 divided by the one week's total instances. The 2005 annual vessel operating hours for each vessel mode and engine type are summarized in Table 5 below.

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

Mode	In Transit		Hotelling
	Main Engine (hrs)	Auxiliary Engine (hrs)	Auxiliary Engine (hrs)
Tug Assist – OGV	231	231	--
Tug-in-Transit (OGV)	504	504	--
Tug Lay Berth	--	--	8,414

Summary

The annual operating times of each vessel modes multiplied by the emission factors, total horsepower, 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 Benicia.

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

Engine Modes	Emissions (tons/year)				
	ROG	CO	NO_x	PM	SO_x
Tug Assist					
Main Engines	0.22	0.90	3.62	0.14	0.03
Auxillary Engines	0.01	0.04	0.15	0.01	0.00
Tug In-Transit	0	0	0	0	0
Main Engines	0.78	3.15	12.75	0.50	0.10
Auxillary Engines	0.03	0.10	0.33	0.02	0.00
Lay Berthing	0	0	0	0	0
Auxillary Engines	0.43	1.62	5.49	0.30	0.04
Total	1.47	5.80	22.34	0.97	0.17

* SOx emission is based on total fuel consumption.

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